U. S. Steel Corporation

Attached please find U. S. Steel's comments on MPCA's Proposed Site Specific Standard Framework. U. S. Steel appreciates the opportunity to provide this feedback. Please contact me if you have any questions.

Thank you,

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Chrissy Bartovich
Director – Environmental

September 1, 2023

VIA ELECTRONIC SUBMISSION

Minnesota Pollution Control Agency
520 Lafayette Road North
Saint Paul, MN 55155-4194

Re: Comments of U. S. Steel on the Framework for Developing and Evaluating Site-Specific Sulfate Standards for the Protection of Wild Rice

Dear Sir or Madam,

United States Steel Corporation ("U. S. Steel") appreciates the opportunity to provide the following comments regarding Minnesota Pollution Control Agency's (MPCA) Proposed Framework for Developing and Evaluating Site-Specific Sulfate Standards for the Protection of Wild Rice (Proposed Framework), wq-s6-66 (June 20, 2023). The comment period runs through September 4, 2023.

U. S. Steel owns and operates two facilities in Minnesota which are directly affected by the regulatory decisions made by and frameworks proposed by MPCA: Minntac in Mt. Iron; and Keetac in Keewatin. U. S. Steel's Minnesota facilities discharge water into various water bodies, including some waters that may potentially be included in those encompassed by MPCA's Waters Used for Production of Wild Rice (WUFPOWR). In the past, U. S. Steel has also submitted multiple site-specific standard proposals for its facilities that have not yet been acted upon by MPCA. Thus, U. S. Steel has a direct interest in and provides the following comments on the Proposed Framework. U. S. Steel also supports the Minnesota Chamber of Commerce and Iron Mining Association of Minnesota's comments regarding the Proposed Framework and incorporates those comments herein by reference.

As an initial matter, U. S. Steel asserts that the Proposed Framework is overbroad, goes far beyond MPCA's authority under the Clean Water Act, state statutes, and the agency's own rules, and includes requirements that exceed the scope of what is necessary to protect the designated use of wild rice via a site-specific water quality standard. This Proposed Framework drastically expands the requirements for submitting a site-specific standard application to require a decade of data, and includes new criteria by which MPCA will evaluate such applications.

The Proposed Framework is also arbitrary in the requirements it does choose to implement and does so without supporting citations. Due to the overly broad scope of these requirements, compliance with the Proposed Framework will result in extreme, unnecessary costs, that are not proven to provide any additional protection to wild rice, to U. S. Steel and other regulated parties, which is directly in contradiction with state law. The specific deficiencies in the Proposed Framework are more particularly outlined below.

A. **Unpromulgated Rulemaking**

MPCA's Proposed Framework provides such sweeping revisions and new requirements for site-specific applications that it must be treated as a proposed rule, and thus move through the requisite processes of such a document.

Under the Minnesota Administrative Procedure Act (APA), a rule is defined as:

> every agency statement of general applicability and future effect, including amendments, suspensions, and repeals of rules, *adopted to implement or make specific the law enforced or administered by it* or to govern its organization or procedure.

Minn. Stat. § 14.02, subd. 4 (emphasis added). Further, "[u]nder the APA, if an agency believes a policy needs to be formulated, it must express that policy in the form of a proposed rule accompanied by a detailed statement of need and reasonableness." *In re Hibbing Taconite Co.*, 431 N.W.2d 885, 894 (Minn. Ct. App. 1988) (citing Minn. Stat. § 14.131 (1986)). That process, including public notice and comment, "is intended to insure that the rule, and the policy expressed, is within the scope of the enabling statute and is otherwise reasonable and constitutional before it is implemented." *Id.* (citing Minn. Stat. §§ 14.05-47 (1986)). "[N]otice and comment procedures exist for good reason: to ensure that unelected administrators, who are not directly accountable to the populace, are forced to justify their quasi-legislative rulemaking before an informed and skeptical public." *Swenson v. Emerson Elec. Co.*, 374 N.W.2d 690, 702 (Minn. 1985) (quotation omitted).

With the Proposed Framework, MPCA has created multiple new, burdensome requirements with general applicability and future effect for site-specific standard applications that fall squarely under the APA as a "rule" – the Proposed Framework was drafted to be generally applicable, to be effective in the future, and to implement or make specific applicable laws concerning site-specific standards. *See, e.g.*, Minn. R. 7050.0220, subp. 7. In short, the Proposed Framework is an interpretative rule that, according to longstanding Minnesota case law, is valid only if promulgated in accordance with the APA. *See, e.g.*, *Mapleton Community Home, Inc. v. Minnesota Dep't of Human Services*, 391 N.W.2d 798, 801 (Minn. 1986) (quoting *Minnesota-Dakotas Retail Hardware Ass'n v. State*, 279 N.W.2d 360, 364 (Minn. 1979).[1] It is of little

[1] Notably, the Proposed Framework does not meet either of the established exceptions to the rulemaking requirement for interpretative rules, i.e., it is not a long-standing policy position of MPCA's (it is being proposed for the first time) nor does it fall within the "plain meaning" of the underlying rule, Minn. R. 7050.0220, subp. 7, which

importance as to what an agency calls or labels its policies; rather, if the policies meet the definition of "rule" they must be promulgated pursuant to the rulemaking procedures in MAPA to be valid. *McKee v. Likins*, 261 N.W.2d 566, 577-78 (Minn. 1977) (finding a "policy bulletin" to fit the definition of a "rule"). Ultimately, the widespread impacts of the Proposed Framework highlight and sharpen the need for the proper public notice and comment process here. MPCA cannot proceed with finalizing this document without running contrary to the Minnesota APA and the established administrative process for a Minnesota agency adopting what is in effect a "rule." This is highlighted and made even more obvious throughout the remainder of the comments below.

B. Application of Beneficial Use

MPCA states in the Proposed Framework that the comprehensive list of WUFPOWR will be public-noticed in the agency's Guidance Manual for Assessing the Quality of Minnesota Surface Waters for Determination of Impairment: 305(b) Report and 303(d) List. However, the agency goes on to provide detail as to how MPCA has determined where the beneficial use for Class 4A wild rice exists. The Proposed Framework purportedly seeks to apply the WUFPOWR designation regardless of any specific population-size wild rice threshold. That designation will in turn trigger Minnesota's Class 4A subclass designation for water used for production of wild rice, with a 10 mg/L sulfate standard. MPCA specifically states that "stand-level documentation of wild rice presence" is sufficient to consider a waterbody WUFPOWR and, thus, beneficial use protections should apply. MPCA goes so far as to say that "[m]inimal stands or sparse rice still constitutes a "production of wild rice." Thus, as MPCA reasons, "[t]he 10 mg/L sulfate standard to protect wild rice is applicable to these waters." However, this is far too sweeping of an approach, and will inevitably result in classification of most of the state's waterbodies as WUFPOWR. Not only is this infeasible, but it is not supported technically, and is unduly burdensome on regulated dischargers in the state. Every upstream discharger will have to scramble to draft some form of site-specific standard or variance application if most of the state's waterbodies are classified as WUFPOWR. Further, it is almost impossible to come up with ten years of data and/or two boom-bust cycles of wild rice to determine a site-specific standard when the waters only contain "minimal" or "sparse" rice stands.

The Class 4A beneficial use category applies to waterbodies for which water quality must be sufficient "to permit their use for irrigation without significant damage or adverse effects upon any crops or vegetation usually grown in the waters or area." Minn. R. 7050.0224, subp. 2. The wild rice subclass is "applicable to water used for production of wild rice during periods when the rice may be susceptible to damage by high sulfate levels." *Id.* Nowhere do these beneficial use classes mention that minimal, even single stands of wild rice trigger an entire protective classification. One can easily imagine absurd scenarios where a single stray rice stalk or stand is noted in a waterbody that was perhaps never traditionally supportive of wild rice stands, but

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states simply that MPCA, in reviewing site-specific standard requests, must "evaluate all relevant data in support of a modified standard and determine whether a change in the standard for a specific water body or reach is justified." With the Proposed Framework, MPCA is attempting to add specificity to help implement this language, i.e., it is engaged in rulemaking and must follow the APA.

which nonetheless triggers an entire classification that is unnecessary for the aquatic wildlife that grows there. Put simply, there must be a technically and legally defensible threshold for application of the subclass 4A wild rice standard, and MPCA has not provided one. Instead, it purports to seek classification of every waterbody where even a single stand of rice is present. Production must be for a purpose such as a food source. Even a few sparse stands would not be sufficient as a food source for waterfowl. Additionally, there is no requirement that the rice be naturally occurring which means that individuals could artificially seed a given lake or water body and the resulting stands would result in a WUFPOWR under the current proposal.

The same type of comments can be made regarding a threshold cut-off for discharges far removed from WUFPOWR impaired waters. There must be such a threshold, or once again there will be absurd scenarios where a discharger "upstream" of an impaired waterbody practically a state away could somehow be held to water quality standards tied to that waterbody despite minimal, if any, actual impacts to such waterbody. Dischargers should be able to show minimal impacts to waterbodies, and thresholds should apply to discharges that are far attenuated from the waterbody.

Lastly, MPCA should undergo rulemaking both to (a) establish the comprehensive list of WUFPOWR and (b) clarify the beneficial use. MPCA previously understood that rulemaking was required for these steps, which is why it undertook rulemaking for the 2017 proposed rule. Moreover, rulemaking was and still is mandated for clarifying the beneficial use and listing the waters in which the use is protected. It is improper for MPCA to suddenly decide it can shoehorn these critical matters of state policy into an agency guidance on site-specific standards.

C. Data Required

In its Proposed Framework, MPCA highlights new types of data and data requirements it will be looking for in site-specific standard applications. Most significantly, the Proposed Framework section titled "Expectations of detailed supporting data and analysis" states that "population data spanning ten years or two boom-bust cycles, whichever is shorter" must be submitted for a site-specific standard. This is an entirely new requirement for site-specific standard applications, one which is not contained in the state's statutes or regulations on site-specific standards. Not only did the agency fail to go through the appropriate rulemaking routes to establish such a firm, bright-line standard for a site-specific standard application, it also just inherently created a ten-year wait for any discharger to be able to apply for site-specific standards in the state of Minnesota without a stop-gap in the meantime. This is another example of the Proposed Framework attempting to make the site-specific standard rule more specific – which is, again, a clear indication that it must go through rulemaking. *See* Minn. R. 7050.0220, subp. 7.

Collecting this amount of data is also expensive and time-consuming for permittees. While U. S. Steel does not dismiss the importance of a boom-bust cycle for wild rice, an adequate data pool along with a healthy and robust wild rice population should be sufficient for the MPCA to continue protecting the wild rice beneficial use. As such, U. S. Steel requests that the MPCA reconsider the amount of data and the two boom-bust cycles that are necessary to support a site-specific standard request, shortening the amount of time and data necessary for the MPCA to make the determination for the permittee, while protecting wild rice.

In addition, in the Proposed Framework, MPCA makes multiple incredibly impactful and sweeping conclusions without providing any citations to supporting data, reports, or analysis. For example, the requirement to now submit ten years of population data, or two boom-bust cycles, with site-specific standard applications is unsupported by any citation to literature, studies, analyses, etc. Without such support, it is impossible to review the reasoning behind such a requirement and comment on it. Further, citations and underlying data supporting the "baseline" sulfate concentrations in Minnesota are not provided. Nor is any support provided for most of the statements in the examples, including the St. Louis River Estuary example. MPCA does not provide a citation for its percentage breakdown of "loading" of sulfate for the Estuary. It does not provide how it arrived at a baseline sulfate level for that watershed of 10 mg/L. It does not provide the underlying data for its "sulfate loading" figure provided in Figure 6. All of this information is absolutely critical for any regulated entity to be able to provide meaningful comment on a Framework as sweeping as this, and MPCA's failure to provide this information provides even more support for the conclusion that the Proposed Framework must be withdrawn and instead advanced through proper rulemaking.

D. "Baseline" Sulfate Concentrations

The Proposed Framework section titled "Document and examine ambient sulfate in the context of regional baseline levels" asserts that sulfate concentrations vary substantially across ecoregions, except for the Northern Lakes and Forest (northeastern) ecoregion where baseline sulfate concentrations are consistently below 10 mg/L, except for waters flowing from the Iron Range where the taconite mines and tailings basins contribute to anthropogenic loading of sulfate. These assertions are misguided for several reasons, including but not limited to:

1) The Northern Lakes and Forest ecoregion contains a variety of geologies and is particularly variable in the area of the "Iron Range" where the Biwabik Iron Formation and Duluth Complex meet and overlap; therefore, even without the taconite mines and tailings basins, one would anticipate more natural water quality variability in this small portion of the much larger Northern Lakes and Forest ecoregion.
2) The MPCA concedes that "this is not a rigorous natural background calculation", but then goes on to rely on these faulty maps and data to make sweeping, impactful conclusions about the Iron Range. MPCA uses this method to state that sulfate concentrations do not vary across the northeastern ecoregion, to try to establish that the primary sources of sulfate are anthropogenic in the north/northeastern portion of the state, and to state that the sulfate baseline concentrations in the St. Louis River Estuary are less than 10 mg/L. The data and methods supporting these sweeping conclusions must be scientifically defensible. But, as MPCA acknowledges, this is not a rigorous nor defensible manner to establish baseline or background sulfate concentrations in watersheds. This method ignores extremely important data that would go into a true "baseline" sulfate concentration for a given watershed. Moreover, MPCA does not provide the back-up calculations, data, methods, etc. that it used to support its conclusions. This is, again, indefensible and must be corrected before parties can move forward to discuss how to address site-specific standards.

Additionally, the Proposed Framework's discussion of ecoregion sulfate concentrations focuses on sulfate concentrations being either greater or less than the 10 mg/L wild rice sulfate standard. Although this remains an approved water quality standard in Minnesota, it continues to be problematic as it is a scientifically unsupported value. As the MPCA asserted during the 2017 proposed wild rice rulemaking process, the "correlation of wild rice with low sulfate does not indicate cause and effect between sulfate and wild rice, which is what the 10 mg/L standard was based on" and "there is no statistically significant relationship between sulfate concentration and wild rice occurrence"; rather "the MPCA-sponsored research clearly demonstrated, in peer-reviewed publications, that the true cause and effect is more complicated, and that the production of porewater sulfide is primarily responsible for the presence and absence of wild rice in Minnesota" (reference X). Furthermore, although an Administrative Law Judge rejected the MPCA's 2017 proposed rules, they found no fault with the science underlying MPCA's equation-based approach and rejected all science-based objections to the equation that was proposed by the MPCA to replace the 10 mg/L sulfate standard (reference Y).

E. <u>St. Louis River Estuary</u>

The Proposed Framework outlines certain "examples" of watersheds and apparent sulfate loading by sources. One such example is of the St. Louis River Estuary. Specifically, it states:

> *Example – St. Louis River Estuary*
>
> *The St. Louis River Estuary is an impaired WUFPOWR for excess sulfate located in the Northern Lakes and Forest ecoregion, where sulfate baseline concentrations are less than 10 mg/L. <u>Sulfate in the St. Louis River Estuary is dominated by loading from taconite mines with upwards of 95% of sulfate loading to the estuary coming from the mines.</u>*

In that example, MPCA concludes that 95% of sulfate loading to the estuary comes from the mines, and only 2% from municipal wastewater point source dischargers. The agency makes multiple other conclusory assertions, including that if all loading from point sources were eliminated, the estuary would have a sulfate level less than 10 mg/L "reflecting the regional baseline." However, MPCA has provided no information regarding the bases for these numbers and conclusions. Indeed, MPCA is unlikely to even have the data to support these conclusions as many upstream dischargers are not required to monitor the sulfate concentrations in their discharge.

The Proposed Framework document discusses sulfate loading at the Scanlon station and includes a load duration curve, graphing sulfate concentration in the river at various flow rates. The Proposed Framework document states:

> *Sulfate concentrations increase at low flows and decrease at high flows which is an indicator that <u>point sources dominate sulfate loading</u>.*

However, research conducted by the MDNR and MPCA contradicts this conclusion. The research article, *A comparison of results from a hydrologic transport model (HSPF) with distributions of sulfate and mercury in a mine-impacted watershed in northeastern Minnesota,* *2016 Michael E. Berndt, Wes Rutelonis, and Charles P. Regan*, studied contributions of sulfate and other constituents into the St Louis River watershed, using the HSPF model. The study measured contributions of sulfate in the St Louis River at the Scanlon station and identified the contributions by surface water runoff, interflow, groundwater, mining point sources, and non-mining point sources. The study concluded that groundwater was the predominant source of sulfate at the Scanlon station. While mining point sources could account for a greater portion of the sulfate load upstream, their contribution to the total sulfate load in the St. Louis River by the Scanlon station is negligible during the majority of the year and at most not more than 15% of the total sulfate load during dry weather flow conditions.

The limited analysis of sources contributing sulfate to the St Louis River presented in the Proposed Framework document appears to attribute all loading to surface water runoff and mining point sources. It does not appear to account for sulfate contributions from groundwater. The load duration curve presented in the Proposed Framework document is consistent with groundwater sources being the predominant source of sulfate loading at the Scanlon station. This is yet another reason to support moving this Framework into proper rulemaking process; doing so will allow stakeholders and other members of the public to properly review and comment upon the science supporting MPCA's Proposed Framework can be reviewed and commented on, and will ensure that the ultimate effect and requirements imposed by the Framework are consistent with applicable laws.

F. Basis for a New Numeric Standard

The Proposed Framework section titled "Approaches to developing a site-specific sulfate standard" begins with the discussion of the "Basis for a new numeric standard: the sulfate concentration value". The Proposed Framework document states:

Since an application for a SSS must demonstrate that the newly proposed site-specific sulfate standard will support a productive and self-sustaining wild rice population within the specific waterbody, the basis for deriving the sulfate SSS must be considered in that light.

This statement presumes that a sulfate concentration of 10 mg/L or less will support a healthy wild rice population and ignores multiple confounding factors that inhibit the health of wild rice. However, many waters identified as WUFPOWR have not had a productive and self-sustaining wild rice population for years, if ever.

The Proposed Framework identifies two categories of approaches for developing a numeric SSS:

First are standalone approaches that illustrate the association between the surface water sulfate concentration with metrics tracking wild rice abundance and health which can be used independently to justify the proposed site-specific sulfate standard.

The second grouping includes supporting information that can only be used in a weight-of-evidence approach to support a numeric standard constructed via a separate approach in the first grouping.

The standalone approach requires applying the current ambient sulfate concentration if wild rice is healthy. This approach requires long-term monitoring of both surface water sulfate concentrations and wild rice abundance (multiple metrics). Given the definition of "healthy wild rice population" used above, it is not clear why "multiple metrics" are required. Spatial extent and stalk density should be sufficient to assess health over time.

The supporting evidence, or weight of evidence approach includes calculating a sulfate concentration value using the sediment-based equation proposed during the 2017 wild rice rulemaking process. The proposed equations established a statistical relationship between sediment iron, organic carbon, porewater sulfide, and surface water sulfate of wild rice waterbodies, and that relationship could be used to inform the development of a SSS. The MPCA's equations (2017 and 2018 protocols) were developed over several years weighing scientific evidence that refutes the relevance of the 10 mg/L sulfate standard as being supportive of healthy wild rice populations. The MPCA's equations were deemed to be scientifically sound by the Administrative Law Judge in the 2017/18 rulemaking process. Since their inception and prior to the publication of the Proposed Framework document, MPCA staff and management encouraged permittees to collect samples and apply the formula in wild rice waterbodies downstream of their discharges. The sulfate standard determined by the formulas should be the basis for the appropriate sulfate standard for these specific waters, rather than the 10 mg/L standard.

Another supporting evidence approach includes determining a likely sulfate effect threshold based on a review of all available literature pertaining to sulfate and sulfide effects on wild rice, with special attention to sulfate and wild rice health data collected in analogous settings. The burden of reviewing and interpreting the validity of the numerous studies and available literature should not fall on the permittee. Much of the available literature, including many of the studies cited by the Proposed Framework document, are based on mesocosm or bucket studies, of wild rice grown in stagnant water. Such studies are not analogous to wild rice grown in natural environments because, as noted in the *Wild Rice Monitoring Handbook* (Kjerland, 2015), "Stagnant waters do not support wild rice populations." This is a critical distinction as to how rice is performing in the field as compared to containers cut off from flowing water and natural conditions.

An additional supporting evidence approach is determining ambient sulfate concentrations in regional waterbodies that contain healthy wild rice, with special attention given to nearby waterbodies (and waterbodies with analogous environmental characteristics) that are known to contain wild rice and that are unimpacted by sulfur-containing discharges to local surface water or groundwater. There should be an approach or provision to compare nearby unimpacted waterbodies with analogous environmental characteristics, that do not contain healthy populations of wild rice. Numerous studies (including the MPCA's) refute the relevance of the 10 mg/L sulfate standard as being supportive of healthy wild rice populations. Many other confounding factors also impact the productivity and health of wild rice water bodies.

G. Confounding Factors

The Proposed Framework reserves a single paragraph in the section titled "Expectations of detailed supporting data and analysis" to discuss confounding factors that may also damage productivity and recurrence of wild rice. This discussion should take the forefront of any final framework on site-specific standards. The paragraph at issue discusses confounding factors, besides sulfate in the water column and sulfide in the porewater, that damage the productivity and recurrence of wild rice (see page 14). While the Proposed Framework document recognizes that controlling for each confounding factor would be an impossible task, it does not provide an alternative for permittees to obtain a site-specific standard when discharging to WUFPOWRs without healthy, productive wild rice due to confounding factors.

Many waters identified as WUFPOWR have not had a productive and self-sustaining wild rice population for years, if ever. The wild rice beneficial use could be lost due to natural or anthropogenic causes, exclusive of sulfate concentration. Where wild rice may have been historically present but is now no longer present, it should not be presumed that sulfate is the cause.

The U. S. Steel Minntac Twin Lakes Wild Rice Restoration Opportunities Plan (Plan) outlines efforts U. S. Steel undertook to study and evaluate the potential to restore wild rice in the Twin Lakes (Sandy Lake and Little Sandy Lake), located east of the Minntac tailings basin. The Plan outlines several confounding factors that prohibit the re-establishment of wild rice in Twin Lakes, including:

- Water depths have increased over time. Beaver dams constructed downstream of the lakes have contributed to lake depths exceeding the 2.0 to 3.0 feet depths that are optimal for wild rice to flourish.
- Competing aquatic vegetation proliferate in areas of the lakes with optimal water depths for wild rice. Cattails have reproductive advantages that allow them to tolerate water depth fluctuations and prohibit wild rice growth. Once competing aquatic vegetation is established, it can be difficult, if not impossible, for wild rice to proliferate.
- Sediment with a greater portion of sand or gravel is found in areas of the lakes, rather than the organic rich sediment preferred by wild rice.

Another factor that has recently been demonstrated to inhibit the proliferation of wild rice on the St. Louis River estuary is consumption of developing plants by geese. The 1854 Treaty Authority's monitoring report documents this problem. The report has photos depicting dense stands of wild rice in enclosures protected from geese, while adjacent water subject to consumption by geese have scant wild rice. The report also notes that impacts from geese "likely affect monitoring results and restoration success." In fact, the impact is so significant, authorities recently killed off some 300 geese to try and help wild rice grow in the St. Louis River: "Canada geese have posed a persistent challenge, feeding heavily on the grain and causing considerable mortality before poorly established young plants are able to withstand the onslaught of black-billed birds." Peter Passi, Duluth News Tribune, *First Duluth Goose 'Roundup' Kills 300 Birds*, July 26, 2023, available at First Duluth goose 'roundup' kills 300 birds - Duluth News Tribune | News, weather, and sports from Duluth, Minnesota. The Duluth area press has multiple additional articles reporting on the struggle to get wild rice to grow in areas with heavy geese populations.

The document, *MDNR 2008 Natural Wild Rice in Minnesota. A Wild Rice Study document submitted to the Minnesota Legislature by the Minnesota Department of Natural Resources* – discusses many of these and other confounding factors that can impact wild rice, including impacts of global and regional climate change, impacts of water-based recreation and shoreland development, and genetic modification on the integrity of native wild rice.

Despite the fact that confounding factors may make obtaining the wild rice beneficial use impossible, the Proposed Framework document appears to assume that wild rice will proliferate if WUFPOWR have a water column sulfate level of 10 mg/L or less. The Proposed Framework does not lay out a clear path to obtaining a site-specific standard in WUFPOWRs without a productive and self-sustaining wild rice population. If the Framework is finalized, it should provide such a path.

H. Contradiction with Legislation

The Proposed Framework also ultimately contradicts the policy behind the state's legislation which prohibits MPCA from requiring permittees to expend money for design or implementation of sulfate treatment technologies or other forms of sulfate mitigation. The legislature has acted multiple times to limit MPCA enforcement of the sulfate water quality standard until it was updated. First, in 2011, the legislature passed a law that directed the MPCA to update the standard and limited enforcement until the standard was revised. Minn. Laws 2011, 1st Spec. Sess., Ch. 2, Art. 4, Sect. 32(a)-(e). Then, in 2015, a new law strengthened the limitations on MPCA implementation of the standard and set 2018 as the deadline to complete the rulemaking to update the standard. Minn. Laws 2015, 1st Spec. Sess., Ch. 4, Art. 4, Sect. 136(a)(1)(i); (c). Specifically, that law stated that, until the MPCA amended the wild rice water quality standard, "the agency shall not require permittees to expend money for design or implementation of sulfate treatment technologies or other forms of sulfate mitigation." *Id.* at 136(a)(1)(i).

By requiring permittees to expend significant resources and time to create the data to support a site-specific standard application, MPCA is requiring permittees to expend money for sulfate mitigation while, apparently, ignoring the statutory mandate to complete the required rulemaking prior to doing so. Further, in the interim decade while permittees are expending those resources on gathering such data, permittees are also faced with expending resources on sulfate compliance with applicable limits in their permit – limits which the permittees are trying to show should be revised based on the site-specific standard application they are trying to submit. This is contrary to the explicit legislative language and intent and makes MPCA's approach to implementing the sulfate standard vulnerable to legal challenge.

I. MPCA Should Contemplate Flexibility of Compliance in Permits to Account for the Complexity and Costs of Developing Site-Specific Standards for the First Time Under this New Framework

The Proposed Framework requires that regulated facilities submit new data and variables in their site-specific standard applications. Moreover, in the vast majority of situations, MPCA is requiring ten years of new data to support such applications. Given that new requirement, facilities seeking to apply for site-specific standards should not be required to comply with any associated permit limits until MPCA has (1) proposed the Framework through proper rulemaking and responded to public comments on the underlying substantive requirements; and (2) established a compliance framework for facilities that cannot immediately comply with the 10 mg/L standard and must collect multiple additional years of data before being able to obtain a site-specific standard. Facilities will need to develop complex methods to assess site-specific standards under this Framework, which will be an extremely time-consuming and resource-intensive effort. Again, this is contrary to state legislation and extremely burdensome to regulated facilities; at the very least, it is incumbent upon MPCA to provide some amount of flexibility for the decade of time that it would take to create a valid site-specific standard application under the Proposed Framework.

J. Conclusion

The Proposed Framework's requirements are protracted, unsupported, arbitrary, overbroad, and contrary to state legislation. The Framework also introduces such sweeping new requirements for site-specific standard applications that the Framework must not be finalized without first moving through the proper rulemaking process. However, if MPCA decides to proceed with the Proposed Framework as it stands, then it should address the substantial policy, legal and scientific concerns raised in these comments, and should consider the specific revisions to the Proposed Framework that U. S. Steel is recommending in this letter.

U. S. Steel appreciates the opportunity to submit these comments concerning the Proposed Framework. If you have any questions or should you need additional information, please do not hesitate to contact me at 218-749-7364 or clbartovich@uss.com.

Sincerely,

Chrissy L. Bartovich
Director – Environmental, U. S. Steel Mining and Tubular Operations
United States Steel Corporation

Natural Wild Rice In Minnesota

A Wild Rice Study document submitted to the Minnesota Legislature by the Minnesota Department of Natural Resources
February 15, 2008

Fiscal Disclosure

Pursuant to Minnesota Statutes, Section 3.197, we estimate that it cost approximately $72,614 to produce this report. This includes Minnesota Department of Natural Resources (MNDNR) staff time for conducting the inventory, attending meetings, drafting and reviewing the report and compiling comments and recommendations ($45,159) and meeting expenses, including travel, for consultation with the Technical and Partnership Teams ($1,772). In addition, costs accrued to other agencies and individuals participating on the Technical Team are $22,618 for time and $3,065 for travel. These costs do not include the costs of preceding research and public participation efforts conducted by the MNDNR or Team members prior to the requirement that this report be prepared.

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Executive Summary

Introduction

This report fulfills the requirements of Session Law 2007, Chapter 57, Article 1, Section 163 requiring the Commissioner of Natural Resources to prepare a study for natural wild rice that includes: (1) the current location and estimated acreage and area of natural stands; (2) potential threats to natural stands, including, but not limited to, development pressure, water levels, pollution, invasive species, and genetically engineered strains; and (3) recommendations to the house and senate committees with jurisdiction over natural resources on protecting and increasing natural wild rice stands in the state.

In fulfilling these requirements, the Minnesota Department of Natural Resources (MNDNR) established a Technical Team of wild rice experts from State, Tribal, and Federal governments, as well as academia and the private sector. The MNDNR also established a Partnership Team representing major stakeholders.

Importance of Natural Wild Rice

Nowhere has natural wild rice been more important, nor had a richer history, than in Minnesota. No other native Minnesota plant approaches the level of cultural, ecological, and economic values embodied by this species. Natural wild rice has been hand harvested as a source of food in the Great Lakes region for thousands of years.

The Ojibwe people have a special cultural and spiritual tie to natural wild rice. Known to their people as Manoomin, it is revered as a special gift from the Creator. In addition many immigrants to Minnesota adopted hand harvesting of natural wild rice as an annual ritual. Annual sales of state licenses for wild rice harvesting peaked in 1968 at over 16,000. In recent years, annual sales have averaged fewer than 1500. In many instances, though, tribal harvesters are not required to buy state licenses. It is thought that more than 3000 tribal members participate in wild rice harvesting, providing a statewide total (tribal and nontribal) of 4000-5000 individuals annually.

The value of natural wild rice to wildlife has been long appreciated by American Indians and was marveled at by early European explorers. Research since then has documented that wild rice provides food and shelter for many fish and wildlife species. It is one of the most important foods for waterfowl in North America. More than 17 species of wildlife listed in the MNDNR's Comprehensive Wildlife Conservation Strategy as "species of greatest conservation need" use wild rice lakes as habitat for reproduction or foraging.

Wild rice harvest has provided important economic benefits to local economies. As with other commodities, the price paid for unprocessed natural wild rice can vary considerably. Although pricing is mainly determined by supply, marketing also plays a role. During the past 70 years, the price of one pound of unprocessed wild rice has ranged from $0.10 in 1940 to $2.17 in 1966. Adjusted for inflation these prices in today's dollars are equivalent to $0.75 and $13 per pound, respectively. As an example, the 1966 harvest of 924,000 lbs would have been worth over $12 million today.

Prior to 1970, Minnesota provided half of the global market supply of wild rice. Most of this rice was from hand harvested natural stands. By 1990, the large-scale production of cultivated wild rice had expanded, and natural wild rice accounted for less than 10% of the global market supply. The total annual yield of cultivated and hand harvested wild rice in Minnesota today ranges from four to eight million pounds. A recent MNDNR survey found the average annual hand harvest of natural stands to be 430 pounds per individual.

Background

Although stands of natural wild rice occur most commonly in central and north-central Minnesota, the historic range of wild rice included all of the state. Based on the inventory conducted for this report, the range of natural wild rice today includes 55 counties in Minnesota. Stands of natural wild rice were present or occurred in recent history on approximately 1286 lakes and river/stream segments. These areas support a minimum of 64,328 acres of natural wild rice when growing conditions are favorable.

The greatest concentration of lakes supporting natural wild rice is in Aitkin (4,859 acres), Cass (8,323 acres), Crow Wing (3,751 acres), Itasca (8,448 acres), and St. Louis (8,939 acres) counties. These counties contain over 60% of the inventoried natural wild rice acreage in Minnesota. These counties also account for over 70% of the harvesting trips for natural wild rice.

Natural wild rice generally requires some moving water, with rivers, flowages, and lakes with inlets and outlets being optimal areas for growth. Wild rice grows well at depths of 0.5 to 3 feet of water, although some plants may be found in deeper waters. As an annual plant, natural wild rice develops each spring from seeds that fell into the water during a previous fall. Germination requires a dormancy period of three to four months of cold, nearly freezing water (35° F or colder). Seeds are unlikely to survive prolonged dry conditions.

The entire process, from germination of a new plant to dropping of mature seeds, requires about 110 to 130 days, depending on temperature and other environmental factors. Seeds begin ripening at the top of the stem and then ripen over several days on an individual plant. Plants within a stand ripen at different times because of genetic, developmental, and environmental variation. This staggered maturation process means that ripe seeds may be available within individual stands for several weeks, and across the entire range of natural wild rice in Minnesota for a month or longer.

The earliest laws and regulations concerning wild rice in Minnesota focused on wild rice harvest and date back more than 75 years. Today, there is a complex mix of tribal, federal, state, and local laws and regulations. These are associated with the formal recognition of the significance of natural wild rice and its protection, management, and harvest. The application of regulations varies by jurisdiction (i.e., tribal versus state) and geography (i.e., on-reservation versus off-reservation, or within various ceded territories). Regulatory authority governing different aspects of wild rice management occurs within several state agencies yet within state statutes there is no unifying policy to provide overall guidance in implementation.

Threats
Despite its rich history and abundance in Minnesota, natural wild rice faces many current and potential threats in this region. In general, any factor that can affect water quality, seasonal water levels, lakebed conditions, regional climate, aquatic vegetation, or the natural genetic diversity of wild rice could potentially threaten natural stands. These threats may work in concert or individually to damage wild rice stands.

Important threats that impact local stands of natural wild rice include changes in local hydrology due to dams and channelization, water-based recreation and shoreland development, and mining and other industrial activities. Although the impacts are to local stands, the cumulative effect of these threats can have statewide implications. Hydrological impacts and shoreland development are particularly important.

On a statewide and regional scale, the most important threats are the potential loss of genetic integrity, invasive species, and climate change. Nearly all of the concern expressed about wild rice genetics focuses on the potential of genetic engineering. Invasive species are an ongoing statewide issue impacting aquatic systems in general. Climate change has the potential for the greatest long-term impacts on natural wild rice.

As citizens become more distant from positive experiences with natural wild rice through harvesting, hunting, trapping, or wildlife watching, they are less likely to recognize the very real impacts that the previously noted threats could have on natural wild rice in Minnesota. This loss of appreciation, while not a direct threat to the wild rice resource, nevertheless increases the risks because the level of resource protection and management is often based on the perceived value of a resource.

Unfortunately wild rice harvesters are relatively few in number and have experienced a long-term decline, although the number of tribal harvesters has rebounded in recent years. Only about 4000-5000 people participate in hand harvesting natural stands of wild rice annually.

The future of natural wild rice in Minnesota will depend in large part on its protection and management by state and tribal natural resource agencies. The role of the agencies is complicated by the limitations of their authority and the challenges posed by multiple jurisdictions, annual variability of wild rice crops due to weather and other factors, and lack of information concerning the natural ecology of wild rice, historical losses, trends in abundance and distribution, threats to its future, and a better understanding of wild rice harvesters.

Recommendations
The following recommendations were developed with valuable input and discussion from the members of the Wild Rice Study Technical Team and Partnership Team. However, the MNDNR assumes sole responsibility for these recommendations as written and presented here.

MNDNR recognizes the importance of protecting natural wild rice beds from genetic modification and agrees with wild rice stakeholders that this protection is critical to the future of this resource. We strongly support the Minnesota Environmental Quality Board in adopting rules that require an Environmental Impact Statement for a proposed release of genetically engineered wild rice (MS 116C.94 Subd.1b).

Recommendation 1

Recodify current wild rice harvest statutes and rules to remove duplication and inconsistencies.

Rationale: The state's wild rice statutes and rules have been developed and modified piecemeal over a long period of time. As a result they contain a number of inconsistencies and duplication.

Recommendation 2

Establish statutory policy guidance on wild rice and its management.

Rationale: Within state statutes there is no unifying policy that provides direction to agencies responsible for some aspect of wild rice management.

Recommendation 3

The MNDNR will convene an interagency workgroup in 2008 to identify desired statutory updates in harvest regulations.

Rationale: Harvest regulations and license fee structure should be reviewed by an interagency work group for suggested changes.

Recommendation 4

The MNDNR will designate and publish a list of important natural wild rice areas.

Rationale: Recognizing important wild rice areas and publishing the list would call attention to the importance of these areas, indicate management priorities, and provide a formal list that may prove useful for local units of government that are considering zoning and surface use restrictions.

Recommendation 5

The MNDNR will convene a standing interagency wild rice workgroup to share information and develop recommendations for inventory methodology and trend assessments, education and information outreach, lake planning and management, harvester recruitment and retention, and other management issues as they arise.

Rationale: Comprehensive protection and management of wild rice involves multiple agencies. Management needs include better inventory information including consistent methodology for trend analysis, documenting natural genetic diversity, and establishing long-term case studies on identified lakes.

Recommendation 6

Increase intensive natural wild rice lake management efforts and accelerate the restoration of wild rice stands within its historic range.

Rationale: Protecting and managing natural wild rice resources on many lakes requires active annual management activities to maintain free flowing outlets. Active management is also required to restore wild rice to wildlife habitat areas within its historic range. These efforts should be accelerated as funding, time, and opportunity permit.

Sacred Food and Medicine

Wild rice, or manoomin, is a sacred food and medicine integral to the religion, culture, livelihood, and identity of the Anishinaabeg. According to our sacred migration story, in the long ago a prophet at the third of seven fires beheld a vision from the Creator calling the Anishinaabe to move west (to a land previously occupied long ago) until they found the place "where food grows on the water." The Anishinaabeg of the upper Mississippi and western Great Lakes have for generations understood their connection to anishinaabe akiing (the land of the people) in terms of the presence of this plant as a gift from the Creator. In the words of White Earth's Tribal Historian, Andy Favorite, "Wild rice is part of our prophecy, our process of being human, our process of being Anishinaabe … we are here because of the wild rice. We are living a prophecy fulfilled."

In our Ojibwe language, manoomin is animate, grammatically referred to as "him/her" not "it," a non-human being, not just an inanimate "resource." It is both difficult and of utmost importance to adequately translate and appreciate this worldview in the language of mainstream culture and society with its scientific advisory boards for the study of humans and animals but not plants. According to Anishinaabe author, Basil Johnson, "…in essence each plant ... was a composite being, possessing an incorporeal substance, its own unique soul-spirit. It was the vitalizing substance that gave to its physical form growth, and self-healing." The Anishinaabeg believe that wild rice will always grow where they live. Menominee chief Chieg Nio'pet said his people did not need to sow rice because it would follow them wherever they went. He told of how Shawano Lake never had manoomin until the Menominee moved there. Similarly when they were banned from Lake Winnebago, the rice that had been plentiful there all but disappeared. Whatever happens to the land and to manooomin happens to the Anishinaabe.

Our ceremonies and aadizookanag -sacred stories- also tell of our people's relations with this plant. White Earth Anishinaabe, Joe LaGarde, notes that wild rice and water are the only two things required at every ceremony. Manoomin accompanies our celebrations, mourning, initiations, and feasts, as both a food and a spiritual presence. It holds special significance in traditional stories, which are only told during ricing time or when the ground is frozen. "In these stories, wild rice is a crucial element in the realm of the supernaturals and in their interactions with animals and humans; these legends explain the origin of wild rice and recount its discovery…" by Wenabozhoo, or Nanabozho, the principal manidoo or spirit in our sacred aadizookanag.

Manoomin is just as central to our future survival as our past. While we try to overcome tremendous obstacles to our collective health, the sacred food of manoomin is both food and medicine. "Wild rice is consequently a very special gift, with medicinal as well as nutritional values—belief reflected in the Ojibwe use of wild rice as a food to promote recovery from sickness as well as for ceremonial purposes." (Vennum 62). Manoomin is inextricably bound to the religion and identity of the Anishinaabeg. This is why these threats are potentially so devastating and why it is essential that the sanctity and integrity of this plant be preserved. If artificially produced or engineered varieties of wild rice were to compromise the wild manoomin that has existed in the lakes for thousands of years, it will compromise the Anishinaabe people and our way of life. Joe LaGarde puts it plainly, "If we lose our rice, we won't exist as a people for long. We'll be done too."

Erma Vizenor, Tribal Chairwoman, White Earth Nation
With the participation of Carlton College Students.

Introduction

This report fulfills the requirements of Session Law 2007, Chapter 57, Article 1, Section 163:

By February 15, 2008, the commissioner of natural resources must prepare a study for natural wild rice that includes: (1) the current location and estimated acreage and area of natural stands; (2) potential threats to natural stands, including, but not limited to, development pressure, water levels, pollution, invasive species, and genetically engineered strains; and (3) recommendations to the house and senate committees with jurisdiction over natural resources on protecting and increasing natural wild rice stands in the state.

In developing the study, the commissioner must contact and ask for comments from the state's wild rice industry, the commissioner of agriculture, local officials with significant areas of wild rice within their jurisdictions, tribal leaders within affected federally recognized tribes, and interested citizens.

In fulfilling these requirements, the Minnesota Department of Natural Resources (MNDNR) established a Technical Team of wild rice experts from State, Tribal, and Federal governments; the Minnesota cultivated wild rice industry; Ducks Unlimited; Save Our Rice Alliance (SORA), an organization of interested citizens who hand harvest natural wild rice; White Earth Land Recovery Project; the University of Minnesota; and the University of Wisconsin (Appendix A). The MNDNR also established a Partnership Team representing the Minnesota wild rice industry, the state commissioner of agriculture, the Association of Minnesota Counties, tribal leaders within affected federally recognized tribes, the United States Fish and Wildlife Service, Ducks Unlimited, Minnesota Waterfowl Association, and SORA (Appendix A).

The Technical Team, working with MNDNR staff, developed drafts of the wild rice study document for review by the Partnership Team. The collaboration of these two teams was instrumental in producing this document for MNDNR review and approval. The MNDNR is indebted to team members for their contributions of time, expertise, and hard work. It should be clear, however, that the MNDNR assumes sole responsibility for the content and recommendations of this document.

The wild rice study document and its appendices are intended to provide the reader with a thorough background on the importance of natural wild rice to Minnesota, its natural ecology and distribution, threats to its future, challenges in managing the resource, and recommendations to insure its abundance for future generations.

Importance of Natural Wild Rice in Minnesota

As directed by the legislature, the wild rice study document focuses on natural wild rice. For this study, we define natural wild rice as native species of wild rice (*Zizania*) that are growing in public waters and are not subject to cultivation. The simplest description of natural wild rice in Minnesota is that it is an annual aquatic grass that produces an edible grain.

This simple description, of course, does not do justice to this unique and valuable plant. History is replete with examples of its importance to wildlife and value to humans both nutritionally and culturally. Wild rice (manoomin to the Ojibwe) is a spiritually significant resource for Native Americans in the Great Lakes region, and it has been for centuries. Nowhere has this grain been more important, nor had a richer history, than in Minnesota. No state harbors more acres of natural wild rice than Minnesota (Moyle and Krueger 1964). No other native Minnesota plant approaches the level of cultural, ecological, and economic values embodied by natural wild rice.

Cultural Importance

Natural wild rice has been hand harvested as a source of food in the Great Lakes region for thousands of years. Evidence of its human use dates back to the Late Archaic and Early Woodland periods, more than 2000 years ago (Valppu 2000). Archeological evidence indicates that from the 1600s to the 1800s wild rice was a staple food for the Algonquian and Dakota peoples throughout the area now known as Minnesota. It has been important historically for gifting and trading, as well. For example, when Dakota Chief Wabasha hosted Zebulon Pike in 1805 he offered gifts of wild rice to the explorer (Vennum 1988).

The Ojibwe people have a special cultural and spiritual tie to natural wild rice. Their Migration Story describes how they undertook a westward migration from the eastern coast of North America. Tribal prophets had foretold that this migration would continue until the Ojibwe people found “the food that grows on water” (Benton-Banai 1988). That food was wild rice, known as manoomin, and is revered to this day by the Ojibwe as a special gift from the Creator (Ackley 2000; Schlender 2000).

Early European explorers and fur traders were impressed with the availability and nutritional quality of wild rice, and attempts were made to import it to Europe as early as 1790 (Oelke 2007). Many immigrants to Minnesota adopted hand harvesting of natural wild rice as an annual ritual. The importance of this harvest to European settlers lessened only when cultivated non-native grains became more readily available.

The tradition of hand harvesting natural wild rice continues to this day among both tribal and nontribal cultures. This tradition has been preserved through tribal code and state regulations that reflect traditional methods of harvesting. State statutes in Minnesota include regulations that restrict the maximum length (18 feet) and width (36 inches) of the harvesting boat, as well as the maximum weight (1 pound) and length (30 inches) of hand flails. The regulations also require that push poles have forks 12 inches or less in length. The use of any machine or mechanical device to harvest natural wild rice is generally prohibited.

Annual sales of state licenses for wild rice harvesting peaked in 1968 at over 16,000. In recent years, annual sales have averaged fewer than 1500. However, because in many instances tribal harvesters are not required to buy state licenses, state numbers do not adequately reflect the numbers of individuals participating in wild rice harvesting. It is thought that more than 3000 tribal members participate in wild rice harvesting providing the statewide total (tribal and nontribal) of 4,000 to 5,000 individuals.

Annual harvests can vary greatly. Rice productivity, weather, and harvester participation are all important factors. The MNDNR survey of state licensees from 2004 to 2006 found the average annual harvest to be 430 pounds per individual (MNDNR 2007). Aitkin, Cass, Crow Wing, Itasca, and St. Louis counties accounted for over 70% of the harvesting trips for natural wild rice. Estimates of annual harvest of natural stands in Minnesota between 1940 and 1972 ranged from 20 thousand to nearly 4 million pounds of unprocessed grain (Oelke et al. 1973).

Another aspect of the cultural importance of wild rice is its nutritional value. Noted for its importance as a whole grain, wild rice is an excellent source of complex carbohydrates, vitamins, minerals, fiber and protein. It is a particularly good source of potassium, zinc and riboflavin (Oelke 2007). Access to traditional foods is felt to be an important element of restoring individual and community health of the Ojibwe people (W. LaDuke, personal communication). Natural wild rice is one of the mainstays of traditional foods for the Ojibwe community.

Concerns for the preservation of hand harvesting traditions and related issues led to the formation in 2007 of a tribal and nontribal partnership called Save Our Rice Alliance (SORA). The stated mission of SORA is “To preserve and enhance the culture, economy, and sustainability of native wild rice” (A. Drewes, personal communication).

Ecological Importance

The value of natural wild rice to wildlife has been long appreciated by American Indians and was marveled at by early European explorers (Jenks 1900). Jonathan Carver traveled through eastern portions of North America in the 1760s and observed of wild rice that “the sweetness and nutritious quality of it attracts an infinite number of wild fowl of every kind which flock from distant climes to enjoy this rare repast, and by it become inexpressively fat and delicious” (Stoddard 1957).

Both migrating and resident wildlife rely on the nutritious and abundant seeds of natural wild rice. One acre of natural wild rice can produce more than 500 pounds of seed. These seeds have long been recognized as an important source of food during fall migrations (McAtee 1917). Martin and Uhler (1939) listed wild rice as the ninth most important source of food for ducks throughout the United States and Canada, and the third most important source of food for ducks in the eastern portions of the continent. Research conducted on the Chippewa National Forest found that natural wild rice was the most important food for mallards during the fall (Stoudt 1944). Although the value of wild rice to mallards, wood ducks, and ring-necked ducks is most commonly recognized, other ducks such as black ducks, pintail, teal, wigeon, redheads, and lesser scaup also use stands of wild rice (Rossman et al. 1982, Huseby 1997).

The stems of wild rice provide nesting material for such species as common loons, red-necked grebes, and muskrats; and critical brood cover for waterfowl. The entire wild rice plant provides food during the summer for herbivores such as Canada geese, trumpeter swans, muskrats, beaver, white-tailed deer, and moose (Martin et al.1951, Tester 1995). In addition, rice worms and other insect larvae feed heavily on natural wild rice. These, in turn, provide a rich source of food for blackbirds, bobolinks, rails, and wrens. In the spring, decaying rice straw supports a diverse community of invertebrates and thus provides an important source of food for a variety of wetland wildlife including birds, small fish, and amphibians. Indeed, every stage of growth of natural wild rice provides food for wildlife (McAtee 1917, Stoudt 1944).

As a result, wild rice lakes and streams are breeding and nesting areas for many species. More than 17 species of wildlife listed in the MNDNR's Comprehensive Wildlife Conservation Strategy (2006) as "species of greatest conservation need" use wild rice lakes as habitat for reproduction or foraging (Henderson 1980, Martin et al.1951). Listed bird species can be found in Table 1.

Table 1. Minnesota birds that utilize wild rice habitat and are listed in *Tomorrow's Habitat for the Wild and Rare* as species of special concern.

Birds of Special Concern	Life Cycle Stage
American Black Duck	Breeding and migration
Lesser Scaup	Migrant
Northern Pintail	Migration, Rare Breeder
Trumpeter Swan	Breeding and migration
American Bittern	Breeding and migration
Least Bittern	Breeding and migration
Red-necked Grebe	Breeding and migration
Common Loon	Breeding and migration
Sora Rail	Breeding and migration
King Rail	Casual migrant
Virginia Rail	Breeding and migration
Yellow Rail	Breeding and migration
Black Tern	Breeding and migration
Bobolink	Foraging and migration
Rusty Blackbird	Foraging and migration
Sedge Wren	Breeding and migration
Bald Eagle	Foraging and migration

Natural wild rice has other ecological values as well. Emergent aquatic plants such as wild rice, bulrush, and cattails protect shorelines and provide habitat for fish (Radomski and Goeman 2001). Dense stands of wild rice stabilize loose soils and form natural windbreaks that can limit the mixing of soil nutrients into the water column (Meeker 2000). In addition, natural wild rice has relatively high requirements for nutrients such as phosphorus and nitrogen (Oelke et al. 2000). During periods of rapid growth, which occurs in spring and summer, the plants sequester these nutrients. Thus stands of natural wild rice counter the effects of nutrient loading and the potential increases in algal growth and lake turbidity.

Economic Importance

Prior to European settlement of Minnesota, natural wild rice was the most important grain available to native peoples, early explorers, and fur traders (Vennum1988). Properly dried, and stored in clean, dry conditions, uncooked wild rice has an estimated shelf life of up to 10 years. One pound yields up to ten and a half cups of cooked wild rice (Oelke 2007). As a dietary staple that was so easily stored and used, wild rice had considerable economic value. With the influx of immigrant settlers and the agricultural production of non-native grains, the overall economic value of wild rice waned. Nevertheless, harvest of natural wild rice continued to be popular in Minnesota. During the 1960s, sales of state licenses averaged over 10,000 per year.

The economic value of wild rice is reflected in the efforts of many to expand its occurrence into new waters. Native peoples have long sown wild rice to create additional sources of grain (Vennum 1988). Waterfowl hunters have commonly planted wild rice to attract ducks. The demand for seed of wild rice and other aquatic wildlife foods presumably fostered the establishment of Wildlife Nurseries, Inc. in Oshkosh, Wisconsin in 1898 (Oelke 2007). This firm continues selling wild rice for planting today. Conservation agencies have long participated in planting efforts as well, working to establish new stands of wild rice and perpetuate traditional areas (Moyle 1944b).

David Owens noted the potential benefits of cultivating wild rice as early as 1852 (Vennum 1988). In 1853, Oliver H. Kelley published an article discussing the merits of wild rice cultivation. Albert E. Jenks discussed wild rice cultivation as part of "agricultural development" in 1901. Yet not until 50 years later did James and Gerald Godward pioneer the first real efforts. They began production of cultivated wild rice in central Minnesota, near Merrifield, in 1950 (Oelke 2007).

The 1950s and 1960s may well have been the peak of modern hand harvesting of wild rice. From 1957 to 1963 the state of Minnesota sold an average of 10,012 wild rice harvest licenses (Table 2). The average annual harvest of unprocessed wild rice exceeded 2 million pounds or about 227 pounds per picker per year (Moyle and Krueger 1964).

As with other commodities, the price paid for unprocessed natural wild rice can vary considerably. Although pricing is mainly determined by supply, marketing also plays a role. During the past 70 years, the price of one pound of unprocessed wild rice has ranged from $0.10 in 1940 to $2.17 in 1966 (Oelke 2007). Adjusted for inflation these prices in today's dollars are equivalent to $0.75 and $13 per pound, respectively. The 1966 harvest of 924,000 lbs would have been worth over $12 million today. Since 1990, the price paid for unprocessed rice from the Leech Lake Reservation has varied between $1.00 and $1.50 per pound (R. Robinson,

Table 2. Hand harvesting of natural wild rice 1957-1963.

Year	Licenses sold	Harvest *
1957	7,535	1,057,000
1958	9,702	3,224,000
1959	9,332	2,067,000
1960	9,664	2,301,000
1961	14,660	2,772,000
1962	6,709	1,292,000
1963	12,482	3,212,000

*Harvest is in unprocessed pounds

Jr., personal communication). Sales during this period ranged from approximately 7,400 to 280,000 pounds.

Prior to 1970, Minnesota provided half of the global market supply of wild rice. Most of this rice was from hand harvested natural stands. By 1990, the large-scale production of cultivated wild rice had expanded, and natural wild rice accounted for less than 10% of the global market supply. Cultivated wild rice from Minnesota provided 40% of the market and California provided 50% (Lee 2000). California still leads the cultivated wild rice industry. The total annual yield of cultivated and hand harvested wild rice in Minnesota today ranges from four to eight million pounds.

Although cultivated rice dominates these production numbers, hand harvested natural wild rice remains a vital component of tribal and local economies in Minnesota. The MNDNR survey of 2004 – 2006 state license buyers found an average annual individual harvest of 430 pounds. In 2007, nearly 300,000 pounds of unprocessed rice were purchased from LLBO-licensed harvesters. At $1.50 per pound, this harvest generated more than $400,000 of income for tribal members (R. Robinson, Jr., personal communication).

Wild Rice Background

Taxonomy
Native North American wild rice is classified as a grass in the family *Poaceae* and the genus *Zizania.* The most common species throughout Minnesota is northern wild rice, or *Zizania palustris* L. (Ownbey and Morley, 1991). Two varieties of natural wild rice occur in this region and in other parts of the Upper Midwest: Z. *palustris* var. *palustris* and Z. *palustris* var. *interior* (Gleason and Cronquist, 1991; Flora of North America, 1993+).

A more southern and eastern species, *Zizania aquatica* L., is uncommon but thought by many to occur in Minnesota as well. The precise distribution of *Z. aquatica* is unclear because of differences in taxonomic interpretations and potentially overlapping ranges. *Z. aquatica* is physically larger than *Z. palustris* but its grain is more slender and difficult to harvest. Both of these species are native only to North America.

Distribution and Abundance
Minnesota historically harbored more acres of natural wild rice than any other state (Moyle and Krueger 1964). Despite losses of wild rice habitat, the importance of Minnesota as a center of natural wild rice abundance has actually increased as wild rice acreage has declined elsewhere in the United States. For thousands of years, wild rice thrived in shallow lakes, rivers, and streams left behind by melting glaciers. Although stands of natural wild rice occur most commonly in areas of glacial moraines, such as in central and north-central Minnesota, the historic range of wild rice included all of Minnesota (Moyle 1944b).

Its range also extended westward into the present-day Dakotas and eastward to the Atlantic coast. While not distributed evenly, wild rice likely occurred in many places where its ecological requirements were met. Because wild rice also was planted in areas where it did not occur naturally, it is sometimes difficult today to distinguish between historically natural stands and successfully seeded stands (Vennum 1988).

An updated inventory of the distribution and abundance of natural wild rice was compiled for this study by selected members of the Technical Team and the MNDNR (Appendix B). Data are from lake-habitat surveys, reported observations, and interviews with field personnel of state, federal, and tribal agencies. Although this inventory provides a marked improvement in our understanding of natural wild rice distribution in Minnesota, it should be considered a minimum estimate. The data for many wild rice lakes, streams and rivers is incomplete or totally lacking.

Based on this inventory, the range of natural wild rice today includes 55 counties in Minnesota (Figure 1). The only Minnesota counties without significant populations of natural wild rice are along the western and southwestern boundaries of the state. It should be noted, however, that historical records of wild rice include herbarium specimens that were collected in several western counties not documented by the current inventory. These counties include Pipestone, Cottonwood, Chippewa, Swift, Clay, and western Polk (Moyle 1939, Ownbey and Morley, 1991).

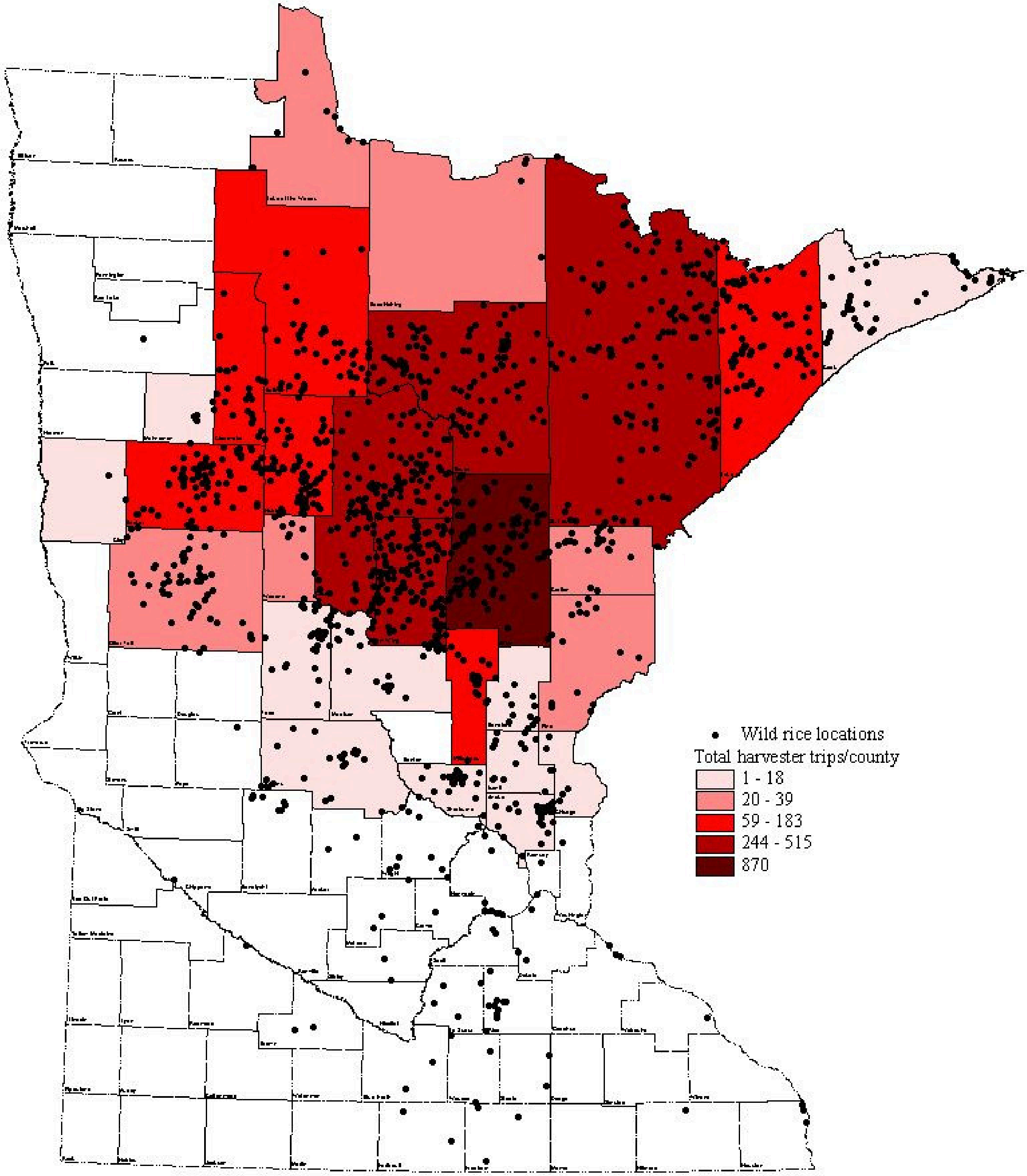

Figure 1. Distribution of wild rice lakes and wild rice harvesting pressure in Minnesota.

Stands of natural wild rice were present or occurred in recent history on approximately 1,286 lakes and river/stream segments (Figure 1). These areas support a minimum of 64,328 acres of natural wild rice when growing conditions are favorable. These areas vary from large, shallow lakes dominated by natural wild rice stands (i.e. Nature's Lake in Cass County) to significant bays within large fish lakes (i.e. Leech Lake) to a narrow fringe along lake/river shorelines. The greatest concentrations of lakes that support natural wild rice are in Aitkin (4,859 acres), Cass (8,323 acres), Crow Wing (3,751 acres), Itasca (8,448 acres), and St. Louis (8,939 acres) counties. These counties contain over 60% of the inventoried natural wild rice acreage in Minnesota. These counties also account for over 70% of the harvesting trips for natural wild rice (MNDNR 2006 harvest survey, Appendix C).

The abundance of natural wild rice in Minnesota today is largely due to abundant suitable habitat, favorable climate, and natural genetic variability that allows for environmental selection of traits that perform well under varying conditions. Studies in Wisconsin found sufficient genetic diversity between geographically separated stands of wild rice to potentially identify regional populations. Within-stand diversity also varied greatly, with larger and denser stands having greater genetic diversity (Waller et al. 2000).

Life History

While the historical range of natural wild rice illustrates its broad distribution, its specific occurrence and abundance is in large part dependent on local environmental conditions. For example, clear to moderately colored (stained) water is preferred, as darkly stained water can limit sunlight and may hinder early plant development.

Wild rice grows within a wide range of chemical parameters (i.e. alkalinity, salinity, pH, and iron; Meeker 2000). However, productivity is highest in water with a pH of 6.0 to 8.0 and alkalinity greater than 40 ppm. While researchers have observed that natural wild rice stands are relatively nutrient rich, excess levels of some nutrients, especially phosphorus, can have significant adverse effects on productivity (Persell and Swan 1986).

Natural wild rice generally requires some moving water, with rivers, flowages, and lakes with inlets and outlets being optimal areas for growth. Seasonal water depth is critical, however. Water levels that are relatively stable or decline gradually during the growing season are preferred. In particular, abrupt increases during the early growing season can uproot plants. Wild rice grows well at depths of 0.5 to 3 feet of water, although some plants may be found in deeper waters (M. McDowell, J. Persell personal communication).

Shallower sites can allow strong competition from perennial emergent plant species, while deeper sites can stress wild rice plants and limit seed production. Although wild rice may occur in a variety of lake bottoms, the most consistently productive stands are those with soft, organic sediment (Lee 1986). Nitrogen and phosphorus are limiting nutrients for wild rice (Carson 2002).

As an annual plant, natural wild rice develops each spring from seeds that fell into the water and settled into the sediment during a previous fall. Germination requires a dormancy period of three to four months of cold, nearly freezing water (35° F or colder). Seeds are unlikely to survive prolonged dry conditions.

Seed germination typically occurs when the substrate and surrounding water temperatures reach about 40° F. Depending on water depth, latitude, and the progression of spring weather, wild rice germinates in Minnesota sometime in April, well ahead of most but not all perennial plants. Within three weeks, the seedlings develop roots and submerged leaves.

The emergent stage begins with the development of one or two floating leaves and continues with the development of several aerial leaves two to three weeks later. The floating leaves appear in late May to mid June in Minnesota, again dependent on water depth, latitude, and weather. Because of the natural buoyancy of the plant, it is at this stage of growth that wild rice is most susceptible to uprooting by rapidly rising water levels. Plants can be significantly stressed even when they remain rooted.

Natural wild rice begins to flower in mid to late July in Minnesota. Flowering times are dependent on both day length and temperature. Flowers are produced in a branching panicle. Female flowers (pistillate or seed-producing) occur at the top of the panicle on appressed branches. Male flowers (staminate or pollen-producing) occur on the lower portion of the panicle on nearly horizontal branches. Natural wild rice is primarily pollinated by wind. High temperatures and low humidity can negatively affect fertilization rates.

Cross-pollination is typical in natural wild rice stands because female flowers develop, become receptive, and are pollinated before male flowers on the same plant shed pollen. Cross-pollination is further enhanced by plant-to-plant variation in flowering times within stands. This cross-pollination within and among wild rice populations helps to preserve the genetic variability and thus biologic potential for wild rice to adapt to changing conditions such as the highly variable climate of the Great Lakes region.

The genetic variability that exists today in natural wild rice may be a critical determinant of whether stands of wild rice can adapt to long-term changes in regional climate. Studies in northern Wisconsin found sufficient genetic diversity among geographically distinct stands of natural wild rice to identify four regional populations. The degree of diversity within stands varied widely as well, with larger and denser stands having greater diversity (Waller et al. 2000).

Wild rice seeds are visible two weeks after fertilization, and they mature in four to five weeks. Immature seeds have a green outer layer that typically turns purplish black as the seed reaches maturity. Seeds begin ripening at the top of the stem and then ripen over several days on an individual plant. Plants within a stand ripen at different times because of genetic and developmental variation. In general, natural wild rice in rivers ripens earlier than that in lakes, rice in shallow waters earlier than that in deeper waters, and rice in northern Minnesota earlier than that in more southerly stands.

This staggered maturation process means that ripe seeds may be available within individual stands for several weeks, and across the entire range of natural wild rice in Minnesota for a month or longer. This extended period of "shattering", or dropping of ripened seed, is an important mechanism to ensure that some seeds will survive environmental conditions and perpetuate the natural stand. The entire process, from germination of a new plant to dropping of mature seeds, requires about 110 to 130 days, depending on water and air temperatures and other environmental factors.

Not all wild rice seeds germinate the following year. Seeds may remain dormant in the bottom sediment for many years to several decades if conditions are not suitable for germination. This mechanism allows wild rice populations to survive through years of high water levels or storms that reduce or eliminate productivity. Moreover, natural wild rice can germinate and re-colonize sites after other species have been reduced or eliminated by environmental disturbance (Meeker 2000).

Even under ideal growing conditions, populations of natural wild rice undergo approximately three to five year cycles in which productivity can vary greatly (Jenks 1900, Moyle 1944b, Pastor and Durkee Walker 2006, Durkee Walker et al. 2006). Highly productive years are frequently followed by a year of low productivity, that is then followed by a gradual recovery in wild rice yield (Moyle 1944b, Grava and Raisanen 1978, Atkins 1986, Lee 1986, Aiken et al. 1988, Archibold et al. 1989).

Recent studies suggest that oscillations in wild rice productivity may be caused in part by the accumulation of old straw from previous growth that inhibits plant growth and seed production (Pastor and Durkee Walker 2006, Durkee Walker et al. 2006). In particular, the amount of wild rice straw, its stage of decay, and its tissue chemistry likely affect nutrient availability, influence wild rice productivity, and thus drive cycling of wild rice populations (Durkee Walker, Ph.D. thesis 2008).

Legal Considerations

The earliest laws and regulations concerning wild rice in Minnesota date back more than 75 years. While some harvesting regulations existed through earlier session laws and statutes, comprehensive state regulation of the wild rice harvest was apparently first codified in 1939. These regulations controlled methods and locations of harvest to reduce damage to natural beds and to distribute the harvest.

Today, there is a complex mix of tribal, federal, state, and local laws and regulations. These are associated with the formal recognition of the significance of natural wild rice and its protection, management, and harvest. It is difficult to capture all the important details that exist within these myriad regulations in a summary overview. The application of regulations varies by jurisdiction (i.e., tribal versus state) and geography (i.e., on-reservation versus off-reservation, or within various ceded territories). In addition, some regulations may be changed over time.

The following discussion is not intended to provide a complete legal brief of the law as it relates to natural wild rice. Rather the intent is to indicate the complexity of this law and to make clear the multiple jurisdictions that have recognized legal interests in Minnesota wild rice.

Treaties and Tribal Regulations

Tribal regulations of the harvest and protection of wild rice within reservation boundaries vary from tribe to tribe. Therefore individual tribal governments or their natural resource departments should be contacted for details.

In addition to tribal regulations, treaties and other agreements with the U.S. government reserved off-reservation harvesting rights for some tribes. For example, the Ojibwe tribes that co-signed the Treaty of 1837 reserved the right to gather wild rice from the lands ceded in that treaty. These include an area that eventually became part of east-central Minnesota. The standing of these off-reservation rights was upheld by the U.S. Supreme Court in 1999. [1,2,3]

Similar off-reservation rights are reserved for other Ojibwe tribes in the 1854 ceded territory, in northeastern Minnesota. Rights of traditional tribal harvesting have also been preserved through other agreements between tribes and the U.S. government. For example, in the early 1900s the U.S. began buying lands adjacent to wild rice stands on Minnesota lakes. These were stands that had traditionally been harvested or lands that were to be used as rice camps by the Minnesota Chippewa Tribe (MCT). Lands were purchased and placed into trust status on Swamp, Mallard and Minnewawa Lakes in Aitkin County; on Basswood Lake in Becker County; on Leech, Mud, and Laura Lakes in Cass County; on Lower Dean Lake in Crow Wing County; on Sugar and Bowstring Lakes in Itasca County; on Onamia and Ogechie Lakes in Mille Lacs County; and on Star Lake in Ottertail County.

MCT members can harvest wild rice on these lakes with a tribal identification card issued under the sovereign authority of their respective tribal governments and current Minnesota statute (MS 84.10). Similarly, local tribal members can harvest wild rice on Rice Lake National Wildlife Refuge and on Tamarack National Wildlife Refuge under the 1936 Collier agreement between the U.S. Bureau of Indian Affairs and Bureau of Biological Survey (predecessor to the U.S. Fish and Wildlife Service).

This Wild Rice Study document is not intended to provide an indepth analysis of treaties and subsequent agreements affecting tribal harvest of wild rice in Minnesota. Tribal governments have sovereignty over the harvest of wild rice within the boundaries of their reservations. Some tribal governments also have the authority to regulate harvest by tribal members within certain ceded lands, while other tribal rights exist for specific off-reservation waters. The state of Minnesota has jurisdiction over the wild rice harvest by nontribal harvesters within ceded territories and over all off-reservation wild rice harvest outside of the ceded lands.

[1,2,3] [Minnesota, et al., Petitioners v. Mille Lacs Band of Chippewa Indians et al. [No. 97-1337].

[2] See McClurken et al., 2003: 30 for a map of ceded lands in Minnesota under this and subsequent treaties.

[3] See McClurken et al., 2003: 486 for exact treaty language pertaining to cession of land and gathering wild rice.

State and Local Regulations

State laws addressing issues of wild rice in Minnesota date back to 1929 or perhaps earlier. These statutes state that wild rice and other aquatic vegetation is owned by the state and that a person may not acquire a property interest in or destroy wild rice except as allowed by law (MS 84.091). State statutes also regulate the harvest of natural wild rice with the exceptions of tribal jurisdictions and regulations, as noted above (MS 84.10, 84.15, 84.027, 84.28). State regulations address the methods and timing of natural wild rice harvest (MS 84.105, 84.111, and 84.152). In addition, several Agency rules also govern the harvest of wild rice in Minnesota (Minnesota Rules 6284.0300 to 6284.0700).

Because State statutes and rules affecting wild rice in Minnesota have been developed and modified over many years, they contain inconsistencies and duplications. These laws could be clarified and made more concise through recodification.

A long-standing tradition of tribal governments and the state of Minnesota involved posting of "closed" signage on selected individual lakes until the wild rice was deemed ripe for harvest. In 1996, after years of criticism from harvesters about particular decisions to open or close wild rice stands, a state law was passed that would open the ricing season on July 15 each year (MS 84.105). The new law also made it illegal to pick wild rice that is not ripe. Wild rice usually ripens in Minnesota between the third week of August and the second week of September, thus the new law was intended to employ a "pick when ripe" philosophy. The opening date was set early enough so that it would always precede the ripening of the rice, and it would also help avoid opening day rushes that can potentially damage rice stands.

One of the rationales behind the new state law was that most other plant products harvested from the wild are picked when the harvester judges them as ready for food, decorative, or medicinal use. Harvesting wild rice before it is ripe produces a product that has no value as a food or cash crop. The new law reduced the need for extensive MNDNR staff time and subjective judgments. It also helps avoid the opening day "stampede" that seems to be associated with all "opening days", which are often perceived as the best day based on "first-come, first-served".

Most of the treaties, agreements, and statutes discussed above are concerned with the harvest of the wild rice grain rather than with protection or enhancement of natural wild rice ecosystems. Harvest issues are moot if the wild rice resource is lost due to damage of natural stands. The viability of these stands often depends on active management.

For example, more than 200 wild rice lakes benefit annually from removal of beaver dams. These dams block the outlets of significant wild rice lakes, and their removal allows the outlets to flow freely; reducing the threat of excessive flooding of wild rice stands. The authority to remove beaver, beaver dams, and beaver lodges is found in MS 97A.045 Subd.1; 97A.401 Subd. 5; and 97B.655, Subd. 2. Without these statutes the current management efforts of the DNR and its partners (i.e., Ducks Unlimited) would be significantly restricted.

Wild rice and other aquatic plants are protected from unauthorized removal under the MNDNR Aquatic Plant Management Program (MS 103G.615). Guidelines prohibit the removal of emergent aquatic plants, including wild rice, without an approved permit. Notable exceptions involve the building of duck hunting blinds and gaining access to open water from shorelines. Removal of aquatic plants is allowed for such access though removal is limited to an area 15 feet or less in width.

Less direct, although important, protection is also provided through shoreland protection laws and regulations (MS 103F.201 through 103F.221). This protection is based on a system of classification for lakes and rivers that applies different zoning regulations depending on classification. Classifications include three for lakes and six for rivers. These regulations are implemented by local units of government within a statewide statutory framework that dictates minimum standards. These standards address issues of shoreland development and uses such as sewage treatment, storm water management, minimum lot size and water frontage, building and septic system setbacks, building heights, subdivisions, and alterations of land and vegetation close to the shore.

The stakeholders group for a pilot project in the five-county north-central lakes area surrounding Brainerd raised concerns about increased shoreline development potentially threatening water quality and the traditional use of individual lakes. One result was the development of alternative shoreland management standards through an advisory committee. The alternative standards provide options for local governments to address specific shoreland issues identified in the five-county area. Subsequently, local governments outside the pilot area began considering elements of these alternative standards for use in their own shoreland ordinances.

In 2005, for example, Beltrami County initiated a review of all of their Natural Environment Lakes in cooperation with the MNDNR and Minnesota Pollution Control Agency (PCA). The MNDNR Section of Wildlife and Division of Ecological Resources procured funding to hire two 2-person crews to conduct site visits to inventory these lakes. Surveys were completed with additional funding from the MNDNR Section of Wildlife in 2006. As a result of this work and the input from a Citizen Advisory Committee, Beltrami County rewrote their shoreland ordinance and reclassified their Natural Environment Lakes. They created one additional lake class, Sensitive Area, with protection criteria intermediate between Natural Environment and the more protective Special Protection. The new Beltrami County Shoreland Ordinance was voted on and approved by the Beltrami County Board in December 2006 (R. Gorham personal communication).

Alternative shoreland management standards may include the promotion of conservation subdivisions over conventional subdivisions (i.e., lot and block); multiple classifications on a single lake (i.e. Natural Environment bay within a General Development lake); districts designated as Sensitive Areas for lakeshore segments so that development standards follow Natural Environment Lake class standards; and a new classification of Special Protection for lakes that have considerable wetland fringe, shallow depth, or unique fish and wildlife habitat.

While these alternative standards can provide protection for natural wild rice habitat, local governments too often lack information on the locations of significant stands of natural wild rice. An updated inventory of wild rice stands in Minnesota would help provide this information.

Further regulation of wild rice occurs through the Minnesota Department of Agriculture (MDA). The MDA has approval authority over the permit-regulated release of genetically modified organisms (GMO), which would include genetically engineered wild rice, under MS Chapter 18. MS Chapter 18 also provides for the issuance of export certificates for the international sale of wild rice. In addition, the MDA inspects and certifies that wild rice seed is free of weed contamination and meets germination standards, and that the labeling of packaged wild rice is truthful and accurate (MS Chapter 21).

The 2006 Minnesota Legislature provided the state Environmental Quality Board (EQB) additional authority over issues related to natural wild rice. The EQB is now required to notify interested parties if a permit to release genetically engineered wild rice is issued anywhere in the United States (MS 116C.92, Subd. 2). The 2006 legislation also requires that EQB adopt rules requiring an Environmental Impact Statement (EIS) for any proposed release and a permit for an actual release of genetically engineered wild rice (MS 116C.94 Subd.1b).

While two other State statutes further signify the importance of natural wild rice in Minnesota, they do not provide additional protection for the resource. One statute, adopted in 1977, recognizes wild rice as the State Grain of Minnesota (MS 1.148). This law needs to be amended, however, to accommodate revised scientific nomenclature.

Another important State statute is the labeling law for packaged wild rice (MS 30.49). This was adopted in 1989 following a joint effort between tribal governments and the Minnesota Cultivated Wild Rice Council. Consumers of wild rice benefit from this law in that it distinguishes among natural lake or river wild rice that is hand-harvested, wild rice that is machine-harvested, and wild rice that is cultivated. This legislation further distinguishes between wild rice that is grown in Minnesota and that which is grown outside of the state.

Threats to Natural Wild Rice in Minnesota

Despite its rich history and abundance in Minnesota, natural wild rice faces many current and potential threats in this region. In general, any factor that can affect water quality, seasonal water levels, lakebed conditions, regional climate, aquatic vegetation, or wild rice's natural genetic makeup could potentially threaten stands of natural wild rice. These threats may work in concert or individually to damage wild rice stands. The order in which the threats are presented in this report is not intended to portray or imply the significance of the threat. Instead these threats are divided into stand level or statewide level categories.

Stand-Level Threats

Hydrologic Changes

Wild rice is by its very nature a shallow water plant and sensitive to changes in water levels. The status of natural wild rice in Minnesota was particularly threatened in the late 1800s and 1900s by installations of dams to increase water levels for navigation, logging, flood control and power production. Although wild rice may persist at depths greater than three feet, these plants typically have poor or no seed production. Over time the plants will decline in numbers and density (Engel 1994). Although some aquatic plants will readily migrate to newly created shallow waters, wild rice apparently does so much less frequently. This may be due to limitations on its rate of seed dispersal.

Even when the normal runout elevation of a lake remains steady, heavy precipitation can cause an abrupt though temporary change in water level that can uproot aquatic plants. Natural wild rice is particularly susceptible to uprooting during its floating-leaf stage, which occurs in early summer. At this stage, any rapid increase in water level can cause damage to natural stands. Changes in lake outlets that reduce flow capacity can also significantly impact wild rice by increasing the frequency and severity of these temporary flood events. For example, permanent dams, beaver dams, culverts, and debris such as mats of vegetation can reduce outlet flow capacity and impact wild rice habitat (Ustipak 1983).

These factors can work in concert to produce cumulative effects. For example, culverts can attract beaver because the culvert is a much more restricted area than the creek or riverbed which channels through it. The roadbed often associated with culverts acts as a ready made dike that further contributes to the ease of blockage. As another example, dams and other outlets can be plugged by vegetation such as floating bogs that break loose in high winds. The effect of the dam in reducing outflows is compounded by the blockage raising water levels and increasing the probability of additional bog breaking off.

Changes in upstream watersheds can also reduce the productivity of natural wild rice stands. Drainage ditches and tiles, pumps, and channelization can increase the quantity and speed of waters moving downstream. The resulting peaks in water levels can produce the same effects as reduced outlet capacity by creating abrupt "bounces" or rapid increases in water depth. Increased sedimentation caused by drainage and channelization can also bury seeds and reduce germination.

Increased sedimentation can also increase the height of runout elevations and reduce outlet capacity. These changes can cause long-term damage to natural wild rice stands. The situation is acerbated by the installation of artificial dams. Removing the natural flushing action at outlets causes sediment to accumulate more readily (R. Ustipak, personal communication).

Dams that maintain stable water levels can have long-term deleterious effects on natural wild rice, as well. Water levels that are held stable year after year can create conditions that favor perennial vegetation and shoreline encroachments that impair wild rice habitat.

Recreational Water Use and Shoreland Development

Natural wild rice represents different things to different people. While some consider this native aquatic grass to be a nuisance, others value it greatly as a spiritual entity or as prime habitat for fish and wildlife.

Minnesota is a national leader in numbers of recreational boaters and anglers, with approximately 862,937 registrations for recreational watercraft. Although wild rice provides habitat for spawning fish and their offspring, stands of wild rice can be very frustrating for anglers to fish. Recreational boaters often consider wild rice to be a nuisance because it can be difficult to motor through. The strong stems of erect plants are easily tangled in propellers and may require removal by hand, often by forcibly cutting the tightly wrapped stems.

As a result, wild rice plants are often removed by boaters near docks, in navigational channels, and in other high-use areas. Removal can be direct or incidental due to cutting by propellers or dislodging by excessive wave action (Asplund 2000, Tynan 2000).

As the human population increases, so will the number of boaters. Predictions of demographic changes in Minnesota suggest that the areas of greatest population increases over the next 20

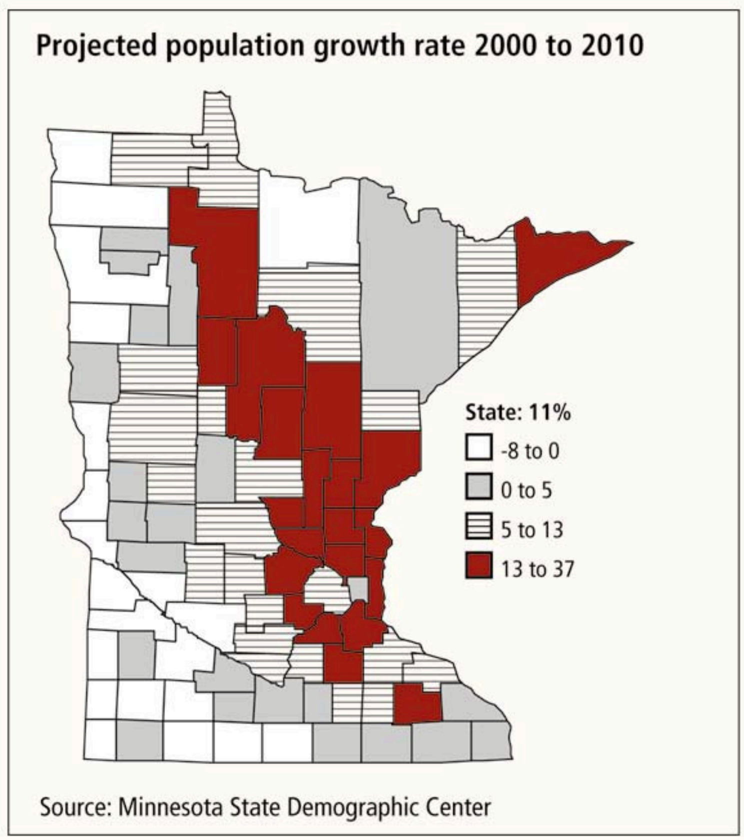

Figure 2. Greatest predicted population growth will occur within the primary range of wild rice in Minnesota.

years will include those counties that currently have the highest occurrence of natural wild rice (Figure 2, Minnesota Department of Administration 2007).

The damming of lakes to enhance recreational water use often corresponds with the increased development of shorelands. Shoreland development has increased dramatically in Minnesota, especially in those counties that include the greatest amount of habitat for natural wild rice. This development is often associated with installations of docks, removal of aquatic vegetation, and increases in nutrient-rich runoff.

Seasonal housing across the lake country of the upper Midwest jumped 500% during the past twenty years (United States Forest Service 2007). As lands bordering deeper lakes become more fully developed, prospective lakeshore buyers are increasingly considering lakes that are shallower, often well-vegetated, and more likely to support wild rice habitat.

The changing pattern of forestland ownership in Minnesota is adding to development pressure. Internationally-owned timber corporations are increasingly divesting of their land holdings as part of their fiscal management strategy. These lands have previously been managed somewhat as public lands and have been protected from development. However, as market values increase for shorelands and riparian areas, corporate stockholders are increasingly interested in selling these parcels. About seven million acres of forestland in Minnesota is privately owned, and predictions are that about one million of these acres may be sold for development (Myers 2006).

Such development often accompanies major changes in shorelines and near-shore vegetation (Radomski and Goeman 2001). Natural wild rice is often viewed only as a nuisance to boaters and other lakeshore users. Few shoreland owners consider the cumulative impacts of docks, vegetation removal, dredging, and runoff.

Although known violations of MNDNR Aquatic Plant Management permits do not always indicate which vegetative species were removed, wild rice is a common target where it occurs. A recent permit violation included the removal of 600 feet of natural wild rice from the shoreline of Upper Whitefish Lake in Crow Wing County. The violator was a new landowner who explained that the plants were an “eyesore”.

Wildlife Activity

Natural stands of wild rice provide excellent habitat for wildlife such as waterfowl and aquatic furbearers. The activities of these animals generally have minimal impact on wild rice stands. Although animals use plant stems for building overwater bird nests and muskrat houses, this activity usually affects only small areas. Moreover, wildlife activity often enhances overall aquatic habitat by creating stand diversity.

An exception to this is when beaver use wild rice stems and other vegetation to plug outlets. The resulting dam increases overall water levels and the probability of damage to natural stands by uprooting wild rice plants.

Birds generally have little impact on natural wild rice. For example, blackbirds, waterfowl and other birds can consume most of the ripening wild rice grain yet still leave more than 200 seeds per square foot (Haramis and Kearns 2004). Canada geese, though, can seriously damage stands of wild rice by grazing on emerging stems. For example, researchers monitored tidal marshes along the Patuxent River in Maryland and documented the loss of existing stands of wild rice due to season-long grazing by the geese (Haramis and Kearns 2004).

Although currently not common in Minnesota, some damage to rice stands has been attributed to Canada geese. High concentrations of geese on small lakes or impoundments have eliminated wild rice crops in some years through overgrazing of the emerging stems (R. Naplin and D. Rhode, personal communication). However, ongoing management of resident populations of Canada geese in Minnesota can limit this type of depredation through increased harvest levels . By contrast, shoreline development that converts communities of native vegetation to managed lawns can result in locally concentrated populations of geese that then may overgraze adjacent wild rice stands.

The effect of trumpeter swans on natural stands of wild rice is less clear. Populations of these native birds are slowly recovering after extirpation in the 1800s from most of their range. Anecdotal reports suggest that swans can damage natural stands of wild rice in particular areas (P. David and R. Naplin, personal communication). Nevertheless, low numbers of trumpeter swans combined with a preference for submergent vegetation suggest that these birds pose a minimal threat to natural wild rice (LaMontagne 2000, Norrgard 2006).

Some non-native species of wildlife do threaten stands of wild rice. These will be discussed below (Non-native Invasive Species section).

Plant Competition

Natural wild rice must compete for space, light, and nutrients with other aquatic plants, particularly perennial species (Rogosin 1951). Competitive species include submerged pondweeds (primarily *Potamogeton* L. spp.), floating leaved plants such as waterlilies (*Nuphar* J.E. Smith and *Nymphaea* L. spp.), and emergents such as cattail (*Typha* L. spp.) and pickerelweed (*Pontederia cordata* L.). Seasonal water levels play an important role in this competition (Meeker 2000). Natural wild rice may be favored at depths of one to two feet.

Pickerelweed may be an exception in at least three locations in Minnesota where ongoing management to benefit wild rice also found pickerelweed increasing significantly (N. Hansel-Welch, personal communication). Promising management responses have included lowering water levels in winter to freeze and desiccate pickerelweed roots, and cutting competitive species during spring and summer using airboats (McDowell, 2006) or harvesting machines (T. Howes, personal communication). However, maintaining stable water levels over many years may favor other species (D. Vogt, personal communication). Perennial species such as pickerelweed can establish footholds and thus gain the advantage in lakes that are maintained at constant levels. .

The seeds of natural wild rice can remain dormant for years until conditions are more favorable for germination. This trait allows rice to maintain long-term viability through years of low productivity. Natural wild rice is well-adapted to annual fluctuations in water levels, while other species may be less suited to such changes.

Strong competition among native aquatic plants appears to be localized and specific to individual stands. It does not appear to be a significant factor limiting the distribution or abundance of natural wild rice in Minnesota (Meeker 2000, Norrgard 2006).

Mining and Other Industrial Activity

Mining and industrial activities can potentially adversely affect stands of natural wild rice. For example, this can occur when hydrology is altered in watersheds that support natural wild rice. Alterations can result from the pumping and dewatering of sites. This increases downstream flows (discussed earlier in Hydrologic Changes section) and subsequent depressions in groundwater in surrounding areas. The potential effects of groundwater depression are not well understood. Water levels in basins with higher gradients could be sufficiently lowered to cause shallow areas inhabited by wild rice to dry out.

Other adverse effects can result from the release of chemicals such as sulfate from mine pits and tailings. These chemicals can negatively affect wild rice as well as other plant and animal species in the area. Seepages from tailings can exceed the state established water quality criteria of 10 mg/L for wild rice waters. For example, sulfate has been measured at 1,000 mg/L in these seepages (Udd 2007). State agencies are working with mining companies to decrease sulfate concentrations in discharge waters. Tribal governments express strong concern over the cumulative impacts of the many historic, currently operational, and planned mines in northeastern Minnesota.

Statewide Threats

Loss of Natural Genetic Characteristics

The cultural, ecological, and economic value of natural wild rice distinguishes it as a unique natural resource in Minnesota. There is strong agreement among stakeholders that it is critically important to maintain the natural genetic diversity of natural stands of wild rice (Porter et al. 2000, LaDuke and Carlson 2003). This importance reflects an understanding of spiritual and cultural values, biological and ecological principles, and agricultural and economic realities.

Natural population diversity provides wild rice the ability to adapt to changing environmental conditions such as annual variations in temperature and precipitation. Maintaining natural genetic diversity provides the best chance for any species to survive variations related to global warming, for example (BSU-CRI 2007). Ongoing analyses continue to support the position that managing for high biodiversity will best insure the survival of plant and animal communities that have characterized the Great Lakes region for thousands of years.

The flower structure and timing of maturation of wild rice promotes cross-pollination within and among stands. Wind pollination further insures genetic diversity. Genetic variability allows for the natural selection of traits that perform best under different environmental conditions. Studies in Wisconsin found sufficient genetic diversity between distinct stands of natural wild rice to identify potentially distinct regional populations. The degree of diversity within the stands also varied widely, with larger and denser stands being most diverse (Lu et al. 2005, Waller et al., 2000). The degree of genetic variability within and among natural stands of wild rice in Minnesota is not known. Thus our ability to recognize changes in the genetics of natural wild rice in this region is limited.

Although some studies of wild rice pollen travel have been conducted (Cregan 2004), more research is needed to understand the potential for genetic transfer among natural and cultivated stands. Drift of wild rice pollen may exceed that of other cultivated crops due to the small size of the pollen and its relatively slow settling rate (P. Bloom, personal communication). In addition, a study in Canada has provided evidence that wild geese, and perhaps ducks, can be important transporters of pollen to lake sediments (McAndrews et al. 2007). This raises the possibility that waterfowl may also serve as transporters of viable pollen.

Another means of introducing new genotypes into local populations is the intentional seeding of wild rice to restore historical sites or to develop new stands. Such plantings have a long history in Minnesota. For example, the demand for seeds of wild rice and other native plants helped to establish businesses such as Wildlife Nurseries, Inc. in 1898, in Oshkosh, Wisconsin (Oelke 2007). However, the risks associated with introducing nonlocal genes into local native gene pools are of increasing concern to many scientists (Maki and Galatowitsch 2004).

Plant breeding programs have developed strains of wild rice suitable for commercial production (Oelke 2007). Consistency in plant morphology, control of shattering, and disease resistance have been important objectives of these programs. Because wild rice pollen is airborne, some have expressed concerns about unplanned cross-pollination between cultivated stands and natural stands. At this point in time, however, traditional wild rice breeding programs are not thought to pose a threat to natural stands since the cultivated varieties reflect the selection of genes from within the naturally occurring gene pool (R. Porter, personal communication).

There have been concerns expressed about the potential impact of transgenic engineering. The dramatic increase in use of this technique to alter food crops has been followed by questions concerning its safety, economic losses, potential impact on the natural environment, regulatory framework and compliance, and the ability to mediate unplanned releases. One of the driving forces behind these concerns is evidence that current gene containment practices cannot achieve absolute protection from unwanted pollination (Thai 2005). The unplanned cross-pollination between cultivated crops such as creeping bentgrass and wild relatives has fueled the concerns of both environmentalists and agricultural producers (Haygood et al. 2003, Weiss 2006).

These concerns are evident in the international guidelines for sustainable forest management developed by the Forest Stewardship Council (FSC). The state of Minnesota has actively sought certification of its public forestlands under the Regional Forest Stewardship Standards published by the council. These standards specifically prohibit the use of genetically modified organisms within certified forests (Minnesota Forest Resource Council 2004).

While there are no known research programs in any country to produce transgenic varieties of wild rice (R. Phillips, personal communication), DNA of wild rice has been transferred to white rice (Abedinia et al., 2000). The very possibility of transgenic engineering wild rice generates deep cultural, economic, and ecologic concerns. These include issues surrounding Native American rights, food safety and nutritional value, protection of economic markets, patenting of species, and protection of natural resources that already face significant threats (LaDuke and Carlson 2003).

This controversy ultimately relates to differing worldviews and the valuation of risk and consequences. For some stakeholders, there is no level of acceptable risk. For others, the potential benefits of genetically engineered wild rice may be worth the possible consequences of escaped transgenic traits. A thorough analysis of the cultural, economic, and ecological consequences of genetic contamination of natural wild rice in Minnesota is required to assess potential impacts.

Transgenic alterations of some U.S. crops will likely continue for the foreseeable future. Traditional plant breeding will also continue. A better understanding of the natural genetic variability of wild rice in Minnesota would increase our understanding of the potential impacts of these activities. Efforts to restore native wild rice to its historical range should be encouraged. Studies of the natural variability and ecological requirements of natural wild rice in this region would enhance these efforts.

Non-native Invasive Species

Non-native invasive species impact every aspect of natural resource management in Minnesota. Protecting and managing natural stands of wild rice is no exception. The movement of watercraft from one wild rice lake to another creates the potential for transfer of invasive animals and plants.

The common carp (*Cyprinus carpio*) leads the way in historical presence and impact. Common carp feed primarily on invertebrates in bottom soils. Their feeding action dislodges plants and suspends fine particles into the water column. The increased turbidity, caused both by disturbed sediments and by algae stimulated by the phosphorus released from disturbed sediments, shades out aquatic plants. Turbidity then increases as non-vegetated lake bottoms are disturbed by wind. The reduction in aquatic vegetation also allows for increased boat traffic and wave action that can further dislodge plants such as wild rice (Pillsbury and Bergey 2000).

Natural stands of wild rice are negatively impacted by turbid conditions during early stages of growth and by disturbances to bottom soils and boat traffic in later stages. The common carp is primarily a problem today in southern Minnesota, where the species occurs in high densities. Carp likely contributed to the loss of natural wild rice from its historic range in this region (Norrgard, 2006). If the predicted changes in climate in northern Minnesota result in warmer waters, carp could achieve higher densities in that region and cause significant damage within the core of prime habitat for natural wild rice.

The non-native rusty crayfish (*Orconectes rusticus*) can directly impact wild rice by cutting stems of the plant. Although the extent of this depredation in Minnesota is not known, significant impacts of native crayfish on cultivated wild rice have been documented (Richards et al. 1995). Native to parts of some states in the Great Lakes region, rusty crayfish have invaded portions of Minnesota, Wisconsin, and Ontario, including areas that are important for wild rice. Rusty crayfish frequently displace the native crayfish, reduce the diversity and abundance of aquatic plants and invertebrates, and reduce some fish populations (MNDNR 2007).

Rusty crayfish were first documented in Minnesota in 1967, at Otter Creek in southern Minnesota. Twenty years later, a statewide survey documented their presence in many areas (Helgen 1990). To date, rusty crayfish have been found in 31 lakes and streams in 11 counties. They prefer areas where rocks, logs, or other debris provide cover. Preferred sediment types include clay, silt, sand, gravel, and rock. The soft organic sediments usually favored by wild rice do not seem to be favored by rusty crayfish and may help minimize their impact.

The non-native mute swan (*Cygnus olor*) can seriously threaten the sustainability of natural wild rice stands (P. Wilson, personal communication). To date, Minnesota has limited the number of these birds to only a few that are held in captivity. With continued efforts to identify free-ranging non-native swans and to respond rapidly with control measures, their impact on natural wild rice in Minnesota could be minimal.

Invasive plants such as purple loosestrife (*Lythrum salicaria* L.), curlyleaf pondweed (*Potamogeton crispus* L.), and Eurasian water milfoil (*Myriophyllum spicatum* L.) occur throughout much of the range of natural wild rice. Although these species may prefer water depths that do not favor wild rice, more research is needed to better understand the potential for competition. It is known that these invasive species can disrupt local aquatic ecosystems and lower habitat quality overall. However, it is also important to monitor the mechanisms of control to insure that these do not have unintended effects on natural wild rice.

Hybrid cattail (*Typha* x *glauca*), a cross of native and non-native cattail (*Typha latifolia* L. and *Typha angustifolia* L., respectively), competes directly with natural wild rice for shallow-water habitat. These plants aggressively form thick mats of roots that can float as water levels fluctuate. The bog-like mats expand across areas of shallow water and can plug lake outlets when broken off and blown by high winds.

Native sedge bogs often border wild rice lakes in northern regions. These bogs are increasingly being invaded and eventually dominated by hybrid cattails. High infestations of hybrid or non-native cattails near lake outlets can increase rates of sedimentation. This, in turn, can combine with the additional plant material to further decrease outlet capacity (R. Ustipak, personal communication).

A relatively new threat to natural stands of wild rice is the non-native flowering rush (*Butomus umbellatus* L.). Found in similar habitats as native bulrush (*Scirpus* L. spp.), which it resembles, flowering rush can persist in either emergent or submergent forms. Though its distribution in Minnesota is limited, its range is expanding. Flowering rush spreads primarily through rootstalks. At a site in Idaho, flowering rush was documented to be out-competing other plants such as willow (*Salix* L. spp.) and cattail (MNDNR 2007).

Another potential threat to natural wild rice in Minnesota is the non-native form of phragmites, or common reed [*Phragmites australis* (Cav.) Trin.]. While phragmites appears in fossil records for North America as early as 40,000 years ago, the non-native form was likely introduced in the late 1700s in ship ballast from Europe. Common reed has since dominated Atlantic coastal marshes and migrated landward, particularly during the 1900s. To date, the non-native form of common reed has invaded natural areas in 18 states including Wisconsin and other Great Lakes states. Although it is still rare in Minnesota, this exotic has been observed in a few disturbed sites in the Minneapolis-St. Paul area and in Duluth harbor (L. Skinner, personal communication).

Although phragmites can spread by seed, the most aggressive growth occurs through rhizomes. Non-native phragmites forms a dense network of roots that can reach several feet in depth. It spreads horizontally by sending out rhizome runners that can grow ten or more feet in a single season if conditions are favorable. Very dense stands are formed, that include live stems as well as standing dead stems from the previous year. The stems of non-native phragmites often reach 15 feet in height along the Atlantic coast.

In a recent study of phragmites in wetlands at Long Point, Lake Erie, researchers found that the occurrence of phragmites increased exponentially in the late 1990s. Of the 31 stands analyzed, 28 (90%) were dominated by the non-native strain (Wilcox et al. 2003). Part of the rapid expansion of the non-native form may be related to its ability to weaken the root structure of adjacent plants through the secretion of gallic acid, which attacks a structural protein (tubulin) in the roots of competing plants (Murray 2007).

Climate Change

The warming of the earth is now evident from measurements and observations. These include increases in average global air and ocean temperatures, widespread melting of snow and ice, and rising global sea levels. The average surface temperature of Earth has risen by about 1.3° F since 1850. The Fourth Assessment Report (AR4) of the Intergovernmental Panel on Climate Change (IPCC), published in 2007, projects that the average global surface temperature is likely to further increase by 3 to 7° F by the year 2100. This projection assumes a moderate level of action to reduce anthropogenic emissions of greenhouse gases.

According to the IPCC, the lower end of this range (i.e., a further warming of 3° F) represents a threshold for the earth beyond which irreversible and possibly catastrophic changes are likely. If the projections of global warming this century are met, most living things on Earth will likely face severe consequences.

What will predicted changes in climate mean for natural stands of wild rice in Minnesota?

Although climatologists agree that temperatures in this region will increase, predictions of precipitation vary (Figure 3, Kling et al. 2003). Some climate models predict that increasing temperatures will lead to increasing frequency and duration of droughts in the Dakotas and western Minnesota. Hot, dry conditions can negatively impact the pollination of wild rice and thereby reduce its seed production.

Warmer temperatures will also reduce the severity of winters. The required cold temperature (35° F or less) dormancy of three to four months for wild rice seeds could be reduced, particularly in the southern portions of its range. In addition, warmer conditions often favor non-native species. In particular, warmer waters may increase the survival and spread of carp across Minnesota. Because wild rice lakes, rivers, and wetlands are interconnected, protection of wild rice habitat from carp could become very difficult.

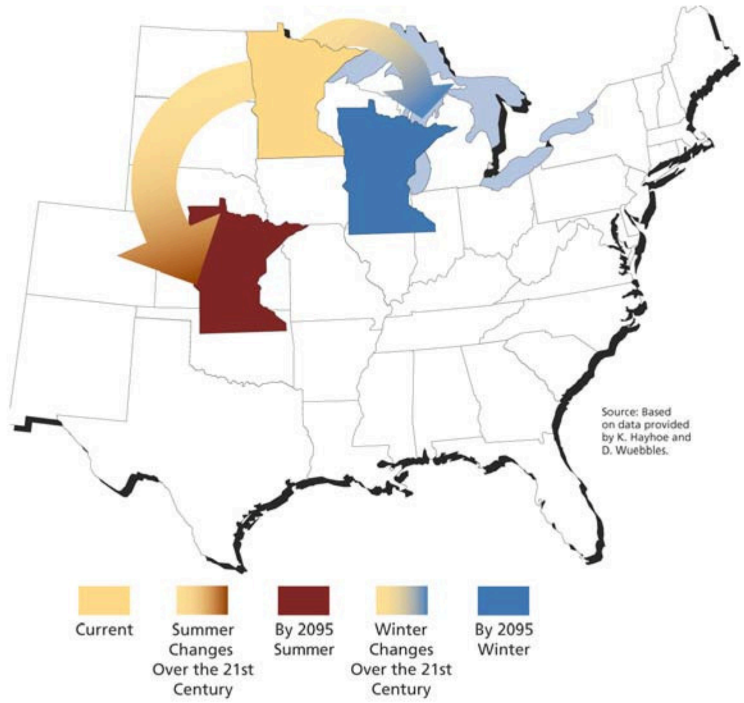

Figure 3. Predicted climate change will effectively alter Minnesota to reflect the climate of states to the south.

Invasive species such as the non-native phragmites may also benefit from warmer temperatures. Many exotics, such as hydrilla *[Hydrilla verticillata* (L. f.) Royle] and water hyacinth *[Eichhornia crassipes* (Martius) Solms-Laub.] are limited by cold climates (Holm et al. 1977; Langeland 1996). Increased average temperatures may enable these extremely invasive non-native species to migrate and gain footholds in Minnesota. Species such as these could have severe impacts on wild rice waters.

The frequency of dewpoints above 70° F is already trending upward in Minnesota (Seeley 2007a). Warm, humid conditions support diseases of wild rice such as brown spot (*Bipolaris oryzae* Luttrel and *Bipolaris sorokiniana* Luttrell) and other pathogens. For example, high humidity and sustained warm overnight temperatures in early August 2007 promoted the development of brown spot in many natural wild rice stands in Minnesota. Estimated crop losses in some stands were 70 to 90% (R. Ustipak, personal communication).

There is strong agreement that global warming will result in increased severity of individual weather events (Seeley 2006). According to Dr. Mark Seeley, University of Minnesota climatologist, 2007 may be representative of the future conditions in Minnesota. In August 2007, the U.S. Department of Agriculture declared 24 Minnesota counties to be in severe drought and eligible for federal assistance. Also in August 2007, the Federal Emergency Management Agency declared seven counties in southeastern Minnesota to be flood disasters, also eligible for federal assistance (Seeley 2007b).

In nearly two hundred years of weather history, there are no records of such extremes occurring in the same month of the same year in Minnesota. Increasing severity of storm events will cause more flooding and hence more abrupt changes in lake levels during the growing seasons of wild rice and other aquatic vegetation. Natural wild rice will be particularly susceptible to damage while in the floating-leaf stage.

The southern edge of the range for natural wild rice may already be receding northward. While many factors have likely contributed to a decline in range of natural wild rice, climate may well be involved.

Lack of Recruitment and Retention of Harvesters

As Minnesotans have fewer positive experiences with natural wild rice through harvesting, hunting, trapping, or wildlife watching, they are less likely to recognize or have concerns about its potential loss. They are also less likely to appreciate the severe impacts that the previously noted threats could have on wild rice, and thus on the historic and culturally rich quality of life in Minnesota. This loss of appreciation, while not a direct threat to rice in itself, nevertheless increases the risks for wild rice because the level of resource protection and management is often based on its perceived value.

The protection and management of natural wild rice relies not only on tribes and agencies, but on the users of the resource, as well. Harvesters support management activities through the purchase of annual licenses. Because they have a personal stake in the future of natural wild rice in Minnesota, they are the ones most likely to report activities that are damaging the resource. Harvesters are also great advocates for natural wild rice. They promote its value within the ricing community and to the state as a whole.

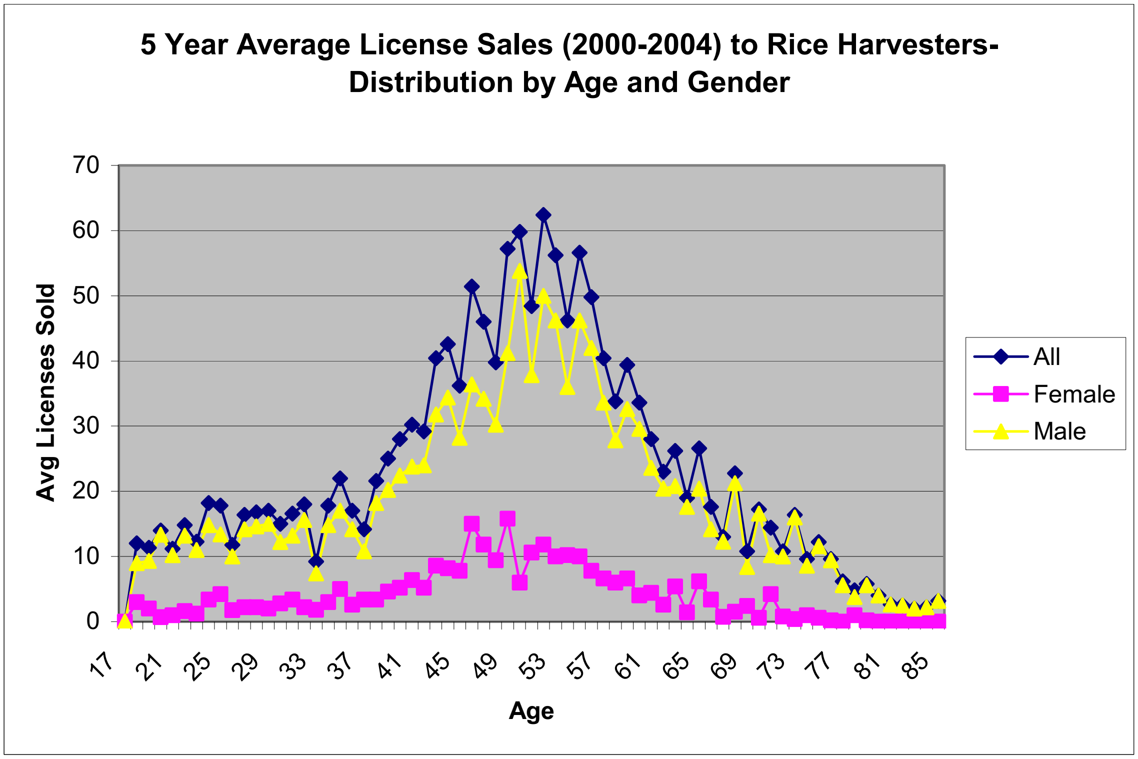

Figure 4. Age distribution of state licensed wild rice harvesters.

Wild rice harvesters are relatively few in numbers, though, and these numbers have declined over the last fifty years. During the 1960s, sales of state licenses in Minnesota averaged over 10,000 per year. Since 2000, these sales have averaged fewer than 1,500 annually. Harvesters under tribal regulations are not required to purchase a state license. Their numbers are estmated to exceed 3000 (R. Norrgard personal communication) and have likely experienced moderate increases in recent years (J. Persell, personal communication).

The MNDNR surveyed wild rice harvesters who purchased licenses from 2004 to 2006 to gather information on harvester characteristics and potential barriers to participation. This survey found that the majority of harvesters were male and at least 40 years old (82% and 81%, respectively). Figure 5 illustrates a similar age distribution from 2000 to 2004. Nearly all of the harvesters who responded had been introduced to wild rice harvesting by a friend or family member (87%).

Although most were satisfied with their harvest experience (82.3%), those surveyed identified several barriers to continuing this tradition. The most important barriers were time, knowing when to harvest, knowing where to harvest, and finding a wild rice processor. Other barriers included finding a ricing partner, physical challenges, financial expenses, finding a buyer, and having proper equipment.

Even for experienced harvesters, the difficulty of finding information on where and when to harvest can limit participation. For those living outside of natural wild rice areas, finding this information can be particularly difficult. For new harvesters, even finding a processor to finish the rice is a significant challenge.

Difficulty in acquiring harvest-related information may influence the distribution of harvesters and harvesting pressure on individual stands. The MNDNR 2006 survey revealed that only 25 lakes accounted for half of all harvesting trips. By contrast, the inventory of wild rice stands compiled for this document indicates that 119 lakes (100+ acres in size) account for more than half of the acreage of natural wild rice in Minnesota.

Addressing the educational or informational needs of Minnesotans interested in natural wild rice has been largely ignored. As with other natural resources in Minnesota, the lack of recruitment and retention of harvesters threatens the sustainability of natural wild rice in the state. Without readily available information and inspiring programs of education, public support of protection and management of the very resources that define Minnesota will likely decline.

Management Challenges

The future of natural wild rice in Minnesota will depend in large part on its protection and management by state and tribal natural resource agencies. The most important management issues relate to those threats identified in the previous section. The challenges that managers of natural wild rice face are further complicated because of limitations to their authority, inherent variability of wild rice production, and the need for additional information concerning wild rice in Minnesota.

Multiple Jurisdictions

Minnesota state statutes provide that ownership of wild rice and other aquatic vegetation is vested in the state (MS 84.091). State statutes also establish regulatory control over wild rice removal and harvest (MS 84.10, 84.15, 84.027, 84.28). Exceptions to state harvest regulations apply in geographic locations that are described by treaties and subsequent agreements, statutes, and rules (MS 84.10, MR 6284.0600 and 6284.0700). State and tribal enforcement officers often operate under temporary agreements until formal agreements are finalized.

The enforcement of harvest regulations in Minnesota is mainly stable and without major controversy. One issue still being discussed, however, is the posting of lakes as "closed" to wild rice harvest until it is determined that the grain is ripe. Both state and tribal governments have done this in the past on lakes that are popular with harvesters. In 1996, a new state law was passed that opened the ricing season on July 15 each year and made it illegal to pick rice that is not ripe (MS 84.105). Because wild rice usually ripens in Minnesota between the third week of August and the second week of September, the new law was intended to encourage a "pick when ripe" philosophy.

Most tribal governments have continued to post popular wild rice lakes within their jurisdictions. For many tribes, this practice is part of a long-standing tradition that relies on counsel provided by tribal committees. Tribes have urged the state to work cooperatively to post additional lakes. The position of the state, however, is that posting is unnecessary for the long-term health of the wild rice resource and the MNDNR currently has statutory authority only to post lakes as "closed" to "protect against undue depletion of the crop so as to retard reseeding or restocking of such area or so as to endanger its effective use as a natural food for waterfowl" (MS 84.15). In some cases, productive wild rice lakes are within both tribal and state jurisdictions. For these lakes, the differences in management philosophy have created conflicts between tribal and state agencies and with some harvesters.

Jurisdictional issues also arise over management of lake resources in general. Although the state of Minnesota has the responsibility of ownership of natural wild rice, the state includes many agencies, and each has its own mission and interest groups. No single agency or governmental entity in Minnesota assumes all of the responsibility for protecting natural wild rice. In public waters, the MNDNR takes the lead to regulate harvest and damage or removal of wild rice plants. Counties take the lead, within state statutory guidelines, to regulate shoreline development and most local recreational surface-water use. The Minnesota Pollution Control Agency regulates discharges to waters throughout the state; the Minnesota Department of

Agriculture assumes the lead for issues involving cultivated wild rice; and the state Environmental Quality Board has the lead responsibility to coordinate, notify, and evaluate any potential release of genetically engineered wild rice.

Within the MNDNR, the Division of Waters assumes the lead on shoreline regulations; the Division of Ecological Resources leads on aquatic plant management and invasive species; and the Division of Fish and Wildlife leads on habitat management for fisheries and wildlife values. The MNDNR Division of Enforcement is responsible for enforcement of natural resource regulations including the harvest of natural wild rice except when tribal regulations apply.

A formal, interdisciplinary planning process for Minnesota lakes does not exist. Lake management plans typically reflect the specific goals of the sponsoring entity. The plans often focus on aspects of either fisheries, wildlife, water quality, or vegetation without considering a comprehensive approach that addresses all of these components of a lake ecosystem.

Within Minnesota state statutes, there is no unifying policy of wild rice management that provides integration of these various agencies. By contrast, a unifying policy is clear regarding wetlands. Under public water laws, state statutes declare that it is in the public interest to increase the quantity, quality, and biological diversity of Minnesota's wetlands (MS 103A.201 subd. 2). A similar policy statement would help insure the sustainability of the natural wild rice resource in Minnesota.

Annual Crop Variability

Management by MNDNR and its conservation partners to maintain water levels beneficial to natural wild rice stands has never been greater. Water level monitoring, beaver control, debris removal, and invasive species management has annually taken place on more than 200 lakes and impoundments with significant wild rice stands. This management is based on the combined efforts of the Minnesota Department of Natural Resources, U. S. Fish and Wildlife Service, Ducks Unlimited, Tribal governments, and at least three lake associations. Much of the funding for these management efforts comes from the revenue generated by wild rice license sales.

Nevertheless, the expectations of those who value natural wild rice often exceed the capabilities of those responsible for protecting and managing this resource in Minnesota. A particularly difficult challenge for managers is the critical role that weather plays in wild rice development. Even when growing conditions have been exceptionally favorable, a single storm can reduce or even devastate the local harvest. At best, wild rice managers can “set the table” by maintaining free-flowing outlets or by setting appropriate runout elevations on water control structures. These management actions improve the harvest potential in good years and lessen the impact of poor conditions in less favorable years.

It can be easy for both user groups and managers to overlook the reality that natural wild rice has adapted to changing weather patterns through strategies that promote long-term survival rather than consistent annual abundance. The boom and bust cycle of natural wild rice has been recognized for centuries. This variation in annual productivity may be driven as much by seed dormancy and nutrient cycling as it is by variable weather. Resource managers, wild rice harvesters, and other stakeholders must remember that productivity of natural wild rice is highly variable, both by stand and by year. Responsible management of this unique resource should strive to maximize its long-term sustainability in the Great Lakes region.

Information Needs

To effectively manage natural wild rice for future generations, resource managers need a better understanding of its natural ecology; its historical losses and patterns of abundance and distribution; threats to its sustainability; and the needs of harvesters.

While much has been learned about the ecology of wild rice over the last several decades, adequate information is still lacking on environmental tolerances and limiting factors such as water and sediment chemistry, seasonal water levels, and disturbance. This information will help create a better understanding of the historical reductions in wild rice distribution and provide much needed guidance for restoration of wild rice habitat.

In addition, a better understanding of ecological relationships in wild rice waters could guide strategies to counter threats such as mining and climate change. Improved ecological understanding would also provide much needed insight into the issues of invasive species. Of particular concern is the potential spread of carp, flowering rush, and exotic phragmites. Better assessments of the damage caused by rusty crayfish are needed as well.

Another concern is that basic information concerning the natural genetic makeup of native stands of wild rice is lacking. An understanding of the natural genetic variability of natural wild rice in the Great Lakes region and genetic drift between stands is critical. This information is needed to guide restoration efforts, particularly in the face of changing climate, and to help detect changes in diversity. We also need to better understand reproduction and its role in population genetics of natural wild rice.

More thorough information is needed on the distribution and overall acreage of natural wild rice in Minnesota. For this study, the MNDNR and the Wild Rice Study Technical Team revised and updated an earlier database of this information (Appendix B). While the recent revision is the most complete and detailed information of its kind for Minnesota, it still represents a gross estimate because information for many lakes, wetlands, rivers, and streams is incomplete or totally lacking. Further refinements and updates to this database are needed. In addition, refined methods are needed to improve the monitoring of annual productivity and the effects of management actions. This information would also help identify new opportunities for harvesters and better distribute harvesting pressure. With improved methods of monitoring and more complete databases, the overall health of the wild rice resource will be better managed.

Managers also need to better understand the harvesters of natural wild rice. What are annual trends? How can agencies and the wild rice community encourage retention of existing harvesters and recruit new people to continue this tradition? Who are the potential harvesters and what do they need in terms of ricing information, education, and support to be successful? The future of the wild rice resource in Minnesota may very well depend on the level of interest in its harvest and traditions.

Department of Natural Resources Recommendations

Introduction

This section is in response to the legislative request to include recommendations "on protecting and increasing natural wild rice stands in the state". The following recommendations were developed with valuable input and discussion from the members of the Wild Rice Study Technical Team and Partnership Team. However, the Minnesota Department of Natural Resources assumes sole responsibility for these recommendations as written and presented here.

MNDNR recognizes the importance of protecting natural wild rice beds from genetic modification and agrees with wild rice stakeholders that this protection is critical to the future of this resource. We strongly support the Environmental Quality Board in adopting rules that require an environmental impact statement for a proposed release of genetically engineered wild rice (MS 116C.94 Subd.1b).

Recommendation 1

Recodify current wild rice harvest statutes and rules to remove duplication and inconsistencies.
Rationale: The state's wild rice statutes and rules have been developed and modified piecemeal over a long period of time. As a result they contain a number of inconsistencies and duplication. Most of these changes relate to the harvest regulations (MS 84.27 – 84.91) although statutory recognition of wild rice as the state grain (MS 1.148) is also out of date in its nomenclature.

Recommendation 2

Establish statutory policy guidance on wild rice and its management.
Rationale: Within state statutes there is no unifying policy that provides direction to agencies responsible for some aspect of wild rice management. In contrast, the policy of the state is clear when it comes to wetlands. State statutes declare that it is in the public interest to increase the quantity, quality, and biological diversity of Minnesota's wetlands (MS 103A.201 subd. 2). A similar policy statement concerning natural wild rice would be useful guidance for state and local agencies. Suggested language includes "The legislature finds that natural wild rice in Minnesota provides public value by its contributions to fish and wildlife habitat, ecological diversity, environmental quality, recreational opportunities, cultural traditions, human sustenance, and economic well-being, and that it is in the public interest to protect existing natural wild rice stands, including their inherent genetic diversity, and restore wild rice to its historic range and abundance for its ecological, economic, and cultural values."

Recommendation 3

The DNR will convene an interagency workgroup in 2008 to identify desired statutory updates in harvest regulations.
Rationale: Harvest regulations and license fee structure should be reviewed by an interagency work group for suggested changes that would work towards resolution of posting lakes closed to harvest and regulating reservation border lakes, as well as encouraging recruitment and retention of wild rice harvesters. Possible changes include broadening the use of funds deposited in the wild rice account to allow for information and education, removal of the season framework, adding a combination (spouse) license, extending special one-day license, providing special one-day mentored license for resident and nonresident participants in formal education programs, and establishing a special youth day when mentors are not required to have a license.

Recommendation 4

The DNR will designate and publish a list of important natural wild rice areas.
Rationale: Recognizing important wild rice areas and publishing the list would call attention to the importance of these areas, indicate management priorities, and provide a formal list that may prove useful for local units of government that are considering zoning and surface use restrictions.

Recommendation 5

The DNR will convene a standing interagency wild rice workgroup to share information and develop recommendations for inventory methodology and trend assessments, education and information outreach, lake planning and management, harvester recruitment and retention, and other management issues as they arise.
Rationale: Comprehensive protection and management of wild rice involves multiple agencies. Management needs include better inventory information including consistent methodology for trend analysis, documenting natural genetic diversity, and establishing long-term case studies on identified lakes. This information will encourage sound restoration strategies and help foster the development of interdisciplinary lake management plans. In addition, the workgroup should focus on developing outreach information for harvesters, shoreline owners, realtors, boaters, and outdoor educators.

Recommendation 6

Increase intensive natural wild rice lake management efforts and accelerate the restoration of wild rice stands within its historic range.
Rationale: Protecting and managing natural wild rice resources on many lakes requires active annual management activities to maintain free flowing outlets. The MNDNR works cooperatively with other agencies and nonprofit organizations such as Ducks Unlimited to accomplish this management. Tribal agencies also conduct independent management efforts on specific lakes. In recent years these efforts have improved wild

rice habitat on approximately 200 lakes and impoundments annually. Additional funding could expand accomplishments beyond current efforts.

The MNDNR has also been involved to a lesser extent in restoring wild rice to wildlife habitat areas within the historic range of natural wild rice. These efforts should be accelerated as funding, time, and opportunity permit.

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Appendix A

Natural Wild Rice Study Development Process

Scope: This study provided an information document on natural wild rice developed with conservation partner input, review, and possible endorsement. The document included the current location and estimated acreage and area of natural stands; potential threats to natural stands, including, but not limited to, development pressure, water levels, pollution, invasive species, and genetically engineered strains; and recommendations to the house and senate committees with jurisdiction over natural resources on protecting and increasing natural wild rice stands in the state.

Format: The final document was formatted to include an Executive Summary, Introduction, Background, Threats, Management Challenges, Recommendations, and Appendices.

Process: A Partnership Team was organized to review, comment, and consider endorsement of the planning process, interim draft of the document, and the final draft to be released for public review. DNR Assistant Commissioner Bob Meier chaired the Partnership Team. Invited members of the Partnership Team included representatives from other agencies and organizations including DNR Tribal Liaison Paul Swenson, the DNR Divisions of Ecological Services, Enforcement and Waters, MN Department of Agriculture, Board of Water and Soil Resources, Minnesota legislature (Representatives Frank Moe and Sondra Erickson), U. S. Bureau of Indian Affairs, U. S. Fish and Wildlife Service, U. S. Natural Resources and Conservation Service, Minnesota Chippewa Tribe, Tribal representatives, Ducks Unlimited, MN Wild Rice Council, Minnesota Waterfowl Association, Save Our Rice Alliance, Minnesota Waters, and the Association of Minnesota Counties. The Partnership Team was offered the opportunity to submit dissenting reports to be included in the appendices.

A Technical Team was organized to propose the document development process, develop the draft document and incorporate revisions as the process proceeded. DNR Wetland Wildlife Program Leader Ray Norrgard chaired the team and assumed the role of lead writer. Invited members of the Technical Team will include DNR wildlife field staff Gary Drotts, Ann Geisen, Shelley Gorham, Beau Liddell, Rob Naplin and Regional Enforcement Supervisor Ken Soring, along with Michelle McDowell (Fish and Wildlife Service), Becky Knowles (Leech Lake Department of Resource Management), Rod Ustipak (Consultant), Jon Schneider (Ducks Unlimited), MN Wild Rice Council (Beth Nelson and Jon Dokter), Rachel Walker (University of Minnesota – St. Paul), Dr. Ron Phillips (University of Minnesota – St. Paul), Dr. Raymie Porter (University of Minnesota- Grand Rapids), Annette Drewes (University of Wisconsin), Thomas Howes (Fond du Lac Reservation), Darren Vogt (1854 Authority), Steve Smith and John Persell (Minnesota Chippewa Tribe), Mike Swan (White Earth Reservation), Andrea Hanks (White Earth Land Recovery Project), and Peter David (Great Lakes Indian Fish and Wildlife Commission).

Timelines: The process began with the passage of the 2007 legislative request and will end with a completed report to the legislature by February 15, 2008. The Technical Team met on August 14, 2007 to develop the final draft of the proposed document development process, and a draft outline of the final document. The Technical Team communicated by email and followed up with meetings on November 13, 2007 and January 7, 2008. The draft study document underwent 10 revisions in all. The Partnership Team met on September 19 and December 3, 2007 to review the Technical Team's proposals. Review of the final working draft of the study document was conducted by mail. The final document will be presented to the legislature by February 15, 2008. Copies of the final document will be posted on the MNDNR website and available upon request through DNR regions and central office.

Partnership Team Roster

Organization	Name	Title
Association of Minnesota Counties	Anna Lee Garletz	Policy Analyst
Bois Forte DNR	Cory Strong	Commissioner
Bureau of Indian Affairs	Bob Jackson	
Clearwater County	Tom Anderson	County Commissioner
DNR Commissioner's Office	Bob Meier	Asst Commissioner/Policy
DNR Division of Ecological Resources	Lee Pfannmuller (Donna Perleberg)	Director
DNR Division of Enforcement	Mike, Hamm	Director
DNR Division of Waters	Kent, Lokkesmoe	Director
DNR Northwest Region Office	Paul Swenson	Tribal Liaison
Ducks Unlimited	Ryan Heiniger	Director, Cons Programs
Fond du Lac Resource Management	Reginald Defoe (Tom Howes)	Director
Grand Portage Tribal Council	Norman Deschampe	Chairman
Leech Lake DRM	Rich Robinson	Director
Mille Lacs Natural Resources	Curt Kalk	Commissioner
Minnesota Chippewa Tribe	Gary Frazer	Executive Director
Minnesota Legislature	Sondra Erickson	State Representative
Minnesota Legislature	Frank Moe	State Representative
Minnesota Waters	Bruce Johnson	Executive Director
Minnesota Wild Rice Council	Beth Nelson (Peter Imle, Ken Gunvalson)	President
MN Board of Water & Soil Resources	John Jaschke (Greg Larson)	Executive Director
MN Department of Agriculture	Gene, Hugoson (Chuck Dale, Chuck Dryke, Geir Friisoe)	Commissioner
MN Valley National Wildlife Refuge	Jim Leach (Barb Boyle)	Director
MN Waterfowl Association	Brad Nylin	Executive Director
Natural Resources Conservation Service	Bill Hunt	State Conservationist
Red Lake DNR	Al Pemberton	Director
Save Our Rice Alliance	Richard Draper	
White Earth DNR	Mike Swan (Doug McArthur)	Director
White Earth Land Recovery Project	Winona LaDuke	Founding Director

Technical Team Roster

First Name	Title	Organization
Peter David	Wildlife Biologist	Great Lakes Indian Fish and Wildlife Commission
Jon Dokter	Associate Director	Wild Rice Council
Annette Drewes	Ph.D Candidate Environmental Studies	University of Wisconsin-Madison Save Our Rice Alliance
Gary Drotts	Area Wildlife Supervisor	MN Department of Natural Resources
Ann Geisen	Wildlife Shallow Lakes Specialist	MN Department of Natural Resources
Shelley Gorham	Area Wildlife Supervisor	MN Department of Natural Resources
Andrea Hanks	Wild Rice Campaign Coordinator	White Earth Land Recovery Project (WELRP)
Tom Howes	Natural resources Manager	Fond du Lac Department of Resource Management
Becky Knowles	Plant Ecologist	LLBO DRM-Fish, Wildlife, and Plants
Beau Liddell	Area Wildlife Supervisor	MN Department of Natural Resources
Doug McArthur	Biologist	White Earth Dept. of Natural Resources
Michelle McDowell	Wildlife Biologist	Rice Lake National Wildlife Refuge
Rob Naplin	Area Wildlife Supervisor	MN Department of Natural Resources
Beth Nelson	President	Wild Rice Council
Ray Norrgard	Wetland Wildlife Program Leader	MN Department of Natural Resources
John Persell	Biologist	LLBO DRM-Fish, Wildlife, and Plants
Ron Phillips	Regents Professor	University of Minnesota
Raymie Porter	Research	University of Minnesota
Jon Schneider	Manager MN Conservation Programs	Ducks Unlimited
Steve Smith	Acting Director - Water Quality	Minnesota Chippewa Tribe
Ken Soring	NE Regional Enforcement Supervisor	MN Department of Natural Resources
Mike Swan	Director	White Earth Dept. of Natural Resources
Rod Ustipak	Consultant	
Darren Vogt	Wildlife Biologist	1854 Treaty Authority
Rachel Walker	Ph.D Candidate Water Resources	University of Minnesota

Appendix B

Wild Rice Distribution and Abundance in Minnesota

EXECUTIVE SUMMARY

Project Leader
Gary Drotts
Minnesota Department of Natural Resources
Area Wildlife Supervisor - Brainerd

Purpose

To further the understanding of natural wild rice distribution and abundance in Minnesota, Minnesota Department of Natural Resources (MNDNR) staff and other Technical Team members of the Natural Wild Rice in Minnesota Legislative Study undertook an effort to consolidate and update existing natural wild rice inventory information. The following objectives guided inventory design and development.

1. Consolidate various data/information on the location (i.e. lake, wetland, or river segment) of natural wild rice stands in Minnesota.
2. Determine size and natural wild coverage for each location.
3. Determine type of water level management structure (if present) on each location and primary management authority.
4. Document Tribal, Treaty and/or State authority for each location.
5. Determine natural wild rice harvest potential, harvest pressure, and access for each location.
6. Provide a starting point for a useable data framework/information system for the long-term protection, management and monitoring of natural wild rice in Minnesota.

Methods

An existing dataset (Microsoft Access) maintained by the MNDNR Shallow Lake Program provided the starting point for this effort. This dataset originated in the late 1980's based on a review and consolidation of the best existing data sources at that time (i.e. MNDNR Enforcement wild rice lists, tribal rice camps, etc.) followed up with field interviews to MNDNR Area Wildlife and Tribal offices in the primary natural wild rice range. This initial assessment found over 700 lakes in 31 counties totaling 1.5 million basin acres contained approximately 61,000 acres of natural wild rice.

Since this initial dataset was formed, various MNDNR, federal, treaty and tribal authorities have accomplished a significant amount of additional inventory work. This information was reviewed, consolidated and added to the initial dataset and sent out for review to MNDNR Area Wildlife and Treaty/Tribal authorities for their comments and input. Return information was entered into a finalized dataset.

Primary information collected consisted of a location (i.e county, basin name), basin area and estimated natural wild rice coverage. For basins having a significant stand of natural wild rice, additional information was requested as to: water level management restrictions (i.e. dam at outlet); general wild rice location within the basin; treaty/tribal authority; and harvest potential, pressure and access.

Information sources

Information sources included the following:

- Minnesota DNR – initial survey data, 2006 Wild Rice Harvesters Survey, Fisheries lake surveys, Wildlife/shallow lake surveys, aquatic plant management permits, and aquatic plant survey data from Ecological Resources.
- Treaty/Tribal - 1854 Treaty Authority, Great Lakes Indian Fish and Wildlife Commission, Fond Du Lac Indian Reservation, Mille Lacs Indian Reservation, Leech Lake Indian Reservation, and, White Earth Indian Reservation.
- U.S. Fish and Wildlife Service, National Wildlife Refuge System

Results

Inventory results note that stands of natural wild rice were present or occurred in recent history on 1,292 lakes or river/stream segments in Minnesota. Of these 1,286 locations, 777 have information on natural wild rice coverage, which totals approximately 64,328 acres. The remaining 509 locations that currently do not have coverage information are primarily small lakes/wetlands on the edge of the current natural wild rice range (southern and western Minnesota) or river/stream segments.

On a county basis, the greatest concentration of natural wild rice locations is in St. Louis (8,939 acres), Itasca (8,448 acres), Cass (8,323 acres), Aitkin (4,859 acres), and Crow Wing (3,751 acres). These five counties contain over 60% of the inventoried natural wild rice acreage in Minnesota.

Recommendations

- This inventory should be considered a work in progress. Further edits and review are needed, especially for small lakes/wetlands on the edge of current natural wild rice range and the numerous river/stream segments that may been missed in this inventory.
- A procedure to review and update this inventory on a regular basis (every 5-10 years) should be undertaken.
- Information gathered on harvest potential, pressure and access to these natural wild rice locations should be listed/posted on appropriate web sites (i.e. MNDNR web site).

County name	Location Name (i.e. Lake or River)	MN Lake ID	Location size (acres)	Estimated wild rice coverage (acres)
Aitkin	Aitkin	01004000	850	298
Aitkin	Anderson	01003100	97	30
Aitkin	Bear	01006400	127	1
Aitkin	Big Sandy	01006200	9,380	94
Aitkin	Birch	01020600	449	5
Aitkin	Blind	01018800	323	39
Aitkin	Brown	01007800	97	34
Aitkin	Camp	01009800	127	30
Aitkin	Clear	01010600	123	20
Aitkin	Cornish Pool	01042700	600	30
Aitkin	Davis	01007101	76	30
Aitkin	Deer	01008600	47	3
Aitkin	Elm Island	01012300	656	30
Aitkin	Farm Island	01015900	2,025	20
Aitkin	Fleming	01010500	326	1
Aitkin	Flowage	01006100	720	432
Aitkin	Gun	01009900	735	60
Aitkin	Hammal	01016100	376	1
Aitkin	Hay	01005900	133	1
Aitkin	Hickory	01017900	183	10
Aitkin	Jenkins	01010000	127	1
Aitkin	Jewett State WMA - Impoundment	01038300	180	30
Aitkin	Johnson	01013100	27	6
Aitkin	Killroy	01023800	23	4
Aitkin	Kimberly State WMA - Lower Pool	01043300	300	30
Aitkin	Kimberly State WMA - Upper Pool	01041100	900	76
Aitkin	Krilwitz	01IMP002	30	6
Aitkin	Lily	01008800	50	2
Aitkin	Little Hill River State WMA - Pool 1	01043300	135	18
Aitkin	Little McKinney	01019700	26	6
Aitkin	Little Pine	01017600	126	1
Aitkin	Little Prairie	01001600	78	1
Aitkin	Little Red Horse Lake	01005200	32	3
Aitkin	Little Willow River State WMA - Upper Pool	W0642001	50	20
Aitkin	Little Willow State WMA - Lower Pool	01033200	140	50
Aitkin	Mallard	01014900	354	320
Aitkin	Mandy	01006800	107	27
Aitkin	Minnewawa	01003300	2,451	130
Aitkin	Monson	01012600	48	25
Aitkin	Moose	01014000	148	117
Aitkin	Moose River	01r4		

County name	Location Name (i.e. Lake or River)	MN Lake ID	Location size (acres)	Estimated wild rice coverage (acres)
Aitkin	Moose Willow State WMA - Moose Pool	01035800	900	89
Aitkin	Moose Willow State WMA - Willow Pool	01043100	300	50
Aitkin	Moulton	01021200	282	1
Aitkin	Mud (Grayling Marsh WMA, pool 1)	01002900	400	1
Aitkin	Mud (Little White Elk)	01019400	135	68
Aitkin	Nelson	01001000	71	1
Aitkin	Newstrom	01009700	97	76
Aitkin	Pine	01000100	391	4
Aitkin	Portage	01006900	387	5
Aitkin	Prairie River	01r6		
Aitkin	Rat	01007700	442	45
Aitkin	Rat House	01005300	122	100
Aitkin	Red	01010700	97	4
Aitkin	Rice	01000500	83	50
Aitkin	Rice (Big)	01006700	3,635	1,700
Aitkin	Rice River	01r1	190	25
Aitkin	Ripple	01014600	676	50
Aitkin	Ripple River	01r3		
Aitkin	Rock	01007200	366	50
Aitkin	Round	01013700	634	1
Aitkin	Salo Marsh State WMA - Pool	01041500	690	76
Aitkin	Sanders	01007600	55	36
Aitkin	Sandy River	01006000	368	200
Aitkin	Sandy River	01r2		
Aitkin	Savanna	01001400	86	1
Aitkin	Savanna River	01r5		
Aitkin	Section Ten	01011500	440	52
Aitkin	Section Twelve	01012000	167	1
Aitkin	Shovel	01020000	230	207
Aitkin	Sissabagamah	01012900	386	39
Aitkin	Sitas	01013200	59	5
Aitkin	Sixteen	01012400	18	1
Aitkin	Sjodin	01031600	43	28
Aitkin	Spectacle	01015600	107	1
Aitkin	Spirit	01017800	523	26
Aitkin	Split Rock	01000200	27	1
Aitkin	Spruce	01015100	80	80
Aitkin	Steamboat	01007102	59	15
Aitkin	Stony	01001700	52	5
Aitkin	Sugar	01008400	23	1
Aitkin	Sugar	01008700	416	1
Aitkin	Swamp	01009200	270	1

County name	Location Name (i.e. Lake or River)	MN Lake ID	Location size (acres)	Estimated wild rice coverage (acres)
Aitkin	Tamarack River	01r7		
Aitkin	Twenty	01008500	153	119
Aitkin	Unnamed (L. Wolf)	01002000	19	1
Aitkin	Unnamed (Rice)	01041900	16	1
Aitkin	Unnamed (Round Lake Pothole)	01028500	15	12
Aitkin	Unnamed (Upper Blind)	01033100	14	3
Aitkin	Unnamed (W. Washburn)	01026200	14	1
Aitkin	Washburn	01011100	73	4
Aitkin	Waukenabo	01013600	819	49
Aitkin	West	01028700	51	20
Aitkin	White Elk	01014800	780	350
Anoka	Carlos Avery WMA - Pool 1	W9001001	180	15
Anoka	Carlos Avery WMA - Pool 13	W9001013	586	2
Anoka	Carlos Avery WMA - Pool 14	W9001014	749	15
Anoka	Carlos Avery WMA - Pool 15	W9001015	365	1
Anoka	Carlos Avery WMA - Pool 16	W9001016	67	
Anoka	Carlos Avery WMA - Pool 17	W9001017	185	
Anoka	Carlos Avery WMA - Pool 2	W9001002	683	20
Anoka	Carlos Avery WMA - Pool 22	W9001022	141	10
Anoka	Carlos Avery WMA - Pool 23	W9001023	1,600	
Anoka	Carlos Avery WMA - Pool 24	W9001024	35	2
Anoka	Carlos Avery WMA - Pool 26	W9001026	200	5
Anoka	Carlos Avery WMA - Pool 3	W9001003	186	120
Anoka	Carlos Avery WMA - Pool 5	W9001005	52	25
Anoka	Carlos Avery WMA - Pool 6	W9001006	200	1
Anoka	Carlos Avery WMA - Pool 7	W9001007	240	3
Anoka	Carlos Avery WMA - Pool 9	W9001009	269	120
Anoka	Carlos Avery WMA - Pool 9(2)	W9001011	71	30
Anoka	East Twin	02002000	171	1
Anoka	Grass	02011300		
Anoka	Grass	02009200		
Anoka	Hickey	02009600	41	
Anoka	Little Coon	02003200	486	10
Anoka	Pickerel	02013000	303	25
Anoka	Rice	02000800		
Anoka	Rice	02004300		
Anoka	Rice Creek	02r1		
Anoka	Rondeau	02001500	552	
Anoka	Rum River	02r2		
Anoka	Swan	02009800	273	33
Anoka	West Twin	02003300	18	
Becker	Abners	03003900	100	80

County name	Location Name (i.e. Lake or River)	MN Lake ID	Location size (acres)	Estimated wild rice coverage (acres)
Becker	Albertson	03026600	73	
Becker	Aspinwall	03010400	178	18
Becker	Axberg	03066000	47	
Becker	Balsam	03029200	148	10
Becker	Bass	03048000	28	
Becker	Bass	03008800	208	10
Becker	Bean	03041100	19	
Becker	Big Basswood	03009600	586	304
Becker	Big Rat	03024600	1,102	110
Becker	Big Rush	03010300	1,128	20
Becker	Blackbird	03019700	284	42
Becker	Blueberry	03000700	160	2
Becker	Booth	03019800	48	43
Becker	Buffalo	03035000	444	89
Becker	Bullhead	03031200	39	6
Becker	Bush	03021200	110	40
Becker	Cabin	03034600	38	
Becker	Camp Seven	03015100	78	8
Becker	Carman	03020900	217	30
Becker	Chippewa	03019600	960	288
Becker	Dahlberg	03057700	77	
Becker	Dead	03016000	296	
Becker	Dinner	03004400	53	11
Becker	Eagen	03031800	85	
Becker	Equay	03021900	73	7
Becker	Flat	03024200	1,970	197
Becker	Gull Creek	03r2		
Becker	Gyles	03006600	42	16
Becker	Halverson	03041200	18	
Becker	Height of Land	03019500	3,943	197
Becker	Hubbel Pond	03024000	561	168
Becker	Indian Creek Imp.	03r4		
Becker	Johnson	03019900	181	40
Becker	Kneebone	03009000	149	15
Becker	Little Basswood	03009200	105	31
Becker	Little Dinner	03004500	12	5
Becker	Little Flat	03021700	235	211
Becker	Little Mud	03002200	25	6
Becker	Little Rice	03023900	110	21
Becker	Little Round	03030200	565	
Becker	Lower Egg	03021000	171	75
Becker	Lyman WPA	03IMP003		

County name	Location Name (i.e. Lake or River)	MN Lake ID	Location size (acres)	Estimated wild rice coverage (acres)
Becker	Manomin Creek	03r5		
Becker	Mary Yellowhead	03024300	68	7
Becker	Mud	03012000	170	
Becker	Mud	03002300	85	42
Becker	Mud	03006700	88	83
Becker	Mud	03001600	86	
Becker	Ottertail River	03r1		
Becker	Pearl	03048600	268	
Becker	Rice	03028500	51	
Becker	Rice	03017300	37	
Becker	Rice	03029100	245	196
Becker	Rice	03020100	245	245
Becker	Rock	03029300	1,198	240
Becker	Round	03015500	1,094	
Becker	Schultz	03027800	103	82
Becker	Shell	03010200	3,147	169
Becker	Shipman	03000500	71	1
Becker	Spindler	03021400	185	125
Becker	Tamarack	03024100	2,227	245
Becker	Tamarack NWR - Ogemash Pool	03IMP002	71	20
Becker	Tea Cracker	03015700	122	30
Becker	Town	03026400	117	35
Becker	Trieglaff	03026300	111	56
Becker	Twin Island	03003300	71	5
Becker	Two Inlets	03001700	643	40
Becker	Unnamed	03008700	23	
Becker	Unnamed	03060000	59	
Becker	Unnamed	03059800	36	
Becker	Unnamed	03059900	34	
Becker	Unnamed	03014000	43	
Becker	Unnamed	03109300	72	7
Becker	Unnamed	03077600	20	10
Becker	Unnamed	03071600	25	12
Becker	Unnamed	03043400	21	17
Becker	Upper Egg	03020600	493	24
Becker	Wild Rice River	03r3		
Becker	Winter	03021600	117	43
Becker	Wolf	03010100	1,453	10
Beltrami	Big	04004900	3,565	250
Beltrami	Big Rice	04003100	642	96
Beltrami	Bootleg	04021100	308	185
Beltrami	Burns	04000100	131	105

County name	Location Name (i.e. Lake or River)	MN Lake ID	Location size (acres)	Estimated wild rice coverage (acres)
Beltrami	Campbell	04019600	462	23
Beltrami	Carr	04014100	51	8
Beltrami	Cass	04003000	15,958	10
Beltrami	Clearwater	04034300	1,039	
Beltrami	Cranberry	04012300	77	46
Beltrami	Dutchman	04006700	171	
Beltrami	Erickson	04006800	111	50
Beltrami	George	04017500	89	18
Beltrami	Grant Creek	04r1		
Beltrami	Grass	04021600	233	
Beltrami	Gull	04006400	170	34
Beltrami	Heart	04027100	10	
Beltrami	Irving	04014000	644	97
Beltrami	Kitchi	04000700	1,850	185
Beltrami	Little Puposky	04019700	158	95
Beltrami	Little Rice	04017000	72	
Beltrami	Little Rice	04001500	123	60
Beltrami	Little Rice Pond	04002300		
Beltrami	Little Turtle	04015500	464	23
Beltrami	Manomin	04028600	288	144
Beltrami	Marquette	04014200	578	
Beltrami	Medicine	04012200	458	69
Beltrami	Mississippi	04r2		
Beltrami	Moose	04001100	617	96
Beltrami	Moose	04034200	133	
Beltrami	Norman	04002900	61	8
Beltrami	Pimushe	04003200	1,350	135
Beltrami	Puposky	04019800	2,120	236
Beltrami	Rabideau	04003400	723	217
Beltrami	Rice	04017400	55	
Beltrami	Rice	04012100	36	
Beltrami	Rice	04025000	124	
Beltrami	Rice Pond	04005900	247	123
Beltrami	Three Island	04013400	836	125
Beltrami	Turtle River	04011100	1,664	
Beltrami	Upper Red	04003501	119,271	
Beltrami	Whitefish	04030900	126	
Blue Earth	Rice	07005900		
Blue Earth	Rice Creek	07r1		
Brown	Altematt	08005400		
Brown	Rice Lake	08003500		
Carlton	Bang	09004600	58	1

County name	Location Name (i.e. Lake or River)	MN Lake ID	Location size (acres)	Estimated wild rice coverage (acres)
Carlton	Bob	09002600	78	1
Carlton	Cedar	09003100	62	10
Carlton	Cross	09006200	110	6
Carlton	Dead Fish	09005100	153	115
Carlton	Flower	09006400	14	10
Carlton	Hardwood	09003000	100	25
Carlton	Hay	09001000	103	1
Carlton	Island	09006000	456	46
Carlton	Jaskari	09005000	74	74
Carlton	Kettle	09004900	611	415
Carlton	Long	09006600	17	4
Carlton	Miller	09005300	156	156
Carlton	Moose	09004300		
Carlton	Moosehead	09004100		
Carlton	Perch	09003600	796	597
Carlton	Rice Portage	09003700	832	120
Carlton	Sterle Pool	W0854002	29	2
Carlton	Tamarack	09006700	228	11
Carlton	Tamarack River	09r1		
Carlton	Wild Rice	09002300	54	36
Carlton	Woodbury	09006300	59	10
Cass	Baby	11028300	736	7
Cass	Bergkeller	11044700	120	5
Cass	Beuber	11035300	135	15
Cass	Big Birch	11001700	255	45
Cass	Big Portage	11030800	956	30
Cass	Big Rice (Remer)	11007300	2,717	1,411
Cass	Big Sand	11007700	752	10
Cass	Birch	11041200	1,262	1
Cass	Bluebill	11039700	51	1
Cass	Bowen	11035000	182	
Cass	Boy (& Boy River)	11014300	5,544	340
Cass	Brockway	11036600	182	55
Cass	Bullhead	11018400	88	
Cass	Cat	11050900	108	5
Cass	Cedar	11048100	34	3
Cass	Cedar	11044400	17	4
Cass	Child	11026300	295	12
Cass	Chub	11051700	57	51
Cass	Ding Pot	11056500	29	29
Cass	Donkey	11028000	54	
Cass	Drumbeater	11014500	376	5

County name	Location Name (i.e. Lake or River)	MN Lake ID	Location size (acres)	Estimated wild rice coverage (acres)
Cass	East Twin	11012300	297	50
Cass	Esterday	11051100	43	3
Cass	Farnham	11051300	142	71
Cass	Five Point	11035100	265	13
Cass	George	11010100	720	262
Cass	Gijik	11018500	118	1
Cass	Goose	11009600	844	844
Cass	Grass	11031500	113	
Cass	Grass	11009000		
Cass	Gull	11030500	9,541	15
Cass	Gull River	11r1	219	110
Cass	Hand (Lower)	11025100	122	50
Cass	Hand (Upper)	11024200	316	20
Cass	Hardy	11033200	89	2
Cass	Hattie	11023200	592	40
Cass	Hay	11019900	364	36
Cass	Hole-In-Bog	11019700	76	
Cass	Hunter	11017000	189	2
Cass	Inguadona	11012000	935	19
Cass	Island	11010200	390	10
Cass	Island	11036000	117	30
Cass	Kelly	11042800	50	10
Cass	Kerr	11026800	81	1
Cass	Kid	11026200	167	3
Cass	Laura	11010400	1,424	854
Cass	Leech	11020300	109,415	4,000
Cass	Lind	11036700	462	95
Cass	Little Birch	11001800	25	25
Cass	Little Boy	11036900	71	1
Cass	Little Boy	11016700	1,396	10
Cass	Little Swift	11013100	62	16
Cass	Little Vermillion	11003000	138	15
Cass	Little Woman	11026500	50	8
Cass	Lizotte	11023100	75	50
Cass	Lomish	11013600	282	197
Cass	Lower Milton	11008000	80	5
Cass	Lower Trelipe	11012900	618	20
Cass	Mad Dog	11019300	27	
Cass	Margaret	11022200	230	3
Cass	McCarthey	11016800	194	78
Cass	McKeown	11026100	171	3
Cass	Moon	11007800	58	5

County name	Location Name (i.e. Lake or River)	MN Lake ID	Location size (acres)	Estimated wild rice coverage (acres)
Cass	Moose	11042400	92	1
Cass	Mud	11030900	18	18
Cass	Mud	11010000	1,440	1,300
Cass	Norway	11030700	498	10
Cass	Nushka	11013700	78	
Cass	Ododikossi	11007400	20	10
Cass	Oxbow	11007500	172	4
Cass	Peterson	11015400	139	3
Cass	Pick	11026700	36	1
Cass	Pickerel	11035200	66	
Cass	Pillager	11032000	213	10
Cass	Pine Mountain	11041100	1,657	40
Cass	Portage	11047600	277	
Cass	Potshot	11014900	28	14
Cass	Rat	11028500	104	
Cass	Ray	11022000	183	37
Cass	Rice	11040200	188	5
Cass	Rice	11016200	342	137
Cass	Rice	11013800	55	1
Cass	Rice (Carrol's)	11022700	46	46
Cass	Rice (Pillager)	11032100	232	100
Cass	Rice Pad	11072000	14	4
Cass	Rock	11032400	249	10
Cass	Sailor	11001900	42	10
Cass	Schafer	11000400	44	2
Cass	Scribner	11044100	93	5
Cass	Six Mile	11014600	1,288	70
Cass	Skunk	11002700	145	30
Cass	Spring	11002200	86	12
Cass	Stephens	11021300	104	1
Cass	Swift	11013300	359	51
Cass	Tamarack	11034700	46	4
Cass	Tamarack	11018900	63	6
Cass	Thiebault	11002000	37	5
Cass	Third Guide	11000100	44	14
Cass	Thirty-Six	11017300	49	1
Cass	Thunder	11006200	1,316	2
Cass	Twin	11048400	168	
Cass	Unnamed	11077700	40	
Cass	Unnamed	11078000	10	4
Cass	Unnamed (Pistol Lake Rice Bed)	11073800	22	20
Cass	Unnamed (Rice Swamp)	11069800	11	

County name	Location Name (i.e. Lake or River)	MN Lake ID	Location size (acres)	Estimated wild rice coverage (acres)
Cass	Unnamed (Rice)	11061500	11	
Cass	Upper Gull	11021800	345	2
Cass	Upper Loon	11022500	114	
Cass	Wabedo	11017100	1,272	5
Cass	Wabegon	11040300	42	4
Cass	Washburn	11005900	1,768	60
Cass	Wax	11012400	95	10
Cass	West Twin	11012500	200	11
Cass	White Oak	11001600	68	1
Cass	Widow	11027300	197	
Cass	Winnibigoshish	11014700	69,821	1,000
Cass	Woman	11020100	5,360	54
Chippewa	Chippewa River	12r1		
Chisago	Goose	13008300	710	
Chisago	Rush	13006900	3,170	
Clay	Cromwell	14010300	27	
Clearwater	Anderson	15007400	53	3
Clearwater	Bagley	15004000	106	
Clearwater	Berg	15002500	50	
Clearwater	Clearwater River	15r1		
Clearwater	Duncan	15002400	18	
Clearwater	Elk	15001000	305	
Clearwater	First	15013900	60	3
Clearwater	Gill	15001900	380	38
Clearwater	Itasca	15001600	1,065	
Clearwater	Lomond	15008100	108	5
Clearwater	Lower Red	15020200		
Clearwater	Lower Rice	15013000	2,375	1,568
Clearwater	Mallard	15001800	123	25
Clearwater	Minerva	15007900	239	36
Clearwater	Mississippi	15r3		
Clearwater	Mud	15006100	294	103
Clearwater	Pine	15014900	1,465	220
Clearwater	Second	15014000	68	7
Clearwater	Sucker	15002000	90	14
Clearwater	Tamarack	15005600	21	
Clearwater	Tamarack	15013600	115	
Clearwater	Third	15014100	38	2
Clearwater	Unnamed (Rice Bed)	15002100	150	45
Clearwater	Upper Rice	15005900	1,860	1,116
Clearwater	Wild Rice River	15r2		
Cook	Bigsby	16034400	89	1

County name	Location Name (i.e. Lake or River)	MN Lake ID	Location size (acres)	Estimated wild rice coverage (acres)
Cook	Caribou	16036000	714	7
Cook	Christine	16037300	192	19
Cook	Elbow	16009600	415	124
Cook	Fente	16074100	35	
Cook	Four Mile	16063900	593	42
Cook	Grassy	16039000	22	
Cook	Gust	16038000	159	1
Cook	Iron	16032800	125	
Cook	Jack	16052100	127	12
Cook	Kelly	16047600	188	56
Cook	Luffs	16000600		
Cook	Mark	16025000	126	
Cook	Marsh	16048800	62	31
Cook	Moore	16048900	64	48
Cook	Mt. Maud	16wtld2		
Cook	North Fowl	16003600	297	
Cook	Northern Light	16008900	443	133
Cook	Peterson	16047800	104	1
Cook	Phoebe	16080800	758	1
Cook	Prout	16001300	18	
Cook	Rib	16054400	89	
Cook	Rice	16045300	230	92
Cook	Richey	16064300	114	
Cook	Royal River	16r1		
Cook	South Fowl	16003400	508	
Cook	Swamp	16000900		
Cook	Swamp River	16r2		
Cook	Swamp River Reservoir	16090100	165	153
Cook	Teal	16000300	73	1
Cook	Temperance River	16r3		
Cook	Toohey	16064500	369	
Cook	Turtle	16025100	61	
Cook	Unnamed	16wtld1		
Cook	Unnamed	16041600	14	14
Cook	White Pine	16036900	374	
Crow Wing	Arrowhead	18036600	285	40
Crow Wing	Bass	18001100	65	13
Crow Wing	Bass	18022900	114	1
Crow Wing	Bay	18003400	2,435	1
Crow Wing	Big Bird	18028500	205	10
Crow Wing	Birchdale	18017500	80	40
Crow Wing	Borden	18002000	1,038	31

County name	Location Name (i.e. Lake or River)	MN Lake ID	Location size (acres)	Estimated wild rice coverage (acres)
Crow Wing	Buffalo	18015200	36	18
Crow Wing	Bulldog	18001400	151	5
Crow Wing	Butterfield	18023100	225	1
Crow Wing	Camp	18001800	537	22
Crow Wing	Caraway	18017900	40	32
Crow Wing	Carlson	18039500	45	1
Crow Wing	Clark	18037400	309	3
Crow Wing	Cole	18012700	114	1
Crow Wing	Crow Wing	18015500	378	
Crow Wing	Dahler	18020400	277	28
Crow Wing	Deadman's	18018800	28	5
Crow Wing	Deer	18018200	78	30
Crow Wing	Dog	18010700	71	71
Crow Wing	Duck	18017800	310	175
Crow Wing	Duck	18031400	160	3
Crow Wing	Eagle	18029600	356	1
Crow Wing	Emily	18020300	675	2
Crow Wing	Erskine	18000900	186	7
Crow Wing	Faupel	18023700	42	25
Crow Wing	Flanders	18024700	181	20
Crow Wing	Garden	18032900	262	100
Crow Wing	Gilbert	18032000	391	7
Crow Wing	Goggle	18022300	107	11
Crow Wing	Goodrich	18022600	382	5
Crow Wing	Grass	18036200	45	1
Crow Wing	Grass	18023000	78	4
Crow Wing	Green	18023300	14	1
Crow Wing	Greer	18028700	384	20
Crow Wing	Half Moon	18023800	70	14
Crow Wing	Happy	18010100	51	36
Crow Wing	Hay	18044400	46	29
Crow Wing	Hole-in-the-Day	18040100	217	90
Crow Wing	Holt	18002900	164	10
Crow Wing	Horseshoe	18031700	33	13
Crow Wing	Island	18005200	37	18
Crow Wing	Island	18038300	85	2
Crow Wing	Jail	18041500	190	2
Crow Wing	Johnson	18032800	129	25
Crow Wing	Lily Pad	18027500	47	30
Crow Wing	Little Pine	18026600	384	20
Crow Wing	Little Pine	18017600	135	30
Crow Wing	Lizzie	18041600	384	100

County name	Location Name (i.e. Lake or River)	MN Lake ID	Location size (acres)	Estimated wild rice coverage (acres)
Crow Wing	Long	18003100	80	4
Crow Wing	Love	18038800	88	18
Crow Wing	Lower Dean	18018100	372	360
Crow Wing	Lower Mission	18024300	739	50
Crow Wing	Lows	18018000	320	45
Crow Wing	Mahnomen	18012600	238	1
Crow Wing	Mallard	18033400	73	4
Crow Wing	Maple	18004500	68	20
Crow Wing	Middle Cullen	18037700	405	2
Crow Wing	Mississippi River	18r1		1
Crow Wing	Mitchell	18029400	460	3
Crow Wing	Mollie	18033500	421	17
Crow Wing	Mud	18009400	78	6
Crow Wing	Mud	18013700	132	40
Crow Wing	Mud	18032600	82	60
Crow Wing	Mud	18019800	103	10
Crow Wing	Nelson	18016400	323	100
Crow Wing	Nisswa	18039900	213	25
Crow Wing	North Long	18037200	6,178	10
Crow Wing	Olson	18017100	28	3
Crow Wing	Ossawinnamakee	18035200	739	1
Crow Wing	Perch	18030400	181	8
Crow Wing	Pine	18026100	391	60
Crow Wing	Platte	18008800	1,768	350
Crow Wing	Pointon	18010500	193	14
Crow Wing	Rat	18041000	100	2
Crow Wing	Red Sand	18038600	569	28
Crow Wing	Rice (Blomberg's)	18012100	78	60
Crow Wing	Rice (Clark Lake rice bed)	18032700	181	124
Crow Wing	Rice (Deerwood)	18006800	185	170
Crow Wing	Rice (Hesitation State WMA)	18005300	168	138
Crow Wing	Rice (Lowell State WMA)	18040500	85	33
Crow Wing	Rice (Pratt's)	18031600	100	90
Crow Wing	Rice Bed	18018700	50	47
Crow Wing	Rock	18001600	210	10
Crow Wing	Rogers	18018400	249	4
Crow Wing	Round	18014700	144	5
Crow Wing	Round (Round-Rice Bed State WMA)	18003200	82	5
Crow Wing	Roy	18039800	310	5
Crow Wing	Sebie	18016100	180	2
Crow Wing	Sewells Pond	18044600	20	16
Crow Wing	Sibley	18040400	412	10

County name	Location Name (i.e. Lake or River)	MN Lake ID	Location size (acres)	Estimated wild rice coverage (acres)
Crow Wing	Smith	18002800	486	49
Crow Wing	South Long	18013600	1,380	4
Crow Wing	Stewart	18036700	254	5
Crow Wing	Tamarack	18031800	34	30
Crow Wing	Terry	18016200	102	55
Crow Wing	Twenty Two	18000800	169	42
Crow Wing	Twin Island	18010600	85	42
Crow Wing	Unnamed	18020100	16	1
Crow Wing	Unnamed	18041300	103	27
Crow Wing	Unnamed	18055000	30	30
Crow Wing	Unnamed	18005500	70	1
Crow Wing	Unnamed (Blackies Slough)	18054400	33	20
Crow Wing	Unnamed (Lost Rice)	18022800	157	80
Crow Wing	Unnamed (Nokasippi R. Rice Bed)	18048500	166	40
Crow Wing	Unnamed (Total's Pothole)	18054300	28	16
Crow Wing	Upper Cullen	18037600	459	23
Crow Wing	Upper Dean	18017000	263	10
Crow Wing	Upper Hay	18041200	640	2
Crow Wing	Upper Mission	18024200	895	5
Crow Wing	Upper Whitefish	18031000	7,969	50
Crow Wing	Velvet	18028400	167	2
Crow Wing	Whipple	18038700	345	40
Crow Wing	Whitefish	18000100	709	30
Crow Wing	Williams	18002400	47	3
Crow Wing	Wilson	18004900	63	4
Crow Wing	Wolf	18011200	218	25
Dakota	Blackhawk	19005900		
Dakota	Chub	19002000	301	1
Douglas	Mud	21023600	50	
Faribault	Minnesota	22003300	1,915	
Faribault	Rice	22000700		
Faribault	Rice	22007500		
Fillmore	Rice Creek	23r1		
Freeborn	Bear	24002800	1,560	
Freeborn	Geneva	24001500	1,875	18
Freeborn	Spicer	24004500	125	100
Freeborn	Trenton	24004900	184	18
Goodhue	Cannon River	25r2		
Goodhue	Rice Bottoms	25r1		
Goodhue	Sturgeon	25001701		
Hennepin	Grass	27008000	326	
Hennepin	Rice	27013200	294	

County name	Location Name (i.e. Lake or River)	MN Lake ID	Location size (acres)	Estimated wild rice coverage (acres)
Hennepin	Rice	27011600		
Houston	Blue	28000503	362	
Houston	Lawrence	28000501	142	
Houston	Target	28000502	424	
Hubbard	Alice	29028600	150	15
Hubbard	Birch Creek	29r1		
Hubbard	Clausens	29009700	222	
Hubbard	Crow Wing	29011600		
Hubbard	Crow Wing River	29river		
Hubbard	Deer	29009000	193	
Hubbard	Eagle	29025600	440	4
Hubbard	Eighth Crow Wing	29007200	493	1
Hubbard	Eleventh Crow Wing	29003600	752	1
Hubbard	Fifth Crow Wing	29009200	406	10
Hubbard	First Crow Wing	29008600	564	50
Hubbard	Fishhook River	29r4		
Hubbard	Fourth Crow Wing	29007800	523	130
Hubbard	Garfield	29006100	984	90
Hubbard	George	29021600	882	18
Hubbard	Hart	29006300	236	118
Hubbard	Hattie	29030000	359	
Hubbard	Holland-Lucy	29009500	44	
Hubbard	Horseshoe	29005900	264	
Hubbard	Island	29025400	522	60
Hubbard	Kabekona River	29r6		
Hubbard	Kabekona River	290075T2		
Hubbard	Kabenkona	29007500		
Hubbard	Little Rice	29018300	27	1
Hubbard	Little Stony	29008000	55	
Hubbard	Loon	29002000	112	
Hubbard	Lower Bottle	29018000	712	10
Hubbard	Lower Mud	29026700	30	30
Hubbard	Mantrap	29015100	1,770	200
Hubbard	Mud	29011900	146	30
Hubbard	Mud Creek	29r3		
Hubbard	Necktie River	29r2		
Hubbard	Ninth Crow Wing	29002500	235	
Hubbard	Oak	29006000	58	1
Hubbard	Oelschlager Slough	29000600	328	
Hubbard	Paine	29021700	258	
Hubbard	Plantagenet	29015600	2,620	
Hubbard	Portage	29025000	429	

County name	Location Name (i.e. Lake or River)	MN Lake ID	Location size (acres)	Estimated wild rice coverage (acres)
Hubbard	Potato	29024300	2,239	30
Hubbard	Rice	29017700	230	58
Hubbard	Schoolcraft	29021500	176	35
Hubbard	Second Crow Wing	29008500	228	5
Hubbard	Seventh Crow Wing	29009100	251	10
Hubbard	Shallow	29008900	295	9
Hubbard	Shell River	29r5		
Hubbard	Sixth Crow Wing	29009300	358	5
Hubbard	Spider	29011700	593	
Hubbard	Spring	29005400	43	
Hubbard	Sunday	29014400	62	
Hubbard	Tamarack	29009400	36	
Hubbard	Tenth Crow Wing	29004500	185	9
Hubbard	Third Crow Wing	29007700	636	40
Hubbard	Tripp	29000500	155	1
Hubbard	Twin	29029300		
Hubbard	Unnamed	29011500	16	
Hubbard	Unnamed	29011800	21	
Hubbard	Unnamed	29011400	24	
Hubbard	Unnamed	29008400	87	
Hubbard	Unnamed	29007900	38	
Hubbard	Unnamed	29017900	16	
Hubbard	Unnamed	29009900	26	
Hubbard	Unnamed	29015800	60	
Hubbard	Unnamed	29002100		
Hubbard	Unnamed	29026300	20	
Hubbard	Unnamed	29001900	15	
Hubbard	Unnamed (Boudora)	29008200	48	1
Hubbard	Unnamed (Hay Creek)	29055400	38	20
Hubbard	Upper Bass	29003400	30	
Hubbard	Upper Bottle	29014800	505	30
Hubbard	Upper Mud	29028400	50	50
Hubbard	Upper Twin	29015700	212	1
Isanti	Elizabeth	30008300	323	
Isanti	German	30010000	340	
Isanti	Grass	30014200	33	
Isanti	Krone	30014000	142	
Isanti	Lindgren	30014400	75	
Isanti	Little Stanchfield	30004400	155	
Isanti	Mud	30006500	300	
Isanti	Mud	30010600	81	
Isanti	Mud	30011700		

County name	Location Name (i.e. Lake or River)	MN Lake ID	Location size (acres)	Estimated wild rice coverage (acres)
Isanti	North Stanchfield	30014300	153	
Isanti	Rice	30001800		
Isanti	Section	30006000	130	
Isanti	South Stanchfield	30013800	433	
Isanti	Typo	30000900	273	
Isanti	Upper Rice	30005700	208	208
Itasca	Ann	31030500	94	5
Itasca	Aspen	31069000	86	5
Itasca	Bass	31057600	2,844	427
Itasca	Big Fork River	31r3		
Itasca	Birdseye	31083400	73	11
Itasca	Blackberry	31021000	240	50
Itasca	Blackwater	31056100	674	300
Itasca	Bluebill	31026500	144	14
Itasca	Bosley	31040300	41	10
Itasca	Bowstring (& Bowstring River)	31081300	8,900	1,335
Itasca	Bowstring River	31r4		
Itasca	Buckman	31027200	222	33
Itasca	Clearwater	31040200	67	10
Itasca	Clubhouse	3105400		
Itasca	Coddington	31088300	70	18
Itasca	Cophenhagen	31053900		
Itasca	Cresent	31029400	42	2
Itasca	Crooked	31020300	80	12
Itasca	Cut Foot Sioux	31085700	3,222	322
Itasca	Damon	31094400	53	20
Itasca	Decker	31093400	292	58
Itasca	Deer	31034400	1,854	
Itasca	Dishpan	31099200	15	15
Itasca	Dixon	31092100	666	67
Itasca	Dora	31088200	477	89
Itasca	Egg	31081700	118	11
Itasca	Farley	31090200	33	5
Itasca	First River	31081800	228	160
Itasca	Grass	31072700		
Itasca	Grass	31052700		
Itasca	Gunny Sack	31026700	81	8
Itasca	Hamrey	31091100	61	15
Itasca	Harrigan	31017400	27	3
Itasca	Hay	31003700		
Itasca	Helen	31084000	109	76
Itasca	Hunters	31045000	162	16

County name	Location Name (i.e. Lake or River)	MN Lake ID	Location size (acres)	Estimated wild rice coverage (acres)
Itasca	Ima	31063400		
Itasca	Irene	31087800	10	1
Itasca	Island	31075400	291	10
Itasca	Kelly	31029100	31	19
Itasca	Lawrence	31023100	382	19
Itasca	Leighton	31003200	242	12
Itasca	Lillian	31075000	90	14
Itasca	Little Ball Club	31082200	181	10
Itasca	Little Cut Foot	31085200	1,357	136
Itasca	Little Drum	31074100	89	22
Itasca	Little Island	31017900	26	3
Itasca	Little Moose	31061000	234	12
Itasca	Little Rice	31071600		
Itasca	Little Spring	31079700	121	3
Itasca	Little White Oak	31074000	493	25
Itasca	Lost	31028900		
Itasca	Lost	31090000	26	5
Itasca	Lower Pigeon	31089300	53	20
Itasca	Marble	31027100	155	20
Itasca	Marie	31093700	45	10
Itasca	Middle Pigeon	31089200	182	15
Itasca	Mississippi River	31r6		
Itasca	Morph	31092900	67	3
Itasca	Mosomo	31086100	47	5
Itasca	Mud	31020600	271	203
Itasca	Munzer	31036000	108	3
Itasca	Nagel	31037700	90	50
Itasca	Natures	31087700	2,885	2,499
Itasca	O'Donnell	31030300	47	10
Itasca	Otter	31030100		
Itasca	Pigeon Dam	31089400	511	500
Itasca	Pokegama	31053200	15,600	100
Itasca	Pothole	31099100		
Itasca	Prairie	31038400	1,167	45
Itasca	Prairie (& Prairie River)	31005300	29	1
Itasca	Rabbits	31092300	209	157
Itasca	Raven	31092500	97	70
Itasca	Rice	31031500	37	15
Itasca	Rice	31071700		
Itasca	Rice	31077700		
Itasca	Rice	31087600	911	729
Itasca	Rice	31020100	115	6

County name	Location Name (i.e. Lake or River)	MN Lake ID	Location size (acres)	Estimated wild rice coverage (acres)
Itasca	Rice	31070700		
Itasca	Rice	31094200	39	
Itasca	Rice Creek	31r5		
Itasca	Rice Creek	31r1		
Itasca	Rice River	31r2		
Itasca	Ruby	31042200	243	5
Itasca	Sand	31082600	3,391	50
Itasca	Shallow Pond	31091000	281	11
Itasca	Simpson	31086700	35	5
Itasca	Sioux	31090700	69	27
Itasca	Skimmerhorn	31093900	30	6
Itasca	Soneman	31027600	40	16
Itasca	Spruce	31034700	58	58
Itasca	Stevens	31071800	224	11
Itasca	Stone Axe	31082800	37	4
Itasca	Swan	31006700	2,472	50
Itasca	Tuttle	31082100	56	16
Itasca	Unnamed	31081500	109	5
Itasca	Unnamed	31096100	10	2
Itasca	Unnamed	31020400	28	3
Itasca	Unnamed	31032200	28	2
Itasca	Unnamed	31006600	23	3
Itasca	Unnamed	31086000	24	5
Itasca	Upper Pigeon	31090800	86	10
Itasca	Walters	31029800	120	18
Itasca	Wart	31085900	14	5
Itasca	White Fish	31014200	31	2
Itasca	White Oak	31077600	905	271
Itasca	Whitefish	31084300	493	10
Itasca	Wilderness	31090100	26	4
Kanabec	Ann	33004000	363	18
Kanabec	Grass	33001300		
Kanabec	Kent	33003500	34	
Kanabec	Knife	33002800		
Kanabec	Mud	33001500		
Kanabec	Pomroy	33000900	267	
Kanabec	Rice	33001100	172	
Kanabec	Rice	33003100		
Kanabec	Sells	33001800	64	
Kanabec	Twin or East	33001900	27	
Kanabec	Unnamed	33002900	21	
Kanabec	Unnamed	33011100	33	27

County name	Location Name (i.e. Lake or River)	MN Lake ID	Location size (acres)	Estimated wild rice coverage (acres)
Kanabec	Unnamed	33001400	30	
Kanabec	Unnamed	33007200	31	1
Kanabec	Unnamed	33001200	11	
Kandiyohi	Bear	34014800	128	
Kandiyohi	Blaamyhre	34034500	121	
Kandiyohi	Eight	34014600	89	
Kandiyohi	Glesne	34035200	205	
Kandiyohi	Monongalia	34IMP001	1,500	
Kandiyohi	Mud	34015800	2,516	
Kandiyohi	Ole	34034200	66	
Kandiyohi	Unnamed	34023600	117	
Koochiching	Nett	36000100	7,369	
Koochiching	Rainy Lake	36000100	7,301	2,000
Koochiching	Rat Root	36000600	734	
Koochiching	Tilson Creek	36r1		
Lake	Bald Eagle	38063700	1,243	
Lake	Basswood	38064500	14,610	485
Lake	Bluebill	38026100	44	11
Lake	Bonga	38076200	138	138
Lake	Cabin	38026000	71	55
Lake	Campers	38067900	56	56
Lake	Charity	38005500	26	
Lake	Christianson	38075000	158	
Lake	Clark	38067400		
Lake	Clark	38064700	49	
Lake	Cloquet	38053900	176	
Lake	Cloquet River	38r1		
Lake	Comfort	38029000	42	
Lake	Cougar	38076700	71	1
Lake	Cramer	38001400	69	55
Lake	Crooked	38002400		
Lake	Crooked	38081700		
Lake	Crown	38041900	69	
Lake	Driller	38065200	24	
Lake	Dumbbell	38039300	476	48
Lake	Ella Hall	38072700	372	1
Lake	Fall	38081100	2,322	23
Lake	Farm	38077900	1,292	
Lake	Flat Horn	38056800	52	
Lake	Fools	38076100	14	14
Lake	Gabbro	38070100	927	
Lake	Garden	38078200	4,236	212

County name	Location Name (i.e. Lake or River)	MN Lake ID	Location size (acres)	Estimated wild rice coverage (acres)
Lake	Gegoka	38057300	174	14
Lake	Greenwood	38065600	1,469	15
Lake	Harris	38073600	121	18
Lake	Hjalmer	38075800	109	2
Lake	Hoist	38025100	117	
Lake	Horse River	38r5		
Lake	Hula	38072800	121	121
Lake	Isabella	38039600	1,318	
Lake	Isabella River	38r4		
Lake	Island River	38084200	49	49
Lake	Kawishiwi	38008000	468	
Lake	Kawishiwi River	38r2		
Lake	Little Gabbro	38070300	151	
Lake	Little Wampus	38068400		
Lake	Lobo	38076600	132	99
Lake	Manomin	38061600	455	23
Lake	Middle McDougal	38065800	104	
Lake	Moose	38003600	201	
Lake	Mud	38074200	164	
Lake	Muskeg	38078800	178	71
Lake	Newton	38078400		
Lake	Nine A.M.	38044500	27	14
Lake	North McDougal	38068600	273	
Lake	Papoose	38081800	54	3
Lake	Phantom	38065300	70	
Lake	Railroad	38065500	11	1
Lake	Rice	38046500	206	206
Lake	Roe	38013900	76	
Lake	Round Island	38041700	58	58
Lake	Sand	38073500	506	51
Lake	Sand River	38r3		
Lake	Scott	38027100	52	
Lake	Silver Island	38021900	1,239	
Lake	Slate	38066600	293	
Lake	Snowbank	38052900	4,819	50
Lake	Source	38065400	35	1
Lake	Sourdough	38070800	17	17
Lake	South McDougal	38065900	277	3
Lake	Stony	38066000	409	245
Lake	Stony River	38r6		
Lake	Upland	38075600	74	1
Lake	Vera	38049100	262	

County name	Location Name (i.e. Lake or River)	MN Lake ID	Location size (acres)	Estimated wild rice coverage (acres)
Lake	Wampus	38068500	146	
Lake	Wind	38064200	952	10
Lake	Wood	38072900	587	125
Lake of the Woods	Baudette River	39r2		
Lake of the Woods	Bostick Creek	39r1		
Lake of the Woods	Lake of the Woods	39000200	950,400	225
Lake of the Woods	Rainy River	39r5		
Lake of the Woods	Roseau Flowage	39IMP001	200	100
Lake of the Woods	Silver Creek	39r3		
Lake of the Woods	Winter Road River	39r4		
Le Sueur	Rice	40wtld1		
Le Sueur	Rice	40011400		
Le Sueur	Rice	40003700		
Le Sueur	Rice	40001600		
Mahnomen	Grass	44004700	22	
Mahnomen	Long	44000200	117	
Mahnomen	Peabody	44-wetld		
Mahnomen	Rice	44002400	120	
Mahnomen	Roy	44000100	689	
Mahnomen	Sargent (Little Rice)	44010800	174	
McLeod	Grass	43001300		
McLeod	Rice	43004200		
McLeod	Schaefer Prairie	43r1		
Mille Lacs	Dewitt Marsh	48002000	110	131
Mille Lacs	Dewitt Pool	48IMP004	146	131
Mille Lacs	Ernst Pool	48003600	300	200
Mille Lacs	Korsness Pool 1	48003500	130	90
Mille Lacs	Mille Lacs WMA - Headquarters 2 Pool	W9004009	500	13
Mille Lacs	Mille Lacs WMA - Jones 1 Dk Pool	W9004008	520	3
Mille Lacs	Mille Lacs WMA - Korsness Pool 2	W9004002	33	30
Mille Lacs	Mille Lacs WMA - Korsness Pool 3	W9004003	18	5
Mille Lacs	Mille Lacs WMA - Olson Pool	W9004007	85	2
Mille Lacs	Mille Lacs WMA - Townhall Pool	W9004010	110	3
Mille Lacs	Ogechie	48001400	732	
Mille Lacs	Onamia	48000900	2,250	1,350
Mille Lacs	Rice	48001000	512	
Mille Lacs	Shakopee	48001200	771	
Mille Lacs	Unnamed	48004300	60	10
Mille Lacs	Unnamed	48004400	500	
Mille Lacs	Unnamed	48005400	32	25
Mille Lacs	W. brnch Groundhouse Riv	48IMP002	50	1
Morrison	Bernhart	49013500	39	

County name	Location Name (i.e. Lake or River)	MN Lake ID	Location size (acres)	Estimated wild rice coverage (acres)
Morrison	Coon	49002000	75	75
Morrison	Crookneck	49013300	200	
Morrison	Hannah	49001400	109	27
Morrison	Long	49001500	128	32
Morrison	Longs	49010400	60	
Morrison	Madaline	49010100	50	
Morrison	Miller	49005100	39	9
Morrison	Mud	49009500	105	
Morrison	Mud	49007200	83	5
Morrison	Mud	49002700	23	9
Morrison	Mud	49001800		
Morrison	Peavy	49000500	140	
Morrison	Pelkey	49003000	113	10
Morrison	Placid	49008000	537	
Morrison	Platte River	49r2		
Morrison	Popple	49003300	153	
Morrison	Rice	49002500	323	250
Morrison	Rice Creek	49r1		
Morrison	Round	49001900	134	14
Morrison	Skunk	49002600	320	256
Morrison	Skunk	49000700		
Morrison	Sullivan	49001600	1,199	20
Morrison	Twelve	49000600	159	80
Nicollet	Rice	52003300		
Otter Tail	Armor	56038100		
Otter Tail	Beauty Shore	56019500	233	
Otter Tail	Berger	56114900	190	
Otter Tail	Davies	56031100	69	
Otter Tail	Dead	56038300	7,827	
Otter Tail	Duck	56092500	41	
Otter Tail	East Red River	56057300	292	
Otter Tail	Emma	56019400	473	
Otter Tail	Gourd	56013900		
Otter Tail	Grass	56011500		
Otter Tail	Grass	56072300		
Otter Tail	Grass	56071700		
Otter Tail	Head	56021300	499	
Otter Tail	Little McDonald	56032800	1,506	
Otter Tail	Long	56021000		
Otter Tail	Mud	56021500	138	
Otter Tail	Mud	56022200	437	
Otter Tail	Mud	56013200	155	

County name	Location Name (i.e. Lake or River)	MN Lake ID	Location size (acres)	Estimated wild rice coverage (acres)
Otter Tail	Mud	56114800	134	
Otter Tail	North Maple	56001300	161	
Otter Tail	North Rice	56034900	103	
Otter Tail	Otter Tail River	56r1		
Otter Tail	Peterson	56047100	141	
Otter Tail	Rankle	56093500	57	
Otter Tail	Reed	56087600	155	
Otter Tail	Rice	56000600		
Otter Tail	Rice	56035200		
Otter Tail	Rice	56070200		
Otter Tail	Rice	56021100	263	
Otter Tail	Rice	56036300	350	
Otter Tail	Rush	56014100	5,340	
Otter Tail	Sharp	56048200	160	
Otter Tail	Sixteen	56010000	107	
Otter Tail	South Maple	56000400	160	
Otter Tail	Star	56038500	4,809	
Otter Tail	Tamarack	56019200	440	
Otter Tail	Tamarack	56043300	470	
Otter Tail	Unnamed	56127300	126	
Otter Tail	Unnamed	56151700	23	
Otter Tail	Unnamed	56155000	14	
Otter Tail	Unnamed	56157800	29	
Otter Tail	Unnamed	56019800	69	
Otter Tail	Unnamed	56028400	83	
Otter Tail	Unnamed	56108300	198	
Otter Tail	Unnamed	56092700	35	
Otter Tail	Unnamed	56125900	12	
Otter Tail	West Battle	56023900		
Otter Tail	West Lost	56048100	915	
Otter Tail	Wing River	56004300	138	
Pine	Big Pine	58013800		
Pine	Cedar	58008900	71	
Pine	Crooked	58002600	94	85
Pine	Fox	58010200		
Pine	Grass	58012500		
Pine	Hay Creek Flowage	58000500	66	40
Pine	Kettle River	58r2		
Pine	Little North Sturgeon	58006600	20	
Pine	McCormick	58005800		
Pine	Passenger	58007600	75	
Pine	Pokegama (& River)	58014200	1,621	16

County name	Location Name (i.e. Lake or River)	MN Lake ID	Location size (acres)	Estimated wild rice coverage (acres)
Pine	Rush	58007800	88	
Pine	Stanton	58011100	84	34
Pine	Willow River	58r1		
Polk	Unnamed (Round)	60072100	9	2
Pope	Rice	61006900		
Ramsey	Grass	62007400		
Redwood	Rice Creek	64r1		
Rice	Cedar	66005200	927	93
Rice	Dudley	66001400	83	
Rice	Hatch	66006300	102	10
Rice	Hunt	66004700	190	19
Rice	Kelly	66001500	62	
Rice	Mud	66005400	269	54
Rice	Pooles	66004600	182	
Rice	Rice	66004800		
Rice	Unnamed	66010300	26	
Rice	Weinberger	66004100	53	8
Rice	Willing	66005100	53	5
Roseau	Bednar Impoundment	68IMP002	240	40
Scott	Artic	70008500		
Scott	Blue	70008800	316	120
Scott	Fisher	70008700	396	190
Scott	Rice	70006000		
Scott	Rice	70002500	328	160
Scott	Rice	70000100		
Sherburne	Big Mud	71008500	263	100
Sherburne	Buck Lake	71IMP007	30	26
Sherburne	Clitty	71011600	56	
Sherburne	Fremont	71001600	466	
Sherburne	Jim	71011100	20	20
Sherburne	Johnson Slough	71IMP004	65	10
Sherburne	Johnson Slought	71008400		
Sherburne	Josephine	71006800	132	
Sherburne	Josephine Pool	71IMP008	143	72
Sherburne	Kliever Marsh	71000300	37	
Sherburne	Long Pond	71003600	82	
Sherburne	Lower Roadside	71IMP006	8	7
Sherburne	Lundberg Slough	71010900	50	
Sherburne	Muskrat Pool	71IMP003	299	15
Sherburne	Orrock Lake	71IMP010	215	162
Sherburne	Rice	71001500	11	
Sherburne	Rice	71007800	505	

County name	Location Name (i.e. Lake or River)	MN Lake ID	Location size (acres)	Estimated wild rice coverage (acres)
Sherburne	Rice	71014200	187	2
Sherburne	Schoolhouse Pool	71IMP009	225	90
Sherburne	Sherburne NWR - Pool 1	71IMP001	2	2
Sherburne	Sherburne NWR - Pool 2	71IMP002	30	15
Sherburne	Sherburne NWR - Pool 31	71IMP011		
Sherburne	Unnamed	71002500	31	
Sherburne	Upper Roadside	71IMP005		
Sibley	Titlow	72004200	924	
St. Louis	???	69IMP002		15
St. Louis	Alden	69013100	190	
St. Louis	Anchor	69064100	316	32
St. Louis	Angell Pool	W0889001	500	80
St. Louis	Artichoke	69062300	306	
St. Louis	Balkan	69086000	36	2
St. Louis	Bear	69011200	125	125
St. Louis	Bear Island River	69r8		
St. Louis	Bear Trap	69008900	131	
St. Louis	Big	69019000	2,049	20
St. Louis	Big Rice	69017800	416	416
St. Louis	Big Rice	69066900	2,072	1,700
St. Louis	Birch	69000300	7,628	381
St. Louis	Black	69074000	118	
St. Louis	Blueberry	69005400	130	13
St. Louis	Bootleg	69045200	352	
St. Louis	Breda	69003700	137	135
St. Louis	Burntside	69011800	7,314	
St. Louis	Canary	69005500	22	1
St. Louis	Caribou	69048900	569	3
St. Louis	Cloquet River	69r5		
St. Louis	Comet	69026700	28	
St. Louis	Cranberry	69014700	69	
St. Louis	Crane	69061600	3,396	600
St. Louis	Deadmans	69IMP001	5	
St. Louis	Dollar	69053400	51	51
St. Louis	Duck	69019100	126	
St. Louis	Eagles Nest #3	69028500	1,028	
St. Louis	East Stone	69063800	92	24
St. Louis	East Twin	69016300		
St. Louis	Echo	69061500		
St. Louis	Ed Shave	69019900	90	
St. Louis	Elliot	69064200	393	20
St. Louis	Embarrass River	69r3		

County name	Location Name (i.e. Lake or River)	MN Lake ID	Location size (acres)	Estimated wild rice coverage (acres)
St. Louis	Five Mile	69028800	106	10
St. Louis	Four Mile	69028100	86	1
St. Louis	Gafvert	69028000	33	1
St. Louis	George	69004000	42	
St. Louis	Gill	69066700	18	
St. Louis	Grand	69051100	1,742	10
St. Louis	Grass	69077600	49	1
St. Louis	Grassey	69091300		
St. Louis	Grassy	69008200		
St. Louis	Grassy	69021600		
St. Louis	Gull	69009200	196	20
St. Louis	Hay	69044100	47	
St. Louis	Hay	69043500	78	78
St. Louis	Hay	69015000	32	1
St. Louis	Hay	69057900	114	114
St. Louis	Hay	69043900	42	1
St. Louis	Hay	69041700	82	45
St. Louis	Hockey	69084900	139	70
St. Louis	Hoodoo	69080200	252	252
St. Louis	Horseshoe	69025500	39	10
St. Louis	Indian	69002300	57	
St. Louis	Jeanette	69045600		
St. Louis	Johnson	69011700	473	24
St. Louis	Joker	69001500	46	5
St. Louis	King	69000800	320	39
St. Louis	Kylen	69003400	16	2
St. Louis	La Pond	69017700	176	176
St. Louis	Leeman	69087500	284	90
St. Louis	Lieung	69012300	476	10
St. Louis	Little Birch	69027100	58	
St. Louis	Little Cloquet River	69r6		
St. Louis	Little Indian Sioux River	69r7		
St. Louis	Little Mesaba	69043600		
St. Louis	Little Rice	69061200	266	266
St. Louis	Little Sandy	69072900	89	89
St. Louis	Little Stone	69002800	163	
St. Louis	Little Vermillion	69060800	558	
St. Louis	Long (Butterball)	69004400	442	400
St. Louis	Low	69007000	353	71
St. Louis	Lower Pauness	69046400	162	1
St. Louis	Martin	69076800	71	
St. Louis	Moose	69079800	82	62

County name	Location Name (i.e. Lake or River)	MN Lake ID	Location size (acres)	Estimated wild rice coverage (acres)
St. Louis	Mud	69015100	51	
St. Louis	Mud	69080000	71	18
St. Louis	Mud	69004700		
St. Louis	Mud Hen	69049400	165	
St. Louis	Myrtle	69074900	876	
St. Louis	Nels	69008000	200	2
St. Louis	Nichols	69062700	444	22
St. Louis	One Pine	69006100	369	37
St. Louis	Oriniack	69058700	748	
St. Louis	Papoose	69002400	16	16
St. Louis	Pelican (& River)	69084100	11,944	119
St. Louis	Perch	69068800	79	32
St. Louis	Petrel Creek	69r4		
St. Louis	Picket	69007900	78	7
St. Louis	Pike River	69r1		
St. Louis	Prairie	69084800	807	16
St. Louis	Rainy	69069400	220,800	
St. Louis	Rainy (Grassy Narrows)	69064000		
St. Louis	Rat	69092200		
St. Louis	Rat	69073700		
St. Louis	Rice	69057800	41	41
St. Louis	Rice	69080300		
St. Louis	Round	69004800	336	
St. Louis	Ruth	69001400	47	9
St. Louis	Sandpoint	69061700		
St. Louis	Sandy	69073000	121	121
St. Louis	Seven Beaver	69000200	1,508	1,282
St. Louis	Shannon (& River)	69092500	135	108
St. Louis	Side	69069900	25	15
St. Louis	Simian Lake	69061900	81	5
St. Louis	Sioux River	69r9		
St. Louis	Six Mile	69028300	103	1
St. Louis	St. Louis River	69r2		
St. Louis	Stone	69004600	230	173
St. Louis	Stone	69068600	160	24
St. Louis	Sturgeon	69093900	2,050	243
St. Louis	Sunset	69076400	309	6
St. Louis	Susan	69074100	305	
St. Louis	Tommila	69003500	87	85
St. Louis	Trettel Pool	W0889002	30	3
St. Louis	Turpela	69042700	76	61
St. Louis	Twin	69050400	18	1

County name	Location Name (i.e. Lake or River)	MN Lake ID	Location size (acres)	Estimated wild rice coverage (acres)
St. Louis	Twin	69069500		
St. Louis	Unnamed	69063400	101	20
St. Louis	Unnamed (Camp 97)	69059400	25	
St. Louis	Upper Bug	69040600	23	
St. Louis	Upper Pauness	69046500	215	1
St. Louis	Vang	69087600	126	3
St. Louis	Vermilion	69037800	49,110	250
St. Louis	Vermilion River	69061300	1,125	562
St. Louis	Wabuse	69040800	64	51
St. Louis	Washusk #1	69040900	51	40
St. Louis	Watercress	69079700	43	43
St. Louis	Watercress (Mud)	69079700	30	
St. Louis	Wheel	69073500	11	6
St. Louis	Whitchel	69053100	71	53
St. Louis	White Iron	69000400		
St. Louis	Wild Rice	69037100	2,133	1
St. Louis	Wolf	69014300	456	
Stearns	Anna	73012600	133	
Stearns	Big Rice	73016800	282	
Stearns	Cedar	73022600	152	
Stearns	Crow	73027900	461	
Stearns	Fifth	73018000	76	
Stearns	Fish	73028100	204	
Stearns	Grass	73029400	157	
Stearns	Gravel	73020400	55	
Stearns	Henry	73016000	62	
Stearns	Henry	73023700	191	
Stearns	Linneman	73012700	108	
Stearns	Little Rice	73016700	56	
Stearns	Lower Spunk	73012300	269	
Stearns	McCormic	73027300	211	
Stearns	Middle Spunk	73012800	242	
Stearns	Mud	73016100	55	
Stearns	Raymond	73028500	126	
Stearns	Rice	73019600	1,568	
Stearns	Sagatagan	73009200	170	
Stearns	Schultz Slough	73020100	29	
Stearns	Tamarack	73027800	470	235
Steele	Oak Glen	74000400	350	4
Steele	Rice	74000100	697	467
Todd	Beck	77005600	57	25
Todd	Cass County	77000400	25	18

County name	Location Name (i.e. Lake or River)	MN Lake ID	Location size (acres)	Estimated wild rice coverage (acres)
Todd	Hayden	77008000	253	1
Todd	Jacobson	77014300	40	
Todd	Jaeger	77007500	46	28
Todd	Lawrence	77008300	172	
Todd	Little Fishtrap	77007400		
Todd	Little Pine	77013400		
Todd	Long	77006900	356	338
Todd	Mud	77008700	398	318
Todd	Pine Island	77007700	156	
Todd	Rice	77006100	675	60
Todd	Robbinson Pond	77IMP001	60	30
Todd	Rogers	77007300	185	130
Todd	Sheets	77012200	100	
Todd	Stones	77008100	63	
Todd	Thunder	77006600		
Todd	Tucker	77013900	43	
Todd	Twin	77002100	317	159
Todd	Unnamed	77020200	70	
Todd	Unnamed	77017600	40	2
Todd	Unnamed	77019700	53	
Todd	Unnamed	77017800	42	23
Todd	Unnamed	77014000	61	
Todd	West Nelson	77000500	84	70
Wabasha	Pool 5	79IMP001	600	35
Wabasha	Unnamed	W0580001	160	25
Wadena	Blueberry	80003400	555	30
Wadena	Burgen	80001800	92	86
Wadena	Finn	80002800	148	30
Wadena	Granning	80001200	50	50
Wadena	Jim Cook	80002700	238	
Wadena	Lower Twin	80003000	267	5
Wadena	Rice	80002400	8	1
Wadena	Round	80001900	58	58
Wadena	Strike	80001300	76	76
Wadena	Unnamed	80000700	16	16
Wadena	Yaeger	80002200	384	346
Wright	Albion	86021200	238	
Wright	Beaver Dam	86029600	253	
Wright	Butler	86019800	131	
Wright	Butternut	86025300	203	
Wright	Carrigan	86009700	162	
Wright	Cedar	86003400	191	

County name	Location Name (i.e. Lake or River)	MN Lake ID	Location size (acres)	Estimated wild rice coverage (acres)
Wright	Gilchrist	86006400	388	
Wright	Gonz	86001900	152	
Wright	Henshaw	86021300	277	
Wright	Long	86019400	255	
Wright	Louisa	86028200	183	
Wright	Malardi	86011200	149	
Wright	Mallard Pass	86018500	51	
Wright	Maple	86019700	82	
Wright	Maple Unit	86015700	177	
Wright	Mary	86004900	331	
Wright	Millstone	86015200	221	
Wright	Mink	86022900	304	
Wright	Mud	86002600	128	
Wright	Mud	86021900	66	
Wright	Pelican	86003100	2,793	
Wright	Pooles	86010200	166	
Wright	Rice	86003200	246	
Wright	Rice	86000200	57	
Wright	Sandy	86022400	118	150
Wright	School	86002500	76	
Wright	School Section	86018000	266	
Wright	Shakopee	86025500	206	
Wright	Smith	86025000	330	
Wright	Spring	86020000	63	
Wright	Taylor	86020400	78	
Wright	White	86021400	145	
Wright	Willima	86020900	246	
	1,286 total locations			
	For the 777 locations that have coverage data		1,569,889	64,328

Appendix C

Wild Rice Harvest Survey

The full report will be posted on the MNDNR website www.dnr.state.mn.us prior to March 1, 2008

Executive Summary

Introduction

The following objectives guided the study design, survey instrument and final report for this effort.

- To determine the characteristics of wild rice harvesters in Minnesota.
- To assess current harvest levels and harvester satisfaction.
- To assess current natural wild rice harvest use of Minnesota lakes and rivers.
- To obtain wild rice harvester opinions of current state regulations and proposed revisions.
- To determine factors that limit wild rice harvesting.
- Identify information needs of wild rice harvesters, and the best means to deliver information to harvesters.
- To determine support for natural wild rice management priorities.

In November of 2006 the Minnesota Department of Natural Resources initiated a self-administered, mail questionnaire of all 2006 wild rice license holders (n=1,625) to gather information on the objectives listed above, and all 2004 and 2005 license holders who did not purchase a license in 2006 (n=945) to gather information on why they did not harvest wild rice in 2006. Completed questionnaires were returned by 53 percent (n=1,365) of the 2,574-license holder sample.

Characteristics

The 2004 to 2006 wild rice license holder respondents were predominately male (82%), Minnesota residents (98%), and averaged 51 years of age. A large majority (81%) are 40 years of age or older. A majority harvested wild rice under only a state license (86%). The average age that harvesters began gathering wild rice was 31. Friends and parents were the primary means of introduction to the activity, and 69 percent of harvesters reported introducing others to gathering wild rice. The average harvester has 13 seasons of experience.

Harvest Levels

Based on responses, an estimated average of 430 pounds of unprocessed natural wild rice was gathered per harvester in 2006. Based on state issued license sales of 1,625 in 2006, this creates a total harvest estimate of approximately 700,000 pounds of natural wild rice. Approximately two percent of 2006 respondents harvested more than 2,000 pounds of rice, while 79 percent harvested less than 500 pounds. When comparing these groups (those harvesting > 500 lbs and those harvesting < 500 lbs) there is a difference in both the average age they began harvesting (20 and 33 years old, respectively) and the average number of seasons participated (25 and 12 years, respectively). A large majority (85%) of harvesters harvest for personal use.

Harvester Satisfaction

A large majority (82%) of 2006 harvesters were satisfied with their overall wild rice harvesting experience, with only one in ten expressing dissatisfaction. Harvesters were neutral on the existing wild rice season opening date (July 15th) and slightly in favor of the current wild rice season hours (9 a.m. to 3 p.m.). Other comment topics included: high licensing fees, less than ideal water levels, lack of processor information, lack of enforcement, weather, shoreline degradation, motor boats in wild rice stands, beaver control, and a need for more regulation of genetically modified wild rice.

Use of Minnesota Lake and Rivers to Harvest Wild Rice
A total of 3,151 trips were reported by 845 harvesters, resulting in an average of 4 trips per person to gather wild rice. Sixty percent (60%) of 2006 harvesters took three or fewer trips, while 12 harvesters (1%) managed 20 or more trips. One half (50%) of the respondents reported harvesting on only one lake, indicating that multiple trips were made to the same lakes. An additional 28 percent reported harvesting on two lakes. The average number of lakes visited for harvesting wild rice was 1.8 across all harvesters. The maximum number of lakes visited was six.

During 2006, over two-thirds (70%) of all wild rice harvesting trips were in Aitkin, St. Louis, Itasca, Crow Wing or Cass counties. The next five counties with the highest number of trips were Becker, Clearwater, Beltrami, Lake and Hubbard counties. The above ten counties had 91 percent of all wild rice harvesting trips. A total of 28 counties were identified as being visited for wild rice gathering.

While 407 locations were identified from the survey results to at least the county level, only 313 noted a specific name (i.e. lake name or river segment). Of these 313 locations, the top ten harvest locations based on harvest pressure (number of trips) account for 27.4 percent of the statewide total. Further review notes that 50 percent of total trips are represented by the top 32 locations and that the top 68 locations represent 66.6 percent of total trips.

State Regulations
About half (53%) of the respondents supported a change in harvesting hours from 9 a.m. - 3 p.m. to 10 a.m. - sunset, and three-fourths (77%) supported changing the wild rice season opening from July 15 to August 14. More than half (62% and 66% respectively) of the respondents opposed use of watercraft up to 38 inches wide or establishing a 7-day nonresident license.

Participation, Information Needs
The most important factors identified by respondents that limit participation in harvesting were personal time, and knowing when and where to harvest wild rice. For respondents that did not harvest is 2006, finding a rice processor ranked highest after personal time. Where and when to harvest are again ranked high for information helpful to 2006 ricers. In order of preference, the preferred method for delivery of information is through web sites, pamphlets or as a section of the DNR Hunting Regulation Handbook. Other limiting factors identified in comments include the cost of the license, fuel and transportation costs, and access (to private and reservation lakes).

Management Priorities
A large majority of respondents ranked water level management as the highest management priority, followed by availability of information. Seeding ranked third, while enforcement of regulations, access site improvement, and wild rice research were ranked fourth, fifth and sixth,

respectively. Other comments included protection from genetically modified rice, increased habitat protection, and excessive license fees. Specific habitat protection comments included more restrictions on shoreline development, protection from motorized watercraft, prevention of the removal of wild rice through aquatic plant management permits, and more management of specific lakes that are historical wild rice lakes.

Appendix D

The Life History of Natural Wild Rice

Growth and Development

The following description of the growth of wild rice plants is adapted primarily from the work of Dr. Ervin Oelke and others at the University of Minnesota unless noted otherwise (Oelke et al. 2000, Oelke 2007).

As an annual plant, wild rice develops each spring from seeds that fell into the water and settled into sediment the previous fall or before. Germination requires three to four months of cold, nearly freezing water (35° F or colder). Seeds exposed to drying die. Seed dormancy is regulated through hormonal growth promoters and inhibitors and by an impermeable, tough, wax-covered pericarp. Low oxygen levels can also inhibit germination.

Seed germination typically occurs when the substrate and surrounding water temperatures reach about 40° F. Depending on water depth, latitude, and the progression of spring weather, wild rice germinates in Minnesota sometime in April, well ahead of most but not all perennial plants. Within three weeks, rooted wild rice seedlings develop three submerged leaves. These leaves usually remain submerged and decay as the plant matures. Adventitious roots arise at the first leaf node and occasionally at the second and third nodes. Most, but not all, roots are shallow, often rust-tinged due to iron deposits, and may spread 8 to 12 inches. Natural mortality can be relatively high during the submerged leaf stage (Meeker 2000).

The emergent stage begins with the development of one or two floating leaves and continues with the development of several aerial leaves two to three weeks later. The floating leaves are apparent in late May to mid June in Minnesota, again dependent on water depth, latitude, and weather. It is at this stage of growth that wild rice is most susceptible to uprooting by rapidly changing water levels due to the natural buoyancy of the plant. Rising water levels can significantly stress the plant even if it remains rooted.

The upper portion of the wild rice stem is hollow, with thin evenly spaced partitions. The number of tillers, or additional flowering stems, can vary with plant density and water depth. In deep water there may only be one stem per plant while in shallow water the number can exceed 30. Tillers typically mature 7 to 14 days later than the main stem (Meeker 2000).

Wild rice begins to flower in mid to late July in Minnesota. Flowering times are dependent on both day length and temperature. Short day lengths trigger earlier flowering but a reduction in kernel number. Longer day lengths delay flowering while increasing kernel number. Warmer temperatures will accelerate development, and cooler temperatures will slow growth. Wild rice flowers are produced in a branching panicle with female flowers (pistillate or seed-producing) at the top of the panicle on appressed branches. Female florets typically number about 130 per plant. Male flowers (staminate or pollen-producing) are produced on nearly horizontal branches on the lower portion of the panicle. Natural wild rice is primarily pollinated by wind. High temperatures and low humidity can negatively affect fertilization rates.

There are several variations of the typical wild rice panicle. One is the bottlebrush variant, often associated with male sterility, in which the male flowering branches remain appressed and give the panicle a compact bottlebrush appearance. Another variant is the crowsfoot panicle, in which the female flowering branches spread in the same manner as the male branches. In another variant, the male florets are replaced by female florets, resulting in a gynoecious or entirely female panicle.

Cross-pollination is typical for natural wild rice because the female flowers develop, become receptive, and are pollinated before the male flowers on the same plant shed pollen. The female florets are receptive over a period of about ten days (Moyle 1944b). Cross-pollination is enhanced by plant-to-plant variation for flowering within the same stand due to the effects of water depth, non-synchronous tillering, and genetic differences among plants (Moyle 1944b, Meeker 2000).

Cross-pollination within and among wild rice populations helps maintain genetic variability and the biologic potential for wild rice to adapt to changing conditions. Some changes may be seasonal or annual in nature; others, such as changing climate in the Great Lakes region, will likely be long term. The variability in natural wild rice genetics that exists today may be a critical determinant of whether natural wild rice can adapt to changes in regional weather. Studies in northern Wisconsin found sufficient genetic diversity among geographically distinct stands of natural wild rice to identify four regional populations. The degree of diversity within stands varied widely, however, with larger and denser stands having higher levels (Waller et al. 2000).

When viable pollen grains land on the female stigma, they germinate within one hour and reach the embryo sac within two. Seeds are visible two weeks after fertilization, and they mature in four to five weeks. Immature seeds have a green outer layer that turns purplish black as the seed reaches physiologic maturity.

Seeds ripen over several days on an individual stem, starting at the top. Primary stems ripen earlier than secondary tillers, plants in rivers ripen earlier than those in lakes, plants in shallow water earlier than those in deeper water, and plants in northern Minnesota earlier than those in more southerly stands.

This staggered maturation process means that ripe seeds may be available within individual stands for several weeks, and across the entire range of natural wild rice in Minnesota for a month or longer. This extended period of “shattering”, or dropping of ripened seed, is an important mechanism that insures at least some seeds will survive to perpetuate the natural wild rice stand. The entire process, from germination of a new plant to the dropping of mature seeds, takes about 110 to 130 days (or about 2600 growing-degree days) depending on temperature and other environmental factors.

Not all wild rice seed germinates the following year. Under some conditions, natural wild rice seeds can remain dormant in the bottom sediment for many years to several decades if conditions are not suitable for germination. This allows wild rice to survive years when high water levels or storms reduce or eliminate productivity. Wild rice can germinate and colonize habitats after other plants have been removed by environmental disturbance if a seed bank is present (Meeker, 1999).

Even under ideal growing conditions, wild rice populations follow approximately three to five year cycles (Jenks 1900, Moyle 1944b, Pastor and Durkee Walker 2006, Walker et al. 2006). Highly productive years are followed by unproductive ones followed by a gradual recovery (Moyle 1944b, Grava and Raisanen 1978, Atkins 1986, Lee 1986, Archibold et al. 1989). Recent study suggests that oscillations in wild rice may be caused by delays in nutrient recycling to plant uptake. Wild rice litter accumulation may inhibit plant growth and production (Pastor and Durkee Walker 2006, Walker et al. 2006). In particular, the amount of wild rice straw, stage of decay, and tissue chemistry (root litter) may affect available nutrients, influence production, and result in population cycling (Walker, Ph.D. thesis 2008).

Habitat Requirements

While the historical range of wild rice illustrates its broad distribution, its specific occurrence and abundance is in large part dependent on local environmental conditions. The following descriptions are a capsulation of the historical and current literature (Moyle 1944a, Rogosin 1951, Lee 2000, Meeker 2000, Oelke 2007). For more detailed information be sure to check the original sources.

Hydrology

Wild rice generally requires some moving water, with rivers, flowages, and lakes with inlets and outlets being optimal areas. Water basins with intermittent or seasonal flow may sustain beds, but annual production will fluctuate more widely. Seasonal water depth is critical. Wild rice grows well in about 0.5 - 3 feet of water, although plants may be found deeper. Shallower sites support strong competition from perennial emergent plants and deeper water stresses the plant to the point that seed production is limited or nonexistent. At Rice Lake National Wildlife Refuge from 2002 to 2005, production and growth parameters were highest at water depths of 1- 30 inches (McDowell, personal communication).

Water levels that are relatively stable or decline gradually during the growing season are preferred. Abrupt water level increases during the growing season can uproot plants. Wild rice is particularly sensitive to this disturbance during the floating leaf stage. However, some observers feel that water levels kept stable over the long term (multiple years) tend to favor perennial aquatic vegetation over wild rice (David and Vogt, personal communication).

Water characteristics

Clear to moderately stained water is preferred, as darkly stained water may limit sunlight penetration and hinder early plant development.

Wild rice grows over a wide range of alkalinity, pH, iron, and salinity. It does best in water that has a pH range of 6.0 - 8.0 and alkalinity greater than 40 ppm. Some of the measured chemistry parameters are alkalinity (5-250 ppm), pH (6.4-10.1 SU), Iron (0.1-3.0 ppm) and True Color (50-300 Pt-Co) (Andryk 1986, Persell and Swan 1986).

The state of Minnesota instituted a water quality criterion for sulfate in wild rice waters of 10 mg/liter. The level was established based on observations by Moyle (1944a), however, other field observations and research show that wild rice can grow in waters with significantly higher sulfate concentrations (Grava 1981, Lee and Stewart 1983, Peden 1982). This research also indicates that factors such as oxygen levels and potential sediment anoxia are involved in the wild rice-sulfate connection.

While researchers have observed that natural wild rice ecosystems are relatively nutrient rich, excess levels of nutrients, especially phosphorus, can have significant adverse effects on natural wild rice productivity (Persell and Swan 1986).

Sediment

Although wild rice may be found growing in a variety of bottom types, the most consistently productive are lakes with soft, organic sediments (Lee 1986). The high organic matter content with a rather low carbon/nitrogen ratio is necessary to meet the rather high nitrogen needs of wild rice (Carson 2002). Nitrogen and phosphorus are major limiting nutrients for wild rice (Carson 2002). Flocculent sediments with nitrogen and phosphorus concentrations less than one gram per square meter are typically incapable of supporting sustained production (Lee 1986).

Competing Vegetation

As an annual plant sprouting each year from seed, wild rice can have difficulty competing with aggressive perennial vegetation, particularly where natural hydrologic variation has been reduced. Cattail (*Typha* spp.), particularly hybrid cattail (*Typha x glauca*), yellow water lily (*Nuphar variegata*), and pickerelweed (*Pontederia cordata*) are examples of plants that have been cited as competing with wild rice (Norrgard, David, and Vogt, personal communication).

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Appendix F
Stakeholder Comments

UNIVERSITY OF MINNESOTA

North Central Research and Outreach Center
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Date: February 10, 2008
To: Legislators of the State of Minnesota
From: Dr. Raymie Porter, University of Minnesota Raymie Porter
Re: The report "Natural Wild Rice in Minnesota" submitted by the DNR

In this statement I do not speak on behalf of the University of Minnesota, but rather as a scientist who has been engaged in research on cultivated wildrice breeding at the University of Minnesota for almost 20 years.

I would like to commend the Technical Team convened by the DNR to pull together the information that contributed to this report. Although the participants represent diverse interests when it comes to wildrice, our meetings have been characterized by a vigorous interchange of ideas with mutual respect, while focusing on what is actually known about wildrice. I hope that future efforts to deal with the issues identified by this report will be as positive and fruitful as what I have experienced in the meetings of the Technical Team. I would like to add the following comments to the report for emphasis.

The loss of genetic diversity should be viewed *not* as a primary *cause*, but rather as an *effect* resulting from other causes. Granted, addressing the loss of genetic diversity is crucial for the species to flourish in state waters. Loss of genetic diversity means loss of the alleles (or variant forms) of genes across the many natural populations of wildrice, which also means that there are fewer genotypes (genetic types) for a given trait within a given population. Having fewer genotypes may limit a population's ability to respond to seasonal, yearly, or long-term changes in the local environment of that population. This is especially true if the genotypes lost are ones needed for adaptation to conditions that prevail at that site. But, since loss of genetic diversity is usually caused by factors that reduce the number of individuals in populations to low numbers, alleviating the problems that reduce wildrice stands will help maintain the genetic diversity of wildrice. The report does a good job of characterizing the primary threats that limit wildrice stands and that could therefore reduce genetic diversity.

But how will we know whether or how genetic diversity is being affected? Only through knowledge about the genetics of wildrice. Sound scientific knowledge about the genetic make-up of natural stands, coupled with knowledge about how different genes respond to various environmental factors, should prove useful in guiding restoration efforts. If seeds need to be brought in from other natural stands in order to restore a site, knowing the genetics of the potential donor stands could help identify those that might be most similar to the population that remains at, or that once existed at, the site.

What about cultivated wildrice? Is the breeding of wildrice really a threat to natural stands from a genetic perspective? The consensus of the Technical Team is that it is not. I agree with this perspective. In fact, I believe that cultivated wildrice should not be made a scapegoat for problems in natural stands. I have heard speculations that cultivated wildrice causes this or that problem observed in a natural stand–speculations without evidence. What I know about population genetics leads me to the conclusion that such speculations will never find evidence to support them. Some basic facts about population genetics and wildrice should shed light on this.

Cultivated varieties (cultivars) of wildrice in Minnesota are not genetically uniform—they are heterogeneous, or made up of many different genotypes. The wildrice breeding project at the University of Minnesota has endeavored to maintain as much genetic diversity as possible in the cultivars released. Also, since all the genes in cultivars ultimately originated in the natural wildrice gene pool, they are a subset of the total genetic variability of wildrice. No new alleles or genes have been artificially added (i.e., no genetic engineering has been done, nor is it being pursued). Therefore, it seems reasonable to assume that cultivated wildrice has less total genetic diversity than natural wildrice. But this is the norm for any cultivated crop species, since breeders would tend to select only those alleles (variant forms) of genes that make the crop better adapted under the narrower range of cultivated conditions. Conversely, breeding a crop for adaptation to cultivated conditions tends to make it less fit for survival in the wild.

But even if a wildrice cultivar were genetically uniform, that uniformity should not impact the vast diversity of natural wildrice. There are many more acres of natural stands than cultivated stands, and they are rarely in close proximity to each other. That wildrice pollen travels over long distances has *not* been established. But even if pollen should travel between cultivars and natural stands, it could just as easily travel from one natural stand to another. And pollen moving from one natural stand to another natural stand nearby would likely be so few in number compared to the pollen produced locally that it would be diluted to insignificant amounts. Also, the viability of that pollen once it arrives is in doubt, given the short life of wildrice pollen.

"Migration" is the term used by population geneticists to describe gene movement between populations. But what would happen in those cases of successful migration of alleles of genes into a population? If the allele of that gene is *already* present in the population, the migration doesn't add anything new. If the allele is *not* already present, it would *add* to the genetic diversity of the population where it has found its home. This new allele, along with all the other alleles already present in the population, are then subjected to the forces of natural selection. If the allele increases the fitness of the plant to survive under the conditions of that population, natural selection favors it, and it will increase in its frequency in the population according to how much fitness it adds. If it decreases the fitness of the plant, natural selection will not favor it, and other plants with more favorable alleles will out-compete it. In this manner, natural selection will determine the genetic make-up of the population.

The heterogeneous nature of wild populations is the response of those populations to ever-changing local conditions. Any given year, some genotypes will do well, others will do poorly. In a different season, other different genotypes may prevail. In short, those plants with alleles that enable the plant to grow well and produce more seed under the local environmental conditions will contribute those genes to the next generation. Natural selection will enable the best plants to survive. This will be the case as long as there is enough genetic variability to allow adaptation to that environment.

Therefore, those factors that are known to adversely impact natural stands should be the focus of efforts to protect and enhance natural wildrice. This would accomplish the most to prevent loss of genetic diversity. It has been stated in the report that the threat of transgenic wildrice doesn't exist—no one knows of anyone who is pursuing it, and it seems unlikely that they would. Traditional (or conventional) breeding of wildrice is not a threat, by consensus of the Technical Team, for the reasons that I have just given. Other threats have been identified as important. Those threats should be addressed.

MINNESOTA CULTIVATED
WildRice
COUNCIL

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February 11, 2008

Ray Norrgard
Wetland Wildlife Program Leader
MN DNR
500 Lafayette Rd.
St. Paul, MN 55155-4020

Dear Mr. Norrgard:

As President of the Minnesota Cultivated Wild Rice Council (MCWRC), I appreciate the opportunity to comment on the Natural Wild Rice in Minnesota Study you were required to complete and are submitting to the Minnesota Legislature. The protection of natural stands of wild rice is an extremely important issue and is supported strongly by the MCWRC.

As I'm sure you know, cultivated wild rice plays an important role in Minnesota's rural economy. It is grown on marginal crop lands, providing income to some of the poorest counties in Minnesota. As forestry, mining, and other industries have lost jobs in the region, alternative opportunities for employment have become more important to the region. The cultivated wild rice industry has provided much-needed economic activity in these northern Minnesota counties. More than 500 people derive full or part-time employment directly from the cultivated wild rice industry in Minnesota, many of them on farms that have been in the family for four generations. On a full-time equivalent basis, these jobs equal more than 200 positions.

Additionally, the wild rice industry generates about $3.1 million in employee compensation annually. It also contributes a total of $8.7 million in total employee payroll and over $21 million in revenues to Minnesota's economy. Other industries share in about $20 million in revenues directly related to the wild rice industry. So you can see how important the cultivated wild rice industry is to northern Minnesota. *(The economic information cited herein is taken from a 1992 study of the economic impact of wild rice in Minnesota. Therefore, these figures understate the contributions of wild rice to Minnesota's economy in today's dollars.)*

With regard to the legislation passed in 2007 which requires an environmental impact statement for any proposed release of genetically modified wild rice and a study of potential threats to natural stands of wild rice, the MCWRC remained neutral. However, we feel it is very important to address a couple of specific issues as they relate to cultivated wild rice in Minnesota.

First, we would like to bring attention to the fact that, as noted in the wild rice study, traditional wild rice breeding programs do not pose a threat to natural stands. Wild rice grown in paddies is the same genus and species as that found in natural stands. Evidence to support this fact can be found by analyzing the 2007 harvest.

In 2007, hand harvesters enjoyed their most productive harvest in more than 40 years - at the same time cultivated wild rice producers recorded their highest production ever, a virtual impossibility if cultivated wild rice truly had a negative impact on natural stands. An article by Rod Ustipak, coordinator of a wild rice management program in Minnesota for Ducks Unlimited (DU) and the Minnesota Department of Natural Resources (DNR), which appeared in the September 16, 2007 edition of the St. Paul Pioneer Press (an article still available online at http://www.ducks.org/news/1359/DroughtimprovesMinne.html), explains how drought conditions over the past few years have actually conspired to create an environment in which natural stands thrived and produced a bumper harvest, conditions completely unrelated to cultivated wild rice production.

Secondly, although it is mentioned in the Natural Wild Rice In Minnesota Study as a concern, we feel it is extremely important to explicitly state the following: ***genetically engineered wild rice does not exist.***

There is a widely held belief, though completely inaccurate, that wild rice is somehow, somewhere being genetically modified or engineered. It is not. The MCWRC is neither developing, nor does it have plans to develop genetically engineered wild rice. We are not aware of any entity that is developing GE wild rice. The federal and state regulatory processes currently in place, coupled with the enormous investment (in the millions of dollars) necessary to develop GE wild rice, renders any effort to do so cost prohibitive. These facts, coupled with the recently passed legislation which requires an environmental impact study prior to the release of any genetically modified varieties of wild rice provide ample safeguards to the environment to ensure food safety and environmental integrity.

Since natural wild rice stands gave birth to the cultivated wild rice industry in Minnesota growers are keenly aware of the importance of protecting them. In fact, the MCWRC board of directors went on record with its support of protecting natural stands when it passed the following resolution at its July 27, 2005, board meeting, *"The MCWRC fully supports the protection of native stands of wild rice in Minnesota. There is no genetic engineering of wild rice occurring. The biosafety requirements in place through the coordinated framework of the USDA, EPA, FDA, the State of Minnesota, and the University of Minnesota are working well to assure a safe environment and food supply."*

Many threats may exist to natural stands of wild rice – shoreline development, climate change, wildlife activity, and recreational water use just to name a few. If we are to be successful in maintaining the vigor and existence of natural stands it is imperative that we analyze and focus our efforts on current threats - those that exist now - rather than perceived threats which are likely never to exist.

Sincerely,

Beth Nelson,
President

Tribal Statement Regarding MNDNR Wild Rice Study
Submitted To the State Legislature February 15, 2008

We appreciate the opportunity to provide input into the development of this *Natural Wild Rice in Minnesota* report. Manoomin (wild rice) is a remarkable and valuable component of the Minnesota landscape, and it is commendable that the State is concerned with its future. We concur with most of the wild rice history, ecology and proposed management recommendations contained therein and offer our statements below as points for emphasis and clarity to the Legislature and State DNR.

Manoomin is an inherent part of being Ojibwe. Our lifestyles and cultural identity are intimately bound to manoomin, spiritually, physically and economically. The importance of manoomin to the Ojibwe people cannot be overstated as it holds a central position in the lives and rich history of the Ojibwe people. It is more than just another grain or crop; it is a cultural resource of indescribable importance. It is a sacred gift from the creator to our people and is used for sustenance, ceremonial and commercial purposes.

The right of the Ojibwe to harvest and use manoomin was reserved and guaranteed in treaties signed between the Chippewa Bands of the region and the federal government that predate Minnesota statehood. Recent Supreme Court rulings have upheld the existence of these treaty reserved rights along with the federal trust responsibility to uphold these rights, and resources they are built upon.[1] Today, Tribal members continue to harvest manoomin, as they have for many years, in numbers greater than the rest of the state population. The very existence of the Ojibwe people depends on the vitality of their environment, their resource use and their culture which is intricately connected to natural wild rice.

Science and technology in the world is rapidly changing and challenging the environment of our daily lives. Threats to the existence and integrity of natural stands of wild rice are of immense concern to the Ojibwe. Today, the thought of genetic modification of wild rice poses an alarming threat into the possibility of irreversible genetic contamination of our natural stands of wild rice. This would have a profound negative impact on the Ojibwe people. The connection between Ojibwe culture and wild rice is not a static concept and should not be viewed as such. Rather, our relationship to wild rice should be acknowledged as a respectful, living force that guides the growth and development of our Ojibwe communities, as it has for centuries.

We feel strongly that manoomin must be protected from genetic engineering. From the beginning of the genetic engineering debate in Minnesota, the tribes have wanted GE wild rice banned. For the Ojibwe, no level of contamination is acceptable. Once genetic contamination occurs, there is likely no way to reverse it. There are published documents and reports demonstrating that genetically engineered plants can escape test plots and intermingle with native populations at distances greater than was previously thought. These same studies have shown that the range of impacts on native populations is significantly greater than currently recognized.[2] Thus, if GE wild rice were to be grown in Minnesota, it is not a question of whether contamination will occur rather, it is a question of how quickly and to what extent contamination will occur.

We recognize and appreciate that the current statute requiring an Environmental Impact Statement prior to any proposed release of GE wild rice represents progress. However, we desire complete and permanent protection for manoomin. There are currently no proven safe guards that could effectively isolate GE strains of wild rice from natural stands. The only way to prevent genetic contamination is to ensure that no GE wild rice is released into the environment. A ban on genetically engineered rice in Minnesota would be the best way to achieve this.

We recommend that the State Legislature require the Environmental Quality Board to specifically include Tribal cultural impacts as part of any GE wild rice Environmental Impact Statement process. Statements should include effects on the cultural practices of the Tribal community and State and address effects on Ojibwe culture, and traditional and customary rights.

We can not afford to hesitate when it comes to protecting natural stands of wild rice. We must conserve the biodiversity of natural wild rice stands. The rapid development of new technology and science combined with corporate exploitation of resources adds to the urgency. We must not allow Minnesota manoomin to be genetically contaminated by genetically engineered varieties that may be developed. This resource is far too precious, far too significant ecologically, economically and culturally, and far too sacred to allow this to occur. The protection and preservation of natural bed wild rice needs to be the concern of all Minnesotans. We desire to work with the State of Minnesota to ensure that wild rice is protected fully and permanently.

Bois Forte Band of Chippewa
Fond du Lac Band of Lake Superior Chippewa
Grand Portage Band of Chippewa
Leech Lake Band of Ojibwe
Mille Lacs Band of Ojibwe
White Earth Band of Ojibwe
The Minnesota Chippewa Tribe
1854 Treaty Authority
Great Lakes Indian Fish and Wildlife Commission
White Earth Land Recovery Project

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[1] None of the material in this report can be construed to abrogate, abridge, affect, modify, supersede or alter any treaty-reserved right or other sovereign rights of the regions Chippewa Bands' as recognized by any means, including but not limited to, agreements with the United States, Executive Orders, statutes, judicial decrees, or Federal law.

[2] The following references represent a small sample of the research on the uncertainty of the impact and fate of genetically engineered organisms on natural ecosystems: Schoen, DJ, Reichman JR, and Ellstrand, NC 2008. Transgene Escape Monitoring, Population Genetics, and the Law. Bioscience Vol. 58 No. 1: 71-77; Ponti, Luigi, 2005. Transgenic Crops and Sustainable Agriculture in the European Context, Bulletin of Science Technology & Society Vol. 25, No. 4: 289-305; Lundmark, C, 2007, Genetically Modified Maize, Bioscience Vol. 57, No. 11: 996.

DUCKS UNLIMITED

Ryan P. Heiniger
Director of Conservation Programs – MN/IA

10075 208TH STREET WEST • LAKEVILLE • MINNESOTA • (952) 469-0956 OFFICE • (952) 807-8769 MOBILE • www.ducks.org

February 12, 2008

Commissioner Mark Holsten
Department of Natural Resources
500 Lafayette Road
Saint Paul, Minnesota 55155

RE: Wild Rice Study Report

Dear Commissioner Holsten:

I am writing to express Ducks Unlimited's support for the recently completed wild rice report. Thanks to you and your staff for developing such a thorough document and set of recommendations. In particular, we are especially pleased with recommendations in the report that call for increased management, inventory, and stewardship of Minnesota's wild rice lakes and wetlands. Ducks Unlimited looks forward to helping your staff and other partners implement those recommendations in the coming years through our Living Lakes Initiative.

As with many of Minnesota's natural resources, wild rice habitat for waterfowl and other wildlife has been impacted and degraded due to changes to our land and waters. Due to the biological, cultural and economical values of wild rice, it is incumbent upon the state of Minnesota in collaboration with local stakeholders to invest new financial resources to protect and enhance the precious wild rice habitat that remains. Wild rice is one of the most important aquatic plants to migratory waterfowl and it is also critically important to other game and non-game wildlife species.

Since 2001, Ducks Unlimited has worked in partnership with the Minnesota Department of Natural Resources to assess, enhance, manage, and protect over 100 wild rice lakes annually throughout northern Minnesota. Grants from the Minnesota Environment & Natural Resource Trust Fund as recommended by the Legislative-Citizen Commission on Minnesota Resources have also provided important funding to both improve wild rice lakes and protect their shoreline through conservation easements.

DU was pleased provide input during the development of the wild rice study and we support the final report the DNR developed for the legislature. Please advise us of any opportunities to provide further support regarding this important wetland and shallow lake conservation issue.

Sincerely,

Ryan Heiniger
Director of Conservation Programs – MN/IA

Cc: Dave Schad, Dennis Simon, Ray Norrgard, & Nicole Hansel-Welch
Jon Schneider & Rod Ustipak

LEADER IN WETLANDS CONSERVATION

DU#Q0016H

United States Department of the Interior

FISH AND WILDLIFE SERVICE
Tamarac National Wildlife Refuge
35704 County Highway 26
Rochert, Minnesota 56578-9638
Phone: 218/847-2641 Fax: 218/847-9141

TMC-08-003

February 15, 2008

Ray Norrgard
Wetland Wildlife Program Leader
Minnesota Department of Natural Resources
500 Lafayette Rd.
St. Paul, MN 55155-4020

Subject: **Wild Rice Study document "Natural Wild Rice in Minnesota."**

Dear Mr Norrgard:

This is a letter of endorsement for the above mentioned document and for the document development process. The U.S. Fish and Wildlife Service (Service) has long recognized the ecological importance of natural wild rice stands and associated wetlands. The establishment of National Wildlife Refuges, such as Tamarac and Rice Lake, for the purpose of managing these wetland habitats for the benefit of migrating and resident wildlife is evidence of this appreciation. This study, which provides exceptional background information on the importance of natural wild rice as well as identifies potential threats and management challenges, will be extremely useful in the continued management of this critical resource. Additionally, the process fostered a close working relationship between State, Tribal and Federal governments, university researchers, non-government organizations and well as interested citizens. This collaborative effort is essential to insuring the abundance of natural wild rice for future generations.

Thank you for the opportunity to participate in this process and provide comments.

Sincerely,

Barbara Boyle

Barbara Boyle
Refuge Manager

MINNESOTA POLLUTION CONTROL AGENCY

Sampling and Analytical Methods for Wild Rice Waters

July 2017

Environmental Analysis and Outcomes Division

The analytical methods and sampling procedures provided in this document are incorporated by reference in Minn. R. pt. 7050.0224. They apply to the analysis and sampling of sediment and sediment porewater for purposes of implementing the sulfate water quality standard applicable to wild rice waters.

Table of Contents

Sediment sampling procedure for wild rice waters

Background

The Minnesota Pollution Control Agency has developed these procedures to ensure that samples taken for the purposes of establishing the sulfate standard to protect wild rice (Minn. R. 7050.0224) are accurate. The sulfate standard is an equation that calculates a sulfate concentration necessary to maintain a sulfide concentrations in sediment less than or equal to 120 µg/L (0.120 mg/L). The standard uses measured sediment concentrations of total organic carbon (TOC) and total extractable iron (TEFe) in the calculation of the protective sulfate concentration. This procedure establishes the methodology that must be used to collect sediment samples in wild rice waters.

The terms used in this document have the following meanings.

- Wild rice water is the entire WID identified in Minn. R. 7050.0471.
- Wild rice habitat identifier describes the type of information available to identify observed or potential wild rice habitat within a wild rice water.
- Sediment sample area is an identified portion of the wild rice water containing wild rice habitat.
- Transect is a straight line across the sediment sample area along which sediment cores are obtained.
- Core sample site is the location along a transect where an individual sediment core is taken.

1. Identify areas of wild rice habitat

The first step is to identify areas within the wild rice water where wild rice is growing or may grow. The entire wild rice water must be evaluated to determine areas of wild rice habitat.

On a map or aerial photograph of the wild rice water, outline the areas of wild rice habitat and identify them with one of the following wild rice habitat identifiers.

1. Areas where wild rice is observed or where there is evidence of wild rice, such as rooted wild rice plants that have been grazed or wild rice plant residue from previous year's growth.
2. Areas where information accurately identifies the past location of wild rice beds. Examples of acceptable information are plant surveys, sampling events, or historical records where the location of wild rice beds can be accurately determined.
3. Areas with yellow or white waterlilies (*Nuphar variegata* and *Nymphaea odorata*) where the water depth is less than 120 cm*.

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* Where a depth defines a habitat, that depth is based on average conditions, i.e., where water is at or below the ordinary high water level, but not at levels typical of flood or drought conditions. If sampling occurs during high or low water conditions, the sampler must determine if the sediment sample area would normally meet the depth criteria.

4. Areas with either floating-leaved plants or emergent plants where water depth is less than 120 cm* (excluding species that form dense monocultures that exclude wild rice, such as cattails (*Typha* species), phragmites *(Phragmites australis*), purple loosestrife (*Lythrum salicaria*), and reed canary grass (*Phalaris arundinacea*)). Examples of the types of floating-leaved or emergent plants that will approximate the conditions for wild rice growth are pondweeds (*Potamogeton* species), watershield (*Brasenia schreberi*), pickerelweed (*Pontederia cordata*), and arrowhead (*Sagittaria latifolia*).
5. Areas where satellite or aerial photographs indicate the past presence of floating-leaved or emergent plants where the water depth is less than 120 cm*.
6. Areas where water depth is between 30 and 120 cm*.

2. Selection of sediment sample areas

The second step is to select sediment sample areas from the areas of wild rice habitat identified in section 1.

Select five representative sediment sample areas based on the following decision framework:

- If the wild rice water contains areas with wild rice habitat identifier #1, all sediment sample areas must be in the #1 areas.
    - If there are at least five separate areas with wild rice habitat identifier #1, five separate areas must be selected.
    - If there are fewer than five separate areas with wild rice habitat identifier #1, the largest areas must be divided to establish five sediment sample areas.
    - If the areas of wild rice habitat #1 are very small or of a very limited number, (e.g. one small bed) all sediment sample areas must be selected in those areas unless it is not possible to obtain the required sediment cores from those areas. In those cases, if there is documentation that wild rice was present in other areas (wild rice habitat identifier #2) those areas may be sampled to provide a total of five sediment sample areas.
- If the wild rice water does not have any areas with wild rice habitat identifier #1, all sediment sample areas must be selected based on the next highest level of wild rice habitat identifier (#s 2, 3, 4, 5, or 6).
    - If there are at least five separate areas with the highest level of wild rice habitat, those areas must be selected as sediment sample areas.
    - If there are fewer than five separate areas with the highest level of wild rice habitat identifier, the largest areas must be divided to establish five separate sample areas with the highest priority wild rice habitat identifier.
    - If the areas of the highest wild rice habitat are very small or of a very limited number, so that it is not possible to obtain the required sediment cores from those areas, additional sediment sample areas can be established in areas with the next highest priority wild rice habitat identifier.

Identify the each sample area as (A) through (E) and record the wild rice habitat number that most closely corresponds to each sampling area.

3. Identify Sampling Transects

The third step is to establish one sampling transect within each of the five identified sediment sample areas. The transect must be

- A straight line across the sediment sample area; and
- Perpendicular to the shore, unless the area is an island of habitat that is far from any shore;

Identify the approximate location of each transect within each sediment sample area on the map or aerial photograph of the wild rice water.

4. Sediment Sample Collection and Processing

The fourth step is to collect the sediment samples. Within each transect, five sediment cores must be collected and composited for analysis.

Collect and composite the sediment samples from each of the five transects using the following procedures:

1. Collect five sediment cores within each transect. To the extent possible, cores must be equally spaced across the entire transect. However, transects that cross areas that do not meet the habitat description (e.g., an area of a #1 sediment sample area where there is no wild rice or evidence of wild rice, or an area of a #3 sediment sample area that is more than 120 cm deep) should apportion the 5 sediment coring sites to the areas that correspond to the habitat description.
2. Record the latitude and longitude coordinates for the first and last core site of each transect. If the coring sites are more than 100 feet apart, record the latitude and longitude at each coring site. Record the coordinates in the format of Sediment sample area, core number (e.g., A1, A2, A3, A4, A5, B1, B2, etc.).
3. Collect each sediment core from the top 10 centimeters of the sediment. Use the same diameter core tube for all cores collected.
4. Place the 10-cm long core into a clean container.
5. Repeat for each of the five cores collected from the transect.
6. Thoroughly mix all five sediment cores together. Discard any large plant or rock material.
7. After mixing, remove a sample of approximately 0.2 L and place into an appropriately labelled sample container.

5. Data Reporting

In the report of the sample data, include:

1. The map or aerial photograph of the wild rice water, marked with the areas of wild rice habitat (required in Step 1), location of the sample areas (required in Step 2) and transects (required in Step 3);
2. The latitude and longitude of the ends of each transect, or the core site if the core sites are more than 100 feet apart; and
3. The wild rice habitat number that most closely corresponds to each sediment sample area.

Example Data Report of sediment samples

Wild Rice Water: Sediment samples and analysis

Sediment sampling date:

Field crew names:

Name of Wild Rice Water:

State of Minnesota ID for the waterbody:

		Location of transect ends, or each core site (if > 100 feet apart)			Sediment sample analytical results	
Sediment Sample Area (A-E)	Wild Rice Habitat Identifier (1-6)	Core Identifier	Latitude	Longitude	TOC	TEFe
A	#	A1				
		A2				
		A3				
		A4				
		A5				
B	#	B1				
		B2				
		B3				
		B4				
		B5				
C	#	C1				
		C2				
		C3				
		C4				
		C5				
D	#	D1				
		D2				
		D3				
		D4				
		D5				

Sediment Sample Area (A-E)	Wild Rice Habitat Identifier (1-6)	Location of transect ends, or each core site (if > 100 feet apart)			Sediment sample analytical results	
		Core Identifier	Latitude	Longitude	TOC	TEFe
E	#	E1				
		E2				
		E3				
		E4				
		E5				

Analytical method for the determination of total extractable iron in sediment

This document describes the methods for the preparation and analysis of sediment samples for total extractable iron (TEFe) for analysis by Inductively Coupled Plasma-Atomic Emission Spectrometry Spectroscopy.

1. Prior to analysis, store the samples at ≤ 6° C to minimize biological activity. Samples must be analyzed within 180 days of collection date.
2. Dry and prepare the sample using either procedure 2a or 2b:
   - 2a.
     - Manually remove large materials such as rocks, shells, and sticks
     - Dry the sample in an oven at 50° C until constant weight is achieved.
     - Manually break the dried sample into pieces.
     - Pulverize the dry sample using a mill.
   - 2b.
     - Freeze-dry the sample.
     - Homogenize the sample using a stainless steel spatula.
     - Remove remaining large materials such as rocks, shells, and sticks.
3. After the sample has been prepared, digest a small aliquot of the sample (0.25 +/- 0.02 grams) and all necessary QC samples by adding 25 mL of 0.5 N hydrochloric acid to all digestion tubes. Digest samples (and all necessary QC samples) on a hot block at 80-85° C or in a water bath at 80-85° C. Once samples reach 80° C, digest samples for 30 additional minutes. After 30 minutes, remove samples immediately and cool to room temperature, and bring to a constant volume. Immediately either centrifuge the tubes at 1000 rpm for 10 minutes or filter using a 0.45 µm PES-type filter. Remove an aliquot and dilute with reagent water to known volume for iron analysis. Determine iron in the diluted aliquot using Inductively Coupled Plasma-Atomic Emission Spectrometry. Report the results in mg/kg (dry weight).
4. Acceptable performance must be demonstrated on an ongoing basis. With every digestion batch, the laboratory must perform the following:
   - Low Background: At the beginning of each batch, analyze a blank (BLK) to determine reagent or laboratory contamination. The background level of the BLK must be below the report level before samples are analyzed.
   - Accuracy: With every batch of 20 samples processed as a group, analyze a Laboratory Control Sample (LCS). The LCS should be prepared at concentrations similar to those expected in the field samples and ideally at the same concentration used to prepare the matrix spike (MS). The acceptance criteria for recovery of the analyte in the LCS is 80 – 120%.
   - A MS must be prepared and analyzed with each batch of 20 samples processed as a group, or a minimum of 10% of the field samples analyzed, whichever is greater. The same solution used to

fortify the LCS is used to fortify the MS. The acceptance criteria for recovery of the analyte in the MS is 80 – 120%.

- Precision: Analyze a Laboratory Duplicate (DUP) with each batch of field samples processed as a group, or 10% of the field samples analyzed, whichever is greater. The acceptance criteria for the relative percent difference is ≤ 20%.

Analytical method for the determination of total organic carbon in sediment

This document describes the methods for the preparation and analysis of sediment samples for the analysis of Total Organic Carbon (TOC) by Non-Dispersive Infrared Detection.

1. Prior to analysis, store the samples at ≤ 6° C to minimize biological activity. Samples must be analyzed within 28 days of collection date.
2. Dry and prepare the sample using either procedure 2a or 2b:
    - 2a. Manually remove large materials such as rocks, shells, and sticks.
        - Dry the sediment sample in an oven at 50° C until sample is completely dried.
        - Manually break the dried sample into pieces.
        - Pulverize the remaining dry sediment using a mill.
    - 2b. Freeze-dry the sample.
        - Homogenize the material using a stainless steel spatula,
        - Remove remaining large materials such as rocks, shells and sticks.
3. After the sample has been prepared:
    - Treat an aliquot of the homogenized sample with a 5% solution of H_3PO_4 to remove any inorganic carbon.
    - Either air-dry or oven-dry (at 105°C) the sample until constant weight is achieved.
    - Analyze the sample (and all necessary QC samples) for Total Organic Carbon content using a Standard Operating Procedure based on EPA Method 9060A.
    - Analyze all environmental samples in duplicate.
    - Report the results in mg C/kg dry sediment, and as percent C in dry sediment.
4. Acceptable performance must be determined for every digestion batch by performing the following activities:
    - Low Background: At the beginning of each batch, analyze a blank (BLK) to determine reagent or laboratory contamination. The background level of the BLK must be below the report level before analyzing samples.
    - Accuracy: With every batch of 20 samples processed, analyze a Laboratory Control Sample (LCS). The LCS must prepared at the same concentrations as the field samples and at the same concentration used to prepare the matrix spike (MS). The acceptance criteria for recovery of the analyte in the LCS is 70 – 130%.

      Prepare and analyze a MS with every 20 samples processed as a group, or a minimum of 10% of the field samples analyzed, whichever is greater. The same solution used to fortify the LCS is used to fortify the MS. The acceptance criteria for recovery of the analyte in the MS is 70 – 130%.

- Precision: Analyze a Laboratory Duplicate or a MS duplicate with every 20 samples processed as a group, or 10% of the field samples analyzed, whichever is greater. The acceptance criteria for the relative percent difference (RPD) is ≤ 30%.
- Analyze every sample in duplicate. The RPD between duplicates must be ≤ 30%.

Porewater sampling and analytical method for the determination of sulfide

This document describes the methods for the sampling and analysis of sediment porewater samples for total dissolved sulfide in sediment porewater samples for analysis by the automated methylene blue method (Standard Methods 4500-S2 E. Gas Dialysis, Automated Methylene Blue Method).

1. Sample Locations:

Before conducting porewater analysis to determine an alternate sulfate standard, sediment in the water body must have been sampled as described in Sediment Sampling Procedure for Wild Rice Waters. Using the same locational data used for the previous sediment sampling, take ten sediment cores for porewater analysis as close as possible to the sediment sample points within each of the five previously established transects, according to the following table (which was established using a random number generator so that the porewater samples would represent the wild rice water).

Transect (a-e)	Sediment Composite sample #1	Sediment Composite sample #2	Sediment Composite sample #3	Sediment Composite sample #4	Sediment Composite sample #5
a	porewater		porewater		
b		porewater		porewater	
c	porewater			porewater	
d		porewater			porewater
e	porewater		porewater		

2. Sample Collection:

Sediment samples for porewater analysis must be taken from undisturbed sediment, preferably from a boat, with a sediment coring device with a 7 cm diameter core barrel.

- Obtain a 15-50 cm long sediment core with at least 10 cm of overlying water. Insert a piston at the bottom end of each core as it is retrieved.
- Keep the core upright and shaded prior to porewater sampling.
- Immobilize the core tube in a rack while on shore or on a suitable stable surface.

3. Porewater sampling:

- Porewater sampling must begin within 4 hours of collecting the sediment sample.
- Shortly before beginning porewater collection, extrude the overlying water from the top of the core sample.
- Extract porewater using a 10-cm long, 2.5 mm diameter, Rhizon™ filter with a mean pore size of 0.15 µm (Rhizon™ filter is available from Rhizosphere.com, Netherlands). Insert the Rhizon™ filter vertically into the core top and connect with a stainless steel needle and either PVC or

polyethylene tubing to a 125-mL evacuated serum bottle that had been capped with a 20-mm thick butyl rubber septum. Obtain a sample of no less than 15 mL of porewater, although 50 mL is preferable.

Before the needle is inserted into the sulfide sample bottle, using a second evacuated bottle, flush air from the Rhizon-tubing assembly with a small amount of sample porewater. As the porewater sample is collected, keep the top of the Rhizon within the wet sediment as the core subsides. The serum bottle must be preloaded with 0.2 mL of 2.0 N zinc acetate, 0.5 mL of 15 M sodium hydroxide, and a stir bar, flushed with a nitrogen atmosphere, evacuated, and preweighed.

4. Sample Analysis:

- Samples must be analyzed within 14 days of the collection date and must be stored at ≤ 6° C to minimize biological activity. At the laboratory, inject 5-6 mL of alkaline antioxidant reagent into each sample bottle through the septum with a Safety-Lok syringe and stir for at least 1 hour prior to subsampling for analysis.
- Sub-samples for analysis of sulfide should be withdrawn from the serum bottle without removing the septum, which preserves the sample for possible re-analysis. Analyze sulfide colorimetrically using a gas dialysis automated methylene blue method, with in-line acid distillation and NaOH trapping method (Standard Methods 4500-$S2^-$ Sulfide).
- Express the results as milligrams sulfide, as sulfur, per liter of porewater (with three significant figures).

5. Acceptable Performance:

Acceptable performance must be demonstrated on an ongoing basis. With every digestion batch, the laboratory must perform the following:

- Demonstration of Low Background: At the beginning of each batch, analyze a blank (BLK) to determine reagent or laboratory contamination. The background level of the BLK must be below the report level; otherwise, investigate and eliminate the source of the contamination before samples are analyzed.
- Accuracy: With every batch of 20 samples processed as a group, analyze a Laboratory Control Sample (LCS). Prepare the LCS at concentrations similar to those expected in the field samples and at the same concentration used to prepare the matrix spike (MS). The acceptance criteria for recovery of the analyte in the LCS is 80 – 120%.
- Prepare a MS is and analyze with each batch of 20 samples processed as a group, or a minimum of 10% of the field samples analyzed, whichever is greater. Use the same solution used to fortify the LCS to fortify the MS. The acceptance criteria for recovery of the analyte in the MS is 80 – 120%.
- Precision: Analyze a Laboratory Duplicate with each batch of field samples processed as a group, or 10% of the field samples analyzed, whichever is greater. The acceptance criteria for the relative percent difference (RPD) is ≤ 20%.

MINNESOTA POLLUTION CONTROL AGENCY

STATEMENT OF NEED AND REASONABLENESS

Amendment of the sulfate water quality standard applicable to wild rice and identification of wild rice waters.

Minn. R. chapters 7050 and 7053

Minnesota Pollution Control Agency

Environmental Analysis and Outcomes Division

July 2017

wq-rule4-15i

The *State Register* Notice of Hearing will be available on the MPCA's Public Notices website during the term of the public comment period:

Additional information about the availability of this Statement of Need and Reasonableness (SONAR), exhibits, and the proposed rule will be available during the public comment period on the MPCA's rulemaking website at https://www.pca.state.mn.us/water/protecting-wild rice-waters

Availability of Rulemaking Documents

Upon request, this Statement of Need and Reasonableness
can be made available in an alternative format, such as large print, Braille, or audio.
To make a request, contact Carol Nankivel at the Minnesota Pollution Control Agency,
Resource Management and Assistance Division,
520 Lafayette Road North, St. Paul, MN 55155-4194;
telephone 651-757-2597;
fax 651-297-8676; or email Carol.nankivel@state.mn.us.
TTY users may call the MPCA at 651-282-5332or 800-657-3864

Notice Regarding the Excerpted Language in this SONAR

The Minnesota Pollution Control Agency has excerpted language from the rules as proposed and included those excerpts in this SONAR at the point that the reasonableness of each change is discussed. These citations are to assist the reader in connecting the proposed changes with its justification. However, there may be slight discrepancies between the excerpted language and the rules as proposed. The MPCA intends that the rule language published in the *State Register* with the Notice of Hearing is the rule language that is justified in this Statement.

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Acronyms or abbreviations

Aquatic Plant Management	APM
Average wet weather design flow	AWWDF
Chapter	ch.
Clean Water Act	CWA
Clean Water Revolving Fund	CWRF
Code of Federal Regulations	CFR
commissioner	Commissioner of the MPCA
cfs	Cubic feet per second
Division of Waters	DOW
EC	Effective concentration
EPA	United States Environmental Protection Agency
HUC	Hydrologic Unit Code
Maximum design flow	mdf
Million gallons per day	MGD or mgd
Minnesota Rules	Minn. Rules
Minnesota Statutes	Minn. Stat.
Minnesota	MN
Minnesota Biological Service	MBS
Minnesota Department of Natural Resources	MDNR
Minnesota Department of Transportation	MnDOT
Minnesota Pollution Control Agency	MPCA
Multiple binary logistic regression	MBLR
Multiple linear regression	MLR
National Pollutant Discharge Elimination System/State Disposal System	NPDES/SDS
Public Land Survey	PLS
Request for Comments	RFC
Reverse Osmosis	RO
Section	§
Statement of Need and Reasonableness	Statement or SONAR

Structural Equation Model	SEM
Technical Support Document	TSD
Total Extractable Iron	TEFe
Total Organic Carbon	TOC
United States Department of Agriculture	USDA
United States Environmental Protection Agency	EPA
Water Quality Standard	WQS
Water quality based effluent limit	WQBEL
Wasteload allocation	WLA
Wastewater Treatment Plant	WWTP
Water Identification number	WID

1. Introduction

Wild rice is important in Minnesota- it is the state grain and it is a cultural/spiritual resource to the Dakota and Ojibwe people. Minnesota has recognized this importance and since 1973 has had a water quality standard to protect wild rice. The Minnesota Pollution Control Agency (MPCA) is proposing to amend the state water quality standards and the rules implementing those standards to protect wild rice from the impact of sulfate, so that wild rice can continue to be used as a food source by humans and wildlife. This Statement of Need and Reasonableness explains the MPCA's proposal.

A. Background and existing rules

Minnesota's water quality rules contain a unique water quality standard to protect wild rice from adverse impacts due to sulfate pollution. The standard is unique for several reasons:

- Wild rice is a resource currently specific to the upper Midwest;
- Wild rice plays a key spiritual and cultural role in Ojibwe, Dakota, and other tribal traditions; and
- It is very rare to have a water quality standard that protects a single species.

The federal Clean Water Act (CWA) requires states to designate beneficial uses for all water bodies (i.e. "waters") and develop water quality standards to protect each use. Water quality standards include one or more of several components:

- Beneficial uses — identification of how people, aquatic communities, and wildlife use waters.
- Numeric standards — typically the allowable concentrations of specific chemicals in a water body established to protect beneficial uses. Can also include measures of biological health.
- Narrative standards — statements of unacceptable conditions in and on the water.
- Antidegradation protections — extra protection for high-quality or unique waters and existing uses.

Minn. Rules ch. 7050 assigns a series of beneficial use classifications to all waters of the state. These use classifications set out the beneficial uses that apply to Minnesota waters. Water use classifications, and their accompanying narrative and numeric standards and antidegradation provisions, make up the state's set of water quality standards. Aquatic life and recreation, industrial uses, agriculture and wildlife, and domestic consumption are some of the beneficial uses that these standards protect. Although there is a lot of commonality among the beneficial uses established by states – for example, every state designates and protects drinking water as a beneficial use – states may also set beneficial uses that reflect the unique nature of their waters and aquatic resources. In Minnesota, the wild rice resource is protected with a unique water quality standard.

The MPCA established the wild rice beneficial use and sulfate standard to protect that beneficial use in 1973. Minn. R. 7050.0224, subpart 2. The sulfate standard was based on research done in the 1930s and 1940s that found that higher levels of sulfate in water correlated with reduced presence of wild rice. The standard was included in the Class 4 beneficial use class that consists of waters protected for use in agriculture and by wildlife. Wild rice was included as part of Class 4A, which requires water quality sufficient to allow for use "without significant damage or adverse effects upon any crops or vegetation usually grown in the waters or area." The numeric standard was set at a 10 mg/L of sulfate applicable to "water used for production of wild rice during periods when the rice may be susceptible to damage by high sulfate levels." The narrative standard was established as "the quality of these waters and the aquatic habitat necessary to support the propagation and maintenance of wild rice plant species must not be materially impaired or degraded."

Over time, the MPCA has received questions about whether the 10 mg/L sulfate standard was necessary and how it should be implemented. Questions were raised as to exactly what constitutes "water used for production of wild rice," and when and where the standard applies. Largely in response to these concerns, and as described below, the Minnesota legislature in 2011 directed the MPCA to undertake further study and, as necessary, revise the wild rice standard. This rulemaking is the result of that direction.

B. Summary of proposed revisions

In revising the wild rice standard, the MPCA has three main goals. These are to: 1) revise the numeric standard to incorporate the latest scientific understanding of the impacts of sulfate; 2) clarify the beneficial use and which waters support the beneficial use; and 3) clarify what it means to meet or exceed the standard.

In order to revise the numeric standard, the MPCA conducted extensive research and obtained information and advice from a number of sources regarding the effect of sulfate on wild rice. Based on this research, the MPCA has concluded that the formation of sulfide, a sulfur compound related to sulfate, in the porewater[1] of the sediment where wild rice grows has deleterious impacts on wild rice. The MPCA has also determined that sulfide concentration is a function of the level of sulfate in the overlying water, and the concentrations of carbon and iron in the sediment. Based on these scientific conclusions, the MPCA has identified a protective sulfide level in the porewater and an equation that derives a protective sulfate value in the surface water based on the iron and carbon levels.

The revisions clarify the wild rice beneficial use, set out requirements for determining the inputs to the equation, and establish other requirements to provide for more effective implementation of the standard.

In order to identify the waters that support the beneficial use, the MPCA reviewed a number of sources to identify those waters where there is a demonstrated harvest of the wild rice by humans or evidence of use of the grain as a food source by wildlife. After reviewing these sources, the MPCA developed a list of waters where the beneficial use is an existing use and needs to be protected. The proposed rules identify these waters as wild rice waters. This list replaces the current "water used for production of wild rice" descriptor, which has only ever been assigned on a case-by-case basis.

[1] Porewater is the water present in saturated sediment between the solid particles of mineral and organic matter.

The revisions also describe the magnitude, duration and frequency that will constitute an exceedance of the sulfate standard.

The MPCA's Technical Support Document (TSD) (Exhibit 1) for this rulemaking provides the detailed scientific technical analysis supporting the rule revisions and is extensively referred to throughout this document.

C. Legislative mandate to adopt rules

In 2011, the Minnesota Legislature provided the MPCA with a $1.5 million appropriation from the Clean Water Fund to conduct a Wild Rice Sulfate Standard Study to gather additional information about the effects of sulfate and other substances on the growth of wild rice. The Legislature also directed the MPCA to undertake rulemaking to identify wild rice waters and to make any other needed changes to the standards following completion of the study.

The legislation also directed the MPCA to:

- Create an advisory group comprising representatives of tribal governments and a variety of stakeholders to provide input on the research and the development of future rule amendments; and
- Establish criteria for waters containing natural beds of wild rice after consulting Minnesota tribes, the Minnesota Department of Natural Resources (MDNR) and stakeholders.

Attachment 1 contains all the legislation related to this wild rice rulemaking and the legislative directions.

D. Description of the proposed revisions

Clarification of the existing sulfate standard and the existing wild rice beneficial use

The existing wild rice standards, found in Minn. R. 7050.0224, consist of a narrative standard in subpart 1 applicable to selected wild rice waters specifically identified in rule, and a numeric standard in subpart 2 that establishes a sulfate standard applicable to "water used for production of wild rice." In Minn. R. 7050.0224, subpart 1, the beneficial use of wild rice is described as "the harvest and use of grains from this plant serve as a food source for wildlife and humans." In amending the wild rice standard, the MPCA proposes to:

- Replace the numeric sulfate standard currently in subpart 2;
- Clarify where the numeric sulfate standard applies;
- Keep the beneficial use substantially the same; and
- Retain the narrative standard and its application to selected wild rice waters as is (though moving the location of the narrative standard within Minn. R. 7050.0224).

The proposed revisions specifically identify each water to which the numeric sulfate standard is applicable, eliminating the existing phrase "water used for production of wild rice," which resulted in the need for case-by-case determination of whether a water body met the definition. Similarly, the proposed revisions retain the list of selected wild rice waters, designated [WR], where the narrative standard applies, and the use but restates the use protected to improve grammatical expression. The beneficial use remains the use of the wild rice grain as a food source for wildlife and humans.

Numeric sulfate standard

Equation

The proposed revisions replace the existing 10 mg/L numeric sulfate standard with an equation that translates a protective concentration of sulfide in the sediment porewater to a calculated sulfate concentration in the overlying water that will be protective of wild rice in that particular wild rice water. The MPCA's research and data analysis show that the pollutant that adversely affects wild rice is not sulfate in the water, but rather sulfide in the sediment porewater. The MPCA has determined that if sulfide does not exceed a level of 120 µg/L (120 micrograms per liter) in sediment porewater, the wild rice beneficial use is protected. The amount of sulfide produced is a factor of sulfate in the water, total extractable iron (TEFe) in the sediment, and total organic carbon (TOC) in the sediment. The proposed equation recognizes that relationship and derives a protective level of sulfate in water in relation to the concentrations of sediment iron and organic carbon. Application of the equation results in a water body-specific calculated numeric sulfate standard that keeps sulfide below harmful levels in the porewater.

Because of the relationship between sulfate in the water, sulfide in the porewater, and iron and carbon in the sediment, an equation is the most accurate approach to protecting wild rice. Compared to a fixed sulfate standard, an equation results in fewer waters where the required sulfate levels will be either over-protective (more stringent than needed to protect wild rice) or under-protective (not sufficiently stringent to protect wild rice). To implement this standard, the sediment of each identified wild rice water must be sampled for organic carbon and iron, and a numeric standard calculated using the equation.

Alternate standard

As an alternative to the equation-derived numeric standard, the proposed rule allows the commissioner to establish an alternate standard based on the actual amount of sulfide in the sediment porewater. The equation-based numeric standard is designed for the vast majority of water bodies, where changes in the porewater sulfide concentration is proportional to changes in sulfate in surface water. An alternate standard may be appropriate when the sulfide in the sediment porewater is being controlled by sulfate in the groundwater, rather than surface water. The MPCA is also proposing to adopt porewater sampling and analytical procedures that will be the basis for establishing an alternate standard.

List of waters

The proposed revisions specifically identify wild rice waters where the standard applies. Wild rice waters are the lakes, reservoirs, rivers, streams, and wetlands where the MPCA has concluded that the wild rice beneficial use has existed since November 28, 1975.[2] The MPCA reviewed numerous sources of information to determine which waters currently meet or formerly met the wild rice beneficial use. The proposed list includes approximately 1,300 waters identified by a water identification number. The proposed rules identify the wild rice waters in each watershed. The proposed wild rice waters are shown in Attachment 2. When the rules are adopted, lists of the identified waters and interactive maps to locate wild rice waters will be available on the MPCA's webpage.

Applying and implementing the standard

To further improve clarity of the rule and provide for more effective implementation, the proposed revisions also provide additional information that defines how the standard will be applied.

In general, numeric water quality standards (also called numeric water quality criteria) include three components: magnitude, duration, and frequency.[3] The number itself is the magnitude, the averaging time of the standard is the duration, and the frequency is how often the magnitude may be exceeded before the standard is considered to be violated. The current wild rice sulfate standard sets a very clear magnitude (10 mg/L). However, it is vague about the duration of the standard ("during periods when the rice may be susceptible to damage by high sulfate levels") and does not speak to the frequency of the standard. The proposed revisions specify a magnitude, define the duration as an annual average, and set a one in ten-year frequency.

The proposal also includes:

- Changes to Minn. R. ch. 7053 to define the flow conditions the MPCA will use to set effluent limits for sulfate.
- A mechanism for the commissioner to determine, via a public process, that a facility does not require a sulfate effluent limit if its discharge cannot impact the wild rice beneficial use in the water body receiving the discharge.
- A reference to the procedures for applying for a variance from the water quality standard, and a waiver of the fee for municipalities that apply for variances.

Future identification of additional wild rice waters and inclusion in rule

The definition of a wild rice water requires that wild rice waters must be identified in Minn. R. 7050.0471; therefore, the standard does not apply until a water is specifically identified in rule. The MPCA recognizes that due to the lack of comprehensive information about wild rice in Minnesota, additional water bodies may be identified as appropriate for likely inclusion in the rule, based on later provided or developed evidence of the wild rice beneficial use. In order to promote public input and discussion about adding wild rice waters to the rule, the proposal requires the commissioner to solicit

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[2] November 28, 1975, is a key date in the CWA. Any beneficial use that a water body actually attained on or since that date is an existing use, and water quality should be such as to ensure that existing use is maintained.

[3] See EPA's Water Quality Handbook, Chapter 3 (https://www.epa.gov/wqs-tech/water-quality-standards-handbook) for more information on magnitude, duration, and frequency.

evidence supporting identifying additional wild rice waters during each "triennial review." The "triennial review" is the process by which the MPCA reviews and takes public comment on any needed changes to the state's water quality standards. The triennial review is required by the CWA and informs what changes to water quality standards proceed to rulemaking.

The proposal identifies the evidence that should be submitted by persons who wish to demonstrate the existing wild rice beneficial use in a water body not presently identified as a wild rice water in 7050.0471. This evidence may include a showing of past or current human harvest of wild rice, the presence of at least two acres of wild rice in a water body, or other evidence that shows that the water body supports or since November 28, 1975, has supported the beneficial use. The proposal also provides examples of types of evidence that may be used. These include but are not limited to written or oral histories, other written records, photographs, or field surveys.

Documents incorporated by reference

It is a standard practice to incorporate documents by reference into the rule when they are either too large to conveniently present as rule language or when they are of specific but limited application. Documents incorporated by reference have the full effect of the rule and, once adopted, cannot be changed without future rulemaking (Minn. Stat. § 14.7, subd.4.) The MPCA is incorporating two documents by reference in this rulemaking: the sampling and analytical procedures and a document to support the economic review of variance requests.

E. MPCA rule development activities

The MPCA's major rule development activities around the wild rice sulfate standard began in response to a 2010 rulemaking petition from the Minnesota Chamber of Commerce (Exhibit 3) that requested the MPCA to convene a group to develop a research protocol to support future wild rice rulemaking. The 2011 Legislature also directed the MPCA to conduct specific activities related to wild rice. Rule development activities and outreach have been extensive, as the MPCA has moved from study and research to rule drafting.

In response to the 2011 legislation, the MPCA undertook the Wild Rice Sulfate Standard Study and convened an Advisory Committee to:

- Provide input on a protocol for scientific research to assess the impacts of sulfate and other substances on the growth of wild rice;
- Review research results; and
- Provide other advice throughout the development of rule revisions to protect wild rice.

Because of the great cultural importance of wild rice to the Ojibwe and Dakota people, the MPCA has made special effort to communicate with Minnesota tribes on this issue. The MPCA's tribal communications have included four formal government-to-government consultations, tribal representation on the Wild Rice Advisory Committee, and many discussions between MPCA and tribal staff.

In 2011, the MPCA convened researchers and the Wild Rice Advisory Committee to provide input on research protocol. Following the completion of the Wild Rice Sulfate Standard Study in December 2013, (Exhibit 4) the MPCA reviewed the results and developed a preliminary analysis of the research, which was shared in March 2014 (Exhibit 5). The MPCA met with Minnesota tribes, the Advisory Committee, EPA, and others to hear their comments on the preliminary analysis, and continued to refine the analysis of the research based on comments received, review of additional literature, and additional statistical analyses. The result of this effort was completion of the Analysis of the Wild Rice Sulfate Standard Study — Draft for Scientific Peer Review in June 2014. (Exhibit 6)

The MPCA then contracted with Eastern Research Group, Inc. (ERG) to convene and facilitate an independent scientific peer review of the study and analysis, which culminated in a meeting in St. Paul, Minnesota on August 13-14, 2014, and completion of a Peer Review Report in September 2014. The charge, purpose, and process for the peer review, and a summary report of the meeting are provided as Exhibits 7, 8, and 9. Details, background documents, and additional information relating to the scientific peer review process can be found on the MPCA's wild rice sulfate standard webpage (https://www.pca.state.mn.us/water/wild rice-sulfate-standard-study).

The MPCA refined its analysis based on the peer review and tribal and Wild Rice Advisory Committee feedback, and in March 2015 released a Draft Proposal for Protecting Wild Rice from Excess Sulfate (Exhibit 10). The Draft Proposal included:

- A proposed draft approach to the wild rice water quality standard;
- A draft list of waters where thewild rice beneficial use is an existing use; and
- Draft criteria for adding waters to the list over time as new or additional information becomes available.

The MPCA shared the Draft Proposal with the Wild Rice Advisory Committee, tribes, and a wide group of stakeholders via a news conference and the MPCA's GovDelivery mailing list of more than 2,000 people who had registered their interest in this topic. The MPCA also briefed the MDNR management and staff and interested legislators.

Publishing a Request for Comments (RFC) is a legal requirement of the Administrative Procedures Act (Minn. Stat. ch. 14) and the MPCA published an RFC on October 26, 2015. (Exhibit 11) The RFC requested comments and information about the wild rice sulfate standard rulemaking and provided notice about the MPCA's March 2015 Draft Proposal. The MPCA received and reviewed more than 600 comment letters in response to the RFC and posted them on the wild rice rulemaking webpage for public review.

As a result of comments and questions received following release of the March 2015 Draft Proposal and the RFC, the MPCA re-analyzed data from the studies using different statistical approaches. The re-analysis included review of the following:

- Field survey data used to relate wild rice presence to sulfide in the sediment;
- Field survey data that relate sulfate to sulfide;
- Basic assumptions relating sulfate to wild rice;

- Choice of which data set of sites from 2011-2013 field work would be most appropriate to use in analyses;
- Variables controlling conversion of sulfate to sulfide; and
- Additional research conducted by others on wild rice sulfate and sulfide since the completion of the MPCA's study.

The MPCA developed a Draft Technical Support Document (Exhibit 12) that presented the results of its research and analysis of the data and released it for public review on July 19, 2016. After receiving extensive comments, and as a result of its own reassessment of the data, the MPCA revised the draft TSD. The MPCA also considered additional research that was completed after the draft TSD was released. The revised final TSD, (Exhibit 1), is a major element in support of the proposed rule revisions and the MPCA's justification provided in this Statement.

Preliminary draft rules (Exhibit 13) and a preliminary draft of the discussion of costs (Exhibit 14) were presented to the Wild Rice Advisory Committee and Tribes in December 2016. The MPCA has made changes to both the preliminary draft rules and to the Regulatory Analysis part of this Statement in response to their comments.

2. Statement of General Need

Minnesota Statutes (Minn. Stat.) § 14.131 requires the MPCA to prepare and make available for public review a statement of the need for proposed rules. Minnesota has extensive water resources and a longstanding cultural and political commitment to the preservation of those resources. The water quality standards established in rule are a crucial piece of the regulatory structure that protects Minnesota's water resources. The fundamental need for any revisions to the water quality standards is the need to incorporate new/refined scientific understanding and maintain a regulatory structure that will continue to ensure the protection of Minnesota's water resources.

A. Need to protect the wild rice resource

Wild rice is an important plant species in Minnesota. Wild rice provides food for humans and waterfowl and is economically important to many who harvest and market it. Wild rice is a significant and sacred cultural resource to the Ojibwe and Dakota people. Wild rice is part of the Ojibwe migration story, and Ojibwe and others have gathered wild rice for generations. Since 1973, Minnesota has had a sulfate water quality standard to protect "water used for production of wild rice." In 1977, the Minnesota legislature designated wild rice as the state grain. Given the importance of the wild rice grain to Minnesotans and the completion of recent scientific studies regarding the effects of sulfate and other substances on wild rice, the MPCA finds there is a need to:

- revise the existing standard to provide the most effective protection for the wild rice grain from sulfate-related impacts, and
- clarify implementation of the standard.

B. Need to revise the standard to reflect current scientific understanding of sulfate/sulfide

The level of understanding of pollutants and the nature of their impact on aquatic communities improves over time. Scientific observation of the presence of wild rice in waters with lower sulfate levels, and its absence in waters with elevated sulfate, led to the adoption of the wild rice sulfate standard in 1973. Although many of the underlying observations on which the standard is based are still valid, the scientific understanding of the chemistry of sulfate in the environment and the mechanisms by which it affects wild rice has greatly improved.

When questions about implementation of the current standard arose in the 2000s, the MPCA decided to undertake a review of the existing standard. Following an initial evaluation of the scientific literature in 2010, the MPCA determined that it needed additional studies to better understand the effects of sulfate and other substances on the growth of wild rice and determine the appropriateness of the standard and its implementation. The Minnesota Legislature funded these studies, which were conducted by researchers at the University of Minnesota under contract with the MPCA. Following completion of the studies, the MPCA produced a preliminary analysis of the study data. In 2014, this preliminary analysis went through a peer review process. The MPCA has since worked to refine the analysis in response to comments so that the proposed rule revisions reflect the best current scientific understanding about sulfate and wild rice.

C. Need to clarify the wild rice beneficial use and where it applies

The existing Class 4 sulfate standard in Minn. R. 7050.0224, subpart 2 is applicable to "water used for production of wild rice during periods when the rice may be susceptible to damage by high sulfate levels." When the sulfate standard was proposed in 1973, it was originally proposed to apply to all waters. During the course of the rulemaking process the standard's application was limited to "water used for production of wild rice." No further description of the beneficial use was provided in the rules, nor were specific waters exhibiting the beneficial use identified.

In a subsequent 1998 rule amendment, the additional descriptor of "harvest and use of the grain from this plant serve as a food source for wildlife and humans" was added to Minn. R. 7050.0224, subpart 1 to describe the beneficial use. At that time, a narrative standard was also added to subpart 1 to apply to "selected wild rice waters" that were specifically listed in part 7050.0470, subpart 1.

Following the 1998 rulemaking, the phrase "production of wild rice" created confusion, as shown by comments that the MPCA received from tribes and many stakeholders. As explained in more detail in Part 6.C.1, the MPCA believes that the connotation of the word "production" has changed over time. The MPCA is proposing to eliminate this confusing term and instead identify specifically where the standard applies, i.e., to a "wild rice water" in order to protect the wild rice beneficial use. The MPCA is not proposing to change the beneficial use of wild rice, but is proposing to modify the phrase in order to more clearly articulate the recognized use. The MPCA is proposing to specifically identify the rivers, streams, lakes, and wetlands demonstrating this beneficial use in Minn. R. 7050.0471.

The MPCA will also make the information about wild rice waters available in an interactive tool that that can be viewed by basin, watershed, or county. The tool will also display information about the sources the MPCA used to demonstrate the beneficial use for each water.

D. Need to clarify the application of the sulfate standard

The proposed rule also clarifies when the numeric standard will be applied. Under current rule, the numeric standard applies "during periods when the rice may be susceptible to damage." The MPCA has generally interpreted this phrase as meaning the standard applies only during the wild rice growing season. The current scientific understanding is that sulfide in the porewater affects wild rice health and that the creation of this sulfide occurs throughout the year. Based on this understanding, the MPCA now finds that the phrase "periods when the rice may be susceptible" is no longer scientifically supported. Essentially, wild rice is susceptible at all times. The proposed revisions therefore eliminate that applicability condition.

The proposed revisions provide additional clarity around the "duration" and "frequency" of the standard (the averaging time, and whether the standard can ever be exceeded). These components were not specified in the original standard, but are important for effective implementation.

E. Need for a process to address wild rice waters identified in the future

The MPCA has used the best information and inventories available to identify those waters that display the wild rice beneficial use to which the sulfate standard applies. However, the MPCA recognizes that additional water bodies may be later identified as wild rice waters. Therefore, the MPCA anticipates that it will conduct future rulemaking to add wild rice waters as the needed information to do so becomes available. In addition, restoration efforts may, and hopefully will, lead to the re-establishment of the beneficial use in some waters where it is not currently documented as existing on or after November 28, 1975.

The proposed revisions address those future rulemakings by requiring the commissioner to solicit information and evidence for adding waters during the triennial standards review process. This ensures that identifying and adding wild rice waters is a continual process. Proposals to amend the list of wild rice waters will be subject to State rulemaking procedures. To add additional wild rice waters, evidence that the proposed waters currently support or have supported the wild rice beneficial use since November 28, 1975 will be required. The MPCA is therefore identifying in this rule the evidence that would be considered to establish and support a reasonable basis to determine that a wild rice beneficial use exists in a future rulemaking. This evidence is similar to the types of evidence the MPCA used to create the list proposed in this rulemaking. This evidence includes a showing of past or current human harvest of wild rice, at least two acres of wild rice being present in a water body, or other evidence that shows the water body supports the wild rice beneficial use. The proposed rule also provides examples of other types of evidence that may be used. These include things like written or oral histories, other written records, photographs, field surveys, and other types of evidence. Including this language in the proposal satisfies the need to provide some clarity about how wild rice waters may be added in the future, without circumventing the requirement to demonstrate the need and reasonableness that would be part of subsequent rulemakings to add to the list of wild rice waters.

F. Need to address legislative mandates to undertake rulemaking

The MPCA has been mandated by legislation to undertake this rulemaking, including the identification of waters to which the standard applies.

Minnesota Laws, 2011, First Special Session, chapter 2, article 4, section 32 directed the MPCA to initiate a process to amend the state water quality standards to make any needed changes to Minnesota's water quality standard to protect wild rice. The legislative mandate also directed the MPCA to identify waters that need such protection and develop criteria for designating wild rice waters. The legislation noted criteria for designating wild rice waters must be based on the existence of natural stands of wild rice and include history of wild rice harvest, minimum acreage, and density.

In 2015, in Minnesota Laws 2015, First Special Session, chapter 4, article 4, section 136, the Legislature additionally directed the MPCA to, when amending the rules refining the wild rice water quality standard in Minn. R. 7050.0224, subpart2*, "consider all independent research and publicly funded research and to include criteria for identifying waters and a list of waters subject to the standard."*

The legislative directives are provided in Attachment 1 to this Statement.

G. Need to make supporting changes to Minnesota rules to facilitate development and implementation of effluent limits

The MPCA has identified certain changes necessary to support the implementation of the revised standard through permit effluent limits.

Minn. R. ch. 7053 establishes specific conditions relating to the implementation of water quality standards through effluent limits and facility discharge permits. Effluent limits restrict how much of a pollutant a facility can discharge into surface water and still be protective of a standard. The proposal makes several changes to Minn. R. ch. 7053, including:

- Establishing the flow rate for determining when a discharge has the "reasonable potential" to cause an exceedance of the standard and for calculating effluent limits for discharges to wild rice waters;
- Defining when an effluent limit may not be needed because of site-specific conditions; and
- Setting forth specific information about variances, which are temporary exemptions from agency rule or standard or from an effluent limit based on an agency rule or standard.

3. Scope of the Proposed Revisions

The following chapters of Minnesota Rules are affected by the proposed changes.

- Minn. R. ch. 7050. This chapter establishes the water quality standards for protection of waters of the state and also lists the waters that are subject to the particular standards, i.e., beneficial use classification of the waters.
- Minn. R. ch. 7053. This chapter establishes the effluent limit development and treatment requirements for discharges to waters of the state.

The MPCA does not propose to amend the rule to address factors affecting wild rice beyond sulfate. The legislative mandate for this rulemaking, the constraints of MPCA resources, and available data and information require the MPCA to limit the scope of this rulemaking to those changes that address the specific needs associated with revising the sulfate standard to protect the wild rice beneficial use. The proposed revisions specifically reflect this scope by including:

- The identification of a protective sulfide level;
- The equation for translating the protective sulfide level into a numeric sulfate standard and documents describing how data must be collected for the equation;
- The specific lakes, rivers, streams, and wetlands that are wild rice waters subject to the standard;
- The duration and frequency of the numeric sulfate standard; and
- Methods for implementing the sulfate standard in effluent limits.

Commenters have raised a number of concerns relating to specific aspects of this rulemaking, and to the protection of wild rice in general. Although these comments raise valid concerns, it is not possible to address every issue through this single rulemaking. Some may be outside the MPCA's regulatory authority and for others there is insufficient information on which to base agency action.

The MPCA considers the following issues to either be outside the scope of this rulemaking or has otherwise decided not to follow the suggestion for the reasons stated below.

1. Commenters suggested that the MPCA address the protection of wild rice through standards applied in the Class 2 aquatic life beneficial use classification, rather than the current Class 4 agriculture and wildlife beneficial use classification. The MPCA disagrees. As originally adopted and currently applicable, the wild rice beneficial use and sulfate standard are appropriately addressed in the Class 4 "agriculture and wildlife" standards. The MPCA is not proposing to change that classification to a Class 2 aquatic life use classification.

   The MPCA notes that all of the waters being proposed as wild rice waters are also protected as Class 2 waters and are protected by Class 2 standards.

2. Commenters suggested that the proposed revisions should expand the applicability of the existing Class 4 wild rice *narrative* standard to all of the wild rice waters identified in this rulemaking. When the MPCA originally added the narrative standard to the rules, it clearly limited the application of

the narrative standard to a subset of wild rice waters and specifically identified 24 [WR] waters as being in that subset. Although in that 1998 rulemaking the MPCA indicated that it intended to continue to expand the scope of the narrative standard by adding to that subset of wild rice waters through successive rulemakings, the MPCA has not yet done so and is not proposing to do so in this rulemaking. The scope of the rules the MPCA is proposing at this time is limited to revising the *numeric* sulfate standard and identifying the waters where the numeric sulfate standard applies. Expanding the application of the existing narrative standard is outside of the scope of this rulemaking. The MPCA notes that all of the [WR] waters subject to the narrative standard are also protected as wild rice waters to which the numeric standard applies.

3. Commenters suggested that the proposed revisions should address all the pollutants that affect wild rice. Adopting a sulfate standard based on sulfide impacts does not address other stressors of wild rice, such as invasive species or climate change, nor does it address other pollutants such as mercury or nutrients that may be affecting wild rice. The MPCA agrees that the proposed revisions do not address all potential stressors and pollutants that may affect wild rice. However, some of the factors that affect wild rice are not "pollutants" as typically considered by the CWA and Minn. R. ch. 7050. In other cases, sufficient technical/scientific information is not available or resources are not sufficient to analyze available information to establish magnitude, duration and frequency information for standards development.
4. Commenters suggested that the MPCA should revise certain of the other numeric and narrative standards in Class 4 to reflect current scientific information. The example cited was the need to provide a more specific standard for radioactive materials in Minn. R. 7050.0224, subparts 2, 3 and 4. The MPCA periodically evaluates and revises the water quality standards but revising standards other than the sulfate standard to protect wild rice is beyond the scope of this rulemaking.[4]
5. Commenters suggested that the rules establish criteria to identify a wild rice water without requiring future rulemaking. The comments suggest that instead of identifying specific lakes, rivers and streams, the rule either establish threshold levels to identify a water as a wild rice water, or specify the suitable habitat that would identify it as a wild rice water. The MPCA rejects this suggestion because it is contrary to the legislative criteria for this rulemaking, which include that the MPCA should "designate each body of water, or specific portion thereof, to which wild rice water quality standards apply." In addition, the MPCA finds that establishing thresholds or habitats would not be feasible because of the complexity of the conditions that promote the growth of wild rice.
6. Commenters have identified concerns that the rules do not address the economic or technological feasibility of meeting the calculated sulfate standard and have suggested that the MPCA base the standard on the Best Available Technology for treating sulfate in wastewater. While the MPCA

[4] *The MPCA currently conducts this process of identifying needs and prioritizing rulemaking activities through the triennial review process, which is a required component of the MPCA's delegation under the CWA.*

recognizes that meeting the standard will be difficult, under the CWA a water quality "standard" must be based on the use, and not on the feasibility of dischargers to control pollutants.

The permit process, through schedules of compliance, variances, and other tools, can take into consideration the cost and technical feasibility of treatment to meet an effluent limit based on the standard.

4. Background

A. Background of standards and water classification

It is important to have a basic understanding of Minnesota's water quality standards to understand the proposed revisions.

As required by the CWA § 303 and Minn. Stat. § 115.44, water quality standards form the fundamental regulatory foundation to preserve and restore the quality of all Waters of the State. Water quality standards include several components:

- Beneficial uses — identification of how people, aquatic communities, and wildlife use our Minnesota waters.
- Numeric standards — typically the allowable concentrations of specific chemicals in a water body, established to protect beneficial uses. Can also include measures of biological health.
- Narrative standards — statements of unacceptable conditions in and on the water.
- Antidegradation protections — extra protection for high-quality or unique waters and existing uses.

Assigning an appropriate beneficial use, and establishing numeric and narrative standards to protect the beneficial use, are responsibilities assigned to the MPCA by Minn. Stat. § 115.03 and Minn. Stat. § 115.44. The assigned beneficial use, and the applicable supporting numeric and narrative standards, are fundamental considerations in decisions relating to the establishment of discharge effluent limitations, implementation of antidegradation requirements and impaired water assessments, and other water quality management activities. Assigning the appropriate beneficial use is an important first step in the process of assuring that the goals for each water body are attainable and can be protected.

Beneficial use classifications

Minnesota has designated seven beneficial use classes associated with surface waters: Class 1 through Class 7 (Table 1).[5]

Table 1. Minnesota's beneficial uses for surface waters.

Use Class	Beneficial Use
Class 1	Domestic Consumption – drinking water protection (includes subclasses 1A, 1B, 1C)
Class 2	Aquatic life and recreation (includes subclasses 2A, 2B, 2C, 2D)
Class 3	Industrial use and cooling (includes subclasses 3A, 3B, 3C, 3D)
Class 4	Agriculture and wildlife (includes subclasses 4A, 4B, 4C)

[5] *The numbers 1 – 7 do not imply a priority ranking.*

Use Class	Beneficial Use
Class 5	Aesthetics and navigation
Class 6	Other uses
Class 7	Limited resource value waters

The water quality standards designate most waters of the state for multiple uses, such as Classes 2, 3, 4, 5 and 6. The only waters that do not also include a designation for the Class 2 beneficial use are waters that have had a use attainability analysis[6] (UAA) conducted and where the UAA demonstrates that the Class 2 beneficial uses cannot be attained due to specific factors set out in the CWA. These waters have a Class 7 designation.

Certain waters are specifically identified in Minn. R. 7050.0470 with their associated beneficial uses; these waters, while numerous, are only a fraction of the total number of waters in Minnesota. Examples of waters that are specifically listed include: cold waters, surface waters protected for drinking, outstanding resource value waters, and limited resource value waters. All waters not listed in Minn. R. 7050.0470 have a default designation of protection for aquatic life and recreation (Class 2), plus additional designations as one or more of Classes 3, 4, 5 and 6 (Minn. R. 7050.0430).

Numeric water quality standards

A numeric standard is the concentration of a pollutant or chemical allowable in water associated with a specific beneficial use. Both Minn. R. ch. 7050 and 7052 include numeric water quality standards. The standards in Minn. R. ch. 7050 apply statewide and the standards in Minn. R. ch. 7052 apply only to the waters in the Lake Superior basin. Numeric standards are specific and relevant to the protection of the beneficial use classification to which they apply.

There are numeric standards for most use classifications.

Narrative water quality standards

A narrative standard (also known as a narrative criterion) is a descriptive statement of the conditions to be maintained or avoided in or upon the water. For example, a narrative standard may state: "*there shall be no material increase in undesirable slime growths or aquatic plants, including algae...*"

Both narrative and numeric standards are fundamental benchmarks used to assess the quality of all surface waters. In general, if applicable numeric and narrative standards are met, the associated beneficial uses are protected.

[6] *A use attainability analysis is a structured scientific assessment of the factors affecting the attainment of **uses** specified in Section 101(a)(2) of the Clean Water Act (the so called "fishable/swimmable" **uses**).*

Antidegradation requirements

In addition to the water use classifications and the numeric and narrative standards, Minnesota's rules also provide water quality protection through antidegradation requirements. Minn. R. chs. 7050.0250 to 7050.0325 establish the State's antidegradation requirements.

Uses of water quality standards

Numeric and narrative water quality standards are used for a variety of purposes by the MPCA and outside parties. Outside parties that routinely use water quality standards include other State agencies; local government entities such as counties, cities and watershed districts; consulting firms; and environmental groups.

Primary uses of water quality standards are to:

- Protect beneficial uses;
- Assess the quality of the State's water resources;
- Identify waters that are polluted or impaired;
- Help establish priorities for the allocation of treatment resources and clean-up efforts; and
- Set effluent limits and treatment requirements for discharge permits and cleanup activities.

The MPCA is required to assess the water quality of rivers, streams, wetlands, and lakes in Minnesota (Code of Federal Regulations (CFR), title 40, part 130). Waters that do not meet water quality standards and do not fully support assigned beneficial uses are defined as "impaired." The MPCA identifies and reports impaired waters to the citizens of Minnesota and to EPA in the biennial CWA 305(b) report and the CWA 303(d) list. The water quality standards are essential to identify water bodies that do not fully support beneficial uses. For a more complete discussion of water quality standards see: http://www.pca.state.mn.us/qzqh1081.

It is important to explain the difference between the water quality standards and effluent limits. Water quality standards describe the conditions that must exist in the water body to fully support each beneficial use. Effluent limits must be set to ensure that a permitted facility will not cause or contribute to a violation of a standard and potential degradation of a use. Effluent limits are established by the MPCA and are specified in a discharger's National Pollutant Discharge Elimination System (NPDES) or State Disposal System (SDS) permit. They define the allowable concentration and mass (e.g., kilograms per day) of pollutants that can be discharged to the receiving water and be protective of the water quality standards.

B. History of the wild rice standard and establishment of the wild rice beneficial use

Minnesota's current wild rice sulfate standard is in the Class 4 use classification, which covers agricultural and wildlife uses. In a subdivision of Class 4A, Minnesota currently has a water quality standard of "10 mg/L sulfate - applicable to water used for production of wild rice during periods when the rice may be susceptible to damage by high sulfate levels." Minn. R. 7050.0224, subpart 2. In the existing rule, 10 mg/L is the numeric standard and "water used for production of wild rice" is where that standard applies. "Production of wild rice" can be inferred as the beneficial use.

The MPCA adopted the current wild rice sulfate standard in 1973. A review of testimony presented at public hearings during that rulemaking shows that the standard was intended to apply to waters with natural wild rice stands and to waters used for commercial cultivation of wild rice. The word "production" was widely used at the time to describe both the growth and harvesting of natural stands of wild rice and commercial cultivation (Edman, 1975).

The next set of wild rice-related rule amendments occurred in 1998 when the MPCA adopted new rules governing water quality standards for Great Lakes Initiative pollutants in the Lake Superior Basin. This rule was codified as Minn. R. ch. 7052 and is now informally referred to as the "Lake Superior Basin" or the "GLI" rule. The 1998 rulemaking included a narrative standard pertaining to selected wild rice waters in the Class 4 Agriculture and Wildlife use class (Minn. R. 7050.0224, subpart 1). This rulemaking designated 22 lakes and two river segments located in the Lake Superior Basin as selected wild rice waters (identified as [WR] waters in Minn. R. 7050.0470, subpart 1) to which that narrative standard applies.

The underlined text below shows the wild rice narrative language added in 1998.

> *The numeric and narrative water quality standards in this part prescribe the qualities or properties of the waters of the state that are necessary for the agriculture and wildlife designated public uses and benefits. <u>Wild rice is an aquatic plant resource found in certain waters within the state. The harvest and use of grains from this plant serve as a food source for wildlife and humans. In recognition of the ecological importance of this resource, and in conjunction with Minnesota Indian tribes, selected wild rice waters have been specifically identified [WR] and listed in part 7050.0470, subpart 1. The quality of these waters and the aquatic habitat necessary to support the propagation and maintenance of wild rice plant species must not be materially impaired or degraded.</u> If the standards in this part are exceeded in waters of the state that have the Class 4 designation, it is considered indicative of a polluted condition which is actually or potentially deleterious, harmful, detrimental, or injurious with respect to the designated uses.*

The 1998 narrative language clearly spelled out the "harvest and use of grains from this plant as a food source for wildlife and humans" as the beneficial use. According to the rulemaking record, the MPCA intended the identification of a select number of lakes and river segments as important wild rice waters to be part of a broader process to provide greater protection for, and greater public awareness of, the ecological importance of wild rice in these waters. This effort was also an affirmation of the MPCA's commitment to work cooperatively with tribal governments and others concerned about wild rice waters. Inclusion of the wild rice narrative standard and the identified waters were considered "first steps" toward future expansion of the list of selected wild rice waters and the development of wild rice-related best management practices.

In the 1998 rulemaking the "MPCA Staff Initial Post-Hearing Responses" (Exhibit 15, at page 14) noted that the 10 mg/L wild rice sulfate standard that applied to water used for production of wild rice was not proposed for revision. Furthermore, as noted in the "1997 MPCA Final Post-Hearing Comments" (Exhibit 16, at page 15), the newly added wild rice narrative standard in the rule applied only to the 24 selected wild rice waters that were specifically listed in Minn. R. 7050.0470. The rule record does not indicate the MPCA intended to limit the 10 mg/L sulfate standard to only the 24 listed waters. Rather, the numeric sulfate standard was intended to continue to have statewide applicability to water used for production of wild rice.

5. Statutory Authority

The MPCA has a general rulemaking authority *to prevent, control or abate water pollution"* under Minn. Stat. § 115.03, subd. 1 (e)

> **115.03 Powers and Duties.**
>
> *Subdivision 1.**Generally.** The agency is hereby given and charged with the following powers and duties:*
>
> *(a) to administer and enforce all laws relating to the pollution of any of the waters of the state;*
>
> *(b) to investigate the extent, character, and effect of the pollution of the waters of this state and to gather data and information necessary or desirable in the administration or enforcement of pollution laws, and to make such classification of the waters of the state as it may deem advisable;*
>
> *(c) to establish and alter such reasonable pollution standards for any waters of the state in relation to the public use to which they are or may be put as it shall deem necessary for the purposes of this chapter and, with respect to the pollution of waters of the state, chapter 116;*
>
> *(d) to encourage waste treatment, including advanced waste treatment, instead of stream low-flow augmentation for dilution purposes to control and prevent pollution;*
>
> *(e) to adopt, issue, reissue, modify, deny, or revoke, enter into or enforce reasonable orders, permits, variances, standards, rules, schedules of compliance, and stipulation agreements, under such conditions as it may prescribe, in order to prevent, control or abate water pollution, or for the installation or operation of disposal systems or parts thereof, or for other equipment and facilities:*

The MPCA also has general authority to "group the designated waters of the state into classes, and adopt classifications and standards of purity and quality…" under Minn. Stat. § 115.44, subd. 2.

> **115.44 Classification of Waters; Standards of Quality and Purity.**
>
> *Subd. 2. **Classification and standards.***
>
> *In order to attain the objectives of sections 115.41 to 115.53, the agency after proper study, and after conducting public hearing upon due notice, shall, as soon as practicable, group the designated waters of the state into classes, and adopt classifications and standards of purity and quality therefor. Such classification shall be made in accordance with considerations of best usage in the interest of the public and with regard to the considerations mentioned in subdivision 3 hereof.*

The MPCA is proposing rules based on these two general authorities in addition to the specific legislative authority under Minnesota Laws, 2011 First Special Session, chapter 2, article 4, section 32, which requires the MPCA to initiate a process to amend the state water quality standards in Minn. R. ch. 7050, and Minnesota Laws, 2017 Regular Session, chapter 93, article 2, section 149, which provides an extension to the deadline for completing the mandated rule revisions.

The MPCA has addressed the statutory mandates relating to the proposal.

6. General Reasonableness

A. Introduction and overview

The proposed revisions are based on extensive research and technical analysis, literature review, scientific peer review, significant internal discussion and review, and broad collaboration with stakeholders, researchers, tribal governments, and other state agencies. In this Part, the MPCA will provide a general description of the process. Information and explanation of how the MPCA conducted the underlying research and analyzed the resulting data beyond what is included in this Statement is in the MPCA's TSD (Exhibit 1). The MPCA's complete justification for the proposed revisions is composed of the general discussions of reasonableness in this Part, the discussions in Part 7 (Specific Reasonableness), and the information provided in the TSD.

In the process of developing the proposed revisions, the MPCA considered numerous alternatives. The MPCA's discussion of the reasons why those alternatives were not selected also supports the reasonableness of the revisions as proposed. Additional discussion of the alternatives considered is provided in Part 10.C (Regulatory Analysis).

B. General reasonableness of the MPCA's proposal

As discussed in Part 2 (Discussion of Need), the MPCA found various problems with the Class 4 wild rice rule. The following discussion of various aspects of the proposed revisions presents the MPCA's justification of how the proposed rule revisions reasonably address the major topic areas of the identified needs.

For each of the major elements of the proposed revisions, the MPCA is providing discussion and justification of multiple subtopics relating to those major elements. It is difficult to organize a logical sequence to discuss the reasonableness of the proposed amendments; many of the issues require background discussion and often those discussions and the responses associated with a particular element are common to other elements of the proposal. For this reason, the following discussion of reasonableness does not directly correspond to the order of the proposed amendments. However, in Part 7 (Specific Reasonableness), the MPCA identifies each part of the proposed rules and either provides a justification or directs the reader to where the applicable justification is provided in Part 6.

In this discussion of general reasonableness, the MPCA is addressing the following major topic areas:

- The wild rice beneficial use. The MPCA is proposing to more clearly state the existing wild rice beneficial use but retain its existing classification as a subclass within Class 4. The discussion of the general reasonableness of the proposed clarification of the beneficial use includes a discussion of:
    - what is meant by a beneficial use;
    - why the Class 4 agriculture and wildlife use class is a reasonable classification for wild rice waters;

- o why the narrative standard is reasonably applied only to selected wild rice waters; and
- o why the proposed standard is proposed to not apply to cultivated wild rice waters.

- · Identifying wild rice waters. The MPCA is proposing a new rule part specifically referencing wild rice waters, applying the numeric standard to them, and maintaining the status quo of the narrative standard applied to a subset of wild rice waters currently listed in Minn. R. 7050.0470, subpart 1 that are designated as [WR] waters. The MPCA proposes to identify approximately 1,300 bodies of water as "wild rice waters." The discussion of the reasonableness of the proposal explains the sources used to identify wild rice waters and how the MPCA used the information provided by the sources. The new rule part will also establish a process by which the MPCA will consider future additions of wild rice waters to the list by rule.
- · The numeric standard. The proposed revisions require that sulfate must be maintained at an annual average level that ensures that sulfide in the porewater sediment does not exceed a concentration of 120 µg/L. Since sulfate is the primary form of sulfur discharged into surface water and subsequently converted into sulfide, the proposal includes an equation to calculate a protective sulfate value for wild rice. The proposal establishes a process for developing an alternate standard where evidence exists that porewater sulfide is at or below 120 µg /L without reference to surface water sulfate levels (as when groundwater is a heavy influence on sediment porewater). The proposed equation derives a protective sulfate value from factors controlling the conversion of surface water sulfate into porewater sulfide - the levels of TEFe and organic carbon present in the sediment. The procedures for sampling and analysis to determine the protective sulfate value and for developing an alternate standard are contained in a document incorporated into the rule by reference. In this Statement, the MPCA provides a general justification of the porewater sulfide level, equation, and analysis of the data. The bulk of the technical basis for the standard is provided in the TSD.
- · Standard application and implementation. The MPCA is proposing revisions relating to the implementation of the proposed standard. These revisions will address how the MPCA will establish effluent limits and address issues associated with implementation.

C. Beneficial use

1. Reasonableness of clarifying the beneficial use.

The proposed rules clarify the existing Class 4 beneficial use for wild rice waters. The MPCA is not removing the existing Class 4 wild rice beneficial use in this rulemaking, nor is the MPCA establishing a new wild rice beneficial use.

The wild rice beneficial use is a Class 4 use, which is described in Minn. R. 7050.0140 as including "…all waters of the state that are or may be used for any agricultural purpose, including stock watering and irrigation, or by waterfowl and other wildlife..." In Minn. R. 7050.0224, subpart 2, the Class 4A beneficial use speaks to maintaining water quality to prevent "…significant damage or adverse effects upon any *crops or vegetation usually grown in the waters or area…*" (emphasis added). In 1973, the MPCA recognized the importance of wild rice and its beneficial use by establishing a specific subcategory of Class 4A, “water used for production of wild rice.” The MPCA also at that time set a numeric sulfate standard to protect the 4A wild rice beneficial use, which was implied by the term “water used for production of wild rice” to be the production of wild rice. At the time they were adopted, the wild rice beneficial use and the associated sulfate standard were reasonably established in the Class 4 agriculture and wildlife use class.

From adoption in 1973, the Class 4 standard applicable to wild rice remained unchanged until 1998, when the MPCA amended Minn. R. ch. 7050 as part of a rulemaking to adopt rules for water quality standards in the Lake Superior Basin. As part of that rulemaking, the MPCA amended Minn. R. 7050.0224 to more clearly describe the beneficial use for wild rice with reference to “harvest and use of grains from this plant serve as a food source for wildlife and humans.” The SONAR for that rulemaking (Exhibit 17, pages 22-24) describes wild rice as a “unique plant in that it is the only cereal grain native to North America with well documented food uses and the only wild grain that is harvested in significant quantities in its natural state.”

The food uses of wild rice for wildlife and humans are well documented in the scientific literature. Wild rice is a nutritious source of food for humans. It is low in fat, and contains more protein, zinc, and potassium than both brown and white rice varieties. (USDA 2002; Oelke 1993). The wild rice grain is also an important food source for waterfowl, rails, and songbirds. Further detail about the importance of wild rice as a food source for wildlife is found in the MPCA’s Draft TSD (Exhibit 12).

The MPCA proposes to clarify the existing beneficial use language in several ways. First, the MPCA proposes to revise the language that describes where the wild rice beneficial use applies by revising the existing phrase “water used for production of wild rice” to “wild rice water.” The word “production” at the time the standard was first adopted in the 1970s was commonly used to describe the amount of rice harvested or yielded from both natural beds of wild rice as well as rice harvested from cultivated paddies (e.g., Edman 1969). Furthermore, environmental scientists used the word “production” to refer to the growth of plants in lakes even when there was no attempt to harvest any part of the plant (e.g., Rich et al. 1971, Warren 1971). Natural lakes and streams with wild rice beds, as well as commercial paddies, were collectively described as wild rice production areas. However, the meaning of the word production has changed over time and the MPCA has heard many comments from tribes and stakeholders that the term “water used for production of wild rice” is confusing, outdated, difficult to understand, and readily misconstrued. As part of its proposal to more clearly state the beneficial use and where it applies, the MPCA is proposing to use the phrase “wild rice water” instead of “water used for production of wild rice” without changing the concept of the use or where it applies. The change only modernizes the language, given that the word “production” has different connotations today than it did historically. Changing the phrasing does not alter the scope or effect of the existing beneficial use, which is the harvest and use of grains from this plant as a food source for wildlife and humans.

The MPCA also proposes to revise the phrasing of the beneficial use to be more grammatically correct. The current phrasing of the beneficial use is “the harvest and use of grains from this plant serve as a food source for wildlife and humans.” This phrase, when closely examined, is not correctly structured: the “harvest and use” of the grains does not serve as a food source, only the “grain” serves as a food source. The MPCA is proposing to rephrase the beneficial use to correct the grammar but does not intend any change to the scope or effect of the existing beneficial use. The proposed revision to the statement of the wild rice beneficial use is: "use of the grain of wild rice as a food source for wildlife and humans."

2. Reasonableness of retaining the existing wild rice beneficial use and the standards that apply to wild rice within the Class 4 standards

Although the MPCA considers that the standards applicable to wild rice waters are appropriately applied as Class 4 agriculture and wildlife standards in the 4A subcategory for irrigation and crops grown in water, the MPCA also considers it appropriate to establish a separate subcategory of Class 4 only applicable to wild rice waters. The qualifier in Minn. R. 7050.0224, subpart 2, stating that the existing 10 mg/L sulfate standard is only "applicable to water used for production of wild rice", separated the standards that apply to wild rice waters from the standards that apply to other Class 4A waters. To add clarity to the rules, the MPCA proposes to subdivide Class 4 to establish a separate 4D use class for wild rice waters, removing wild rice waters from Class 4A. The proposed 4D use class will reasonably consolidate the new and revised requirements applicable to waters that support the beneficial use of wild rice as a food source. Because the MPCA is not proposing to change the beneficial use, it is reasonable to continue to address the wild rice standards in the Class 4 standard, where the existing sulfate standard and the wild rice beneficial use are found. As a result, it is reasonable to move the existing wild rice beneficial use and the revised sulfate standard applicable to wild rice waters into a new subclass of Class 4. Establishing a new wild rice subclass of Class 4D clarifies the structure of the subclasses and recognizes the uniqueness of the wild rice beneficial use.

3. Reasonableness of excluding cultivated wild rice fields as wild rice waters

The MPCA is proposing to exclude cultivated wild rice fields from the 4D use class. These crops will retain their coverage under Class 4A. There are two bases for this proposal.

Minnesota Laws, 2011 First Special Session, chapter 2, article 4, section 32, which establishes the directive to amend the standards for waters containing natural beds of wild rice, also very specifically defines "*waters containing natural beds of wild rice*," as "*where wild rice occurs naturally.*"

This 2011 law definition differentiates between cultivated and natural beds of wild rice and states "*The amended rule shall: (1) address water quality standards for waters containing natural beds of wild rice, as well as for irrigation waters used for production of wild rice. . .".* The techniques used to manage cultivated wild rice fields produce sediment conditions that are rarely seen in natural wild rice waters and which may mitigate negative effects of elevated porewater sulfide (Exhibit 18, Myrbo et al.). Two important research efforts on the toxicity of sulfate to wild rice, Pastor et al., 2017 (Exhibit 19) and Fort et al., 2014, have shown that sulfate is not directly toxic to wild rice at levels commonly found in wild rice waters in Minnesota, rather it is sulfide that exerts significant control over the presence and absence of wild rice. It is the conversion of sulfate into sulfide in the sediment where wild rice grows that results in the toxic effect (Exhibit 19).

The lack of negative sulfate effect in cultivated wild rice is attributed to the now-standard practice of dewatering cultivated wild rice fields from July through September, which allows fall tillage and may oxidize the sediment and reduce sulfide concentrations, and to the use of nitrogen fertilizer. Increased availability of nitrogen may allow wild rice leaves to reach the water surface more rapidly compared to growth in natural waters, which would allow the plants to transport oxygen to roots earlier and minimize the negative impact of sulfide. Since conditions in cultivated wild rice fields reduce any negative effects of sulfate, it is reasonable to exclude cultivated wild rice fields from consideration as wild rice waters subject to the standard. Therefore, the definition of wild rice waters specifies that it does not include cultivated wild rice fields. To the extent that standards are needed to protect irrigation waters used for cultivated wild rice, the MPCA finds that the existing Class 4A standards provide that protection.

4. Reasonableness of re-positioning the narrative standard that applies to [WR] waters

Minn. R. 7050.0224, subpart 1 currently includes, in addition to general directives about Class 4 waters, a narrative standard that only applies to selected wild rice waters, also referred to as [WR] waters, that are specifically identified in the rule.

The MPCA is proposing to move the narrative standard to a separate subpart of Minn. R. 7050.0224, but not to change its meaning, scope, or applicability.

Proposed revisions to subpart 1.

Subpart 1. ***General.*** *The numeric and narrative water quality standards in this part prescribe the qualities or properties of the waters of the state that are necessary for the agriculture and wildlife designated public uses and benefits.* ~~*Wild rice is an aquatic plant resource found in certain waters within the state. The harvest and use of grains from this plant serve as a food source for wildlife and humans. In recognition of the ecological importance of this resource, and in conjunction with Minnesota Indian tribes, selected wild rice waters have been specifically identified [WR] and listed in part 7050.0470, subpart 1. The quality of these waters and the aquatic habitat necessary to support the propagation and maintenance of wild rice plant species must not be materially impaired or degraded.*~~ *If the standards in this part are exceeded in waters of the state that have the Class 4 designation, it is considered indicative of a polluted condition which is actually or potentially deleterious, harmful, detrimental, or injurious with respect to the designated uses.*

The proposal to move the narrative standard to a separate subpart, but not change its intent, is reasonable and necessary because the current arrangement of the subpart is confusing.

Existing subpart 1 places specific conditions relating to select wild rice waters in the middle of a paragraph describing the conditions applicable to all Class 4 waters. This has created confusion regarding the applicability of the general conditions and the specific conditions relating only to [WR] waters.

Existing Minn. R. 7050.0224, subpart 1. General. (expanded to identify each sentence)

1. The numeric and narrative water quality standards in this part prescribe the qualities or properties of the waters of the state that are necessary for the agriculture and wildlife designated public uses and benefits.

2. Wild rice is an aquatic plant resource found in certain waters within the state.

3. The harvest and use of grains from this plant serve as a food source for wildlife and humans.

4. In recognition of the ecological importance of this resource, and in conjunction with Minnesota Indian tribes, selected wild rice waters have been specifically identified [WR] and listed in part 7050.0470, subpart 1.

5. The quality of these waters and the aquatic habitat necessary to support the propagation and maintenance of wild rice plant species must not be materially impaired or degraded.

6. If the standards in this part are exceeded in waters of the state that have the class 4 designation, it is considered indicative of a polluted condition which is actually or potentially deleterious, harmful, detrimental, or injurious with respect to the designated uses.

The structure of existing 7050.0224, subpart 1 is problematic. The first and sixth sentences describe the general applicability of this part to all Class 4 waters. The second sentence is a general statement about wild rice that the MPCA considers is no longer necessary. The third sentence is a statement that pertains to the wild rice beneficial use. The fourth sentence establishes the category of specifically listed waters that are a subset of all wild rice waters and referred to as [WR] waters. The fifth sentence establishes the narrative standard that only applies to those [WR] waters. This structure is proposed to be reasonably re-arranged to more clearly distinguish between the parts that apply to all Class 4 waters, the parts that apply to all wild rice waters (now Class 4D waters), and those parts that only apply to selected wild rice [WR] waters.

Proposed revised Minn. R. 7050.0224, subp. 1. General.

The numeric and narrative water quality standards in this part prescribe the qualities or properties of the waters of the state that are necessary for the agriculture and wildlife designated public uses and benefits. If the standards in this part are exceeded in waters of the state that have the class 4 designation, it is considered indicative of a polluted condition which is actually or potentially deleterious, harmful, detrimental, or injurious with respect to the designated uses.

Proposed revised Minn. R.7050.0224, subpart 6. Class 4D [WR] Selected wild rice waters.

In recognition of the ecological importance of the wild rice resource, and in conjunction with Minnesota Indian tribes, selected Class 4D wild rice waters have been specifically identified [WR] and listed in part 7050.0470, subpart 1. The quality of these waters and the aquatic habitat necessary to support the propagation and maintenance of wild rice plant species must not be materially impaired or degraded.

By re-structuring the narrative wild rice rule language to place it in a new subpart only applicable to the [WR] waters, the proposed change maintains a consistent structure with how the rules describe the narrative standards that apply to the other subcategories of Class 4 waters. For example, the narrative standards in
Minn. R. 7050.0224 for Classes 4B and 4C are:

Subp. 3. ***Class 4B waters***.

The quality of class 4B waters of the state shall be such as to permit their use by livestock and wildlife without inhibition or injurious effects...

Subp. 4. ***Class 4C waters; wetlands***.

The quality of class 4C wetlands shall be such as to permit their use for irrigation and by wildlife and livestock without inhibition or injurious effects and be suitable for erosion control, groundwater recharge, low flow augmentation, storm water retention, and stream sedimentation...

This proposed restructuring is a reasonable clarification that does not change the scope or applicability of the existing wild rice narrative standard. In this rulemaking, the MPCA does not propose to change the narrative standard that applies to the 24 waters that were originally listed in Minn. R. 7050.0470 as [WR] wild rice waters or expand the scope of its applicability.

The rule language also clarifies that the [WR] waters are a subset of the overall Class 4D wild rice waters. This is reasonable to provide additional clarity.

D. Wild rice waters

1. Reasonableness of the MPCA's proposed list of wild rice waters

The current rules apply the wild rice beneficial use to "water used for production of wild rice," but the rules do not specifically identify these waters. Identifying these waters has been a major challenge to the implementation of the existing standard, as identification currently requires a case-by-case evaluation. In 2011, the Minnesota Legislature directed the MPCA to "designate each body of water, or specific portion thereof, to which wild rice water quality standards apply." Legislation also directs the MPCA to establish criteria for waters containing natural beds of wild rice and that the criteria should include (but not be limited to) history of wild rice harvests, minimum acreage and wild rice density.

In this rulemaking, the MPCA is proposing that the wild rice based sulfate standard apply only to waters specifically identified as Class 4D wild rice waters. The MPCA is proposing to identify specific wild rice waters by a water identification number (WID) in proposed Minn. R. 7050.0471. Identifying wild rice waters addresses two needs: it meets the legislative directive to identify waters where the wild rice beneficial use exists and it provides clarity and transparency as to where the wild rice sulfate standard is applicable.

Some commenters have stated that instead of specifically identifying wild rice waters, the MPCA should instead identify habitat that supports the growth of wild rice and apply the standard wherever those conditions exist. A similar proposal would have the MPCA identify every water in Minnesota as a wild rice water except in limited cases where the bottom composition or water velocity prevents the growth of wild rice. Both of these very broadly applicable options for identifying wild rice waters would be extremely difficult to implement. These suggestions do not take into consideration the variability of the conditions for wild rice growth, the presence of other factors that limit the growth of wild rice (e.g. it will not grow where water levels vary too widely), or the fact that in some areas, the existing use has not been established since November 28, 1975. The assumption that the rule can broadly characterize wild rice waters based on certain physical conditions mistakenly assumes a complete understanding all of the variables affecting wild rice presence and growth and the complex relationships between them.

The MPCA is proposing an initial identification of wild rice waters as part of this rulemaking, and the inclusion of provisions addressing how the commissioner will solicit and consider information on which to base future rulemaking efforts to add to the list of identified wild rice waters.

2. Reasonableness of identifying wild rice waters by water body identification numbers (WID)

Background of the use of a water identifier

Surface waters are typically associated with a name (e.g. Lake Pepin, or Mississippi River). In addition, in the scientific and regulatory communities, they typically have a unique numeric identification. This approach helps to distinguish between waters with the same name (e.g. Round Lake in St. Louis County and Round Lake in Crow Wing County.) It also recognizes that waters, especially rivers such as the Mississippi River, can be large and variable over their full extent. It is often necessary to refer to just a reach of a much longer river or stream. The unique numeric identification the MPCA assigns to streams, rivers, and lakes is referred to as a water ID (WID). A river or stream WID is a unique way to identify a specific section of a river or stream and is typically presented as an eleven-digit identifying number that represents a combination of an eight-digit hydrologic cataloging number (HUC-8 watershed number) established by the U.S. Geological Survey and a three-digit stream reach number assigned by the MPCA.[7] Lakes, reservoirs, and wetlands are also identified by WID, although in a different format.[8]

In Minnesota, there are 80 land-based, HUC-8 watersheds that range in size from 13 to 2,862 square miles. (The 81st HUC-8 watershed represents the Minnesota waters of Lake Superior.) To illustrate a WID numbering assignment, consider the reach of the Mississippi River from Lake Itasca to just south of Bemidji, Minnesota. This reach of the river is within HUC-8 watershed number 07010101 (Mississippi River-Headwaters). The river reach number for this segment of the Mississippi River, assigned by the

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[7] *HUC-8 is the eight-digit Hydrologic Unit Code identifying a watershed under the U.S.Geologic Survey hydrologic unit classification system. The MDNR uses the HUC-8 scale to identify their 81 Major Watersheds in the State. For information on hydrologic units, see https://water.usgs.gov/GIS/huc.html*

[8] *The unique ID for lakes, reservoirs and wetlands is the DOW number. DOW is an acronym for the former MDNR Division of Waters and is still used to track lakes by unique DOW number. The former Division of Waters is now part of Division of Ecological and Water Resources.*

MPCA is 753. Therefore, the WID for the portion of the Mississippi River from Lake Itasca to the Schoolcraft River is 07010101-753.

The MPCA assigns WIDs using the following considerations: hydrologically homogenous areas, a change in use class identified in Minn. R. ch. 7050, biology, and site-specific considerations. An exception to this is large rivers, including the Mississippi, Minnesota, Red, Rainy, and St. Croix Rivers. In these rivers, large sections are identified with a single WID between two tributaries where the same beneficial uses exist.

Most stream WIDs range in length from less than one river mile to upwards of 70 river miles. The variation in the length of WIDs is due to hydrologic and classification factors. A WID may be very short if the stream is intersected by a lake or wetland, if there is a change in use class, or if flow is impacted by a physical structure (e.g., dam or tributary). A stream that flows with no significant tributaries or impacts will have a longer WID length than a stream joined by other streams or that flows into a lake.[9]

The MDNR assigns unique numeric identifiers (DOW number) to identify lakes, reservoirs, and wetlands. For purposes of identifying wild rice waters that have been assigned a MDNR DOW, the MPCA relies upon the assigned MDNR DOW as the WID. The MDNR DOW number follows the numbering convention of the two-digit county – four-digit unique lake number – two-digit basin. An example of this is Cedar Lake in Stearns County (73-0226-00).

The MPCA proposes to identify a wild rice water using the respective water body WID. For lakes, wetlands, and reservoirs, this would be the DOW number; for rivers and streams, it would be the HUC-8 and three unique digits discussed above. The MPCA uses the WID approach in its water programs to provide consistent nomenclature to identify and analyze waters, such as in MPCA's assessment effort to determine if a water body is fully supporting beneficial uses. The information collected and maintained by the MPCA identifies water bodies by WID. Using this method to identify wild rice waters allows for increased accuracy and clarity when collecting, analyzing, and sharing information pertaining to a given wild rice water among program areas, and with the public.

An alternative to using a WID could be to identify the wild rice water by its name; however, this is not reasonable due to potential confusion. Many water bodies share the same name and in many cases, a water body has multiple names associated with it. Use of the common name could be confusing when discussing a given wild rice water. It is imperative that a water body is not confused with a different water body that may or may not be a wild rice water.

Another alternative to using a WID could be to identify a specific area within a water as the wild rice water. For example, a given river may have wild rice growing in a certain area and the listed "wild rice water" could be some defined area around the wild rice. The MPCA considered this approach but found it to be unreasonable because a) it creates a completely new system to identify a water and b) wild rice beds are known to "move" within a stream reach from one year to the next depending on hydrology and possibly other factors. A new form of identification would be inconsistent with any of the other means by which the MPCA collects and uses data. Creating a new unique identification would be an inefficient

[9] *Note that in areas where the MPCA does not collect water quality data, all rivers and streams in one watershed are grouped under the same WID (ending in -999) as "unassessed", not divided as otherwise explained.*

use of resources and result in information that could not be effectively shared/compared by internal and external customers.

The existing WID nomenclature provides a consistent, accessible, and reliable system to identify specific portions of streams and rivers as wild rice waters. Although in most cases, a lake has a single WID, the existing process recognizes areas where a bay or basins of the lake are hydrologically separate from the main basin (i.e. water does not flow from the main basin to the bay). This allows only the bay where wild rice grows to be identified as a wild rice water. As an example, Swan Lake in Itasca County has a main basin ID (31-0067002) and a separate southwest bay ID (31-0067-03). The southwest bay is a proposed wild rice water, and not the main lake. Therefore, only the Swan Lake southwest bay ID (31-0067-03) would be the identified wild rice water.

3. Reasonableness of the proposed wild rice waters

In this rulemaking, the MPCA is proposing approximately 1,300 waters specifically identified in rule as Class 4D wild rice waters to which the sulfate standard applies. Each proposed wild rice water is identified by WID.

As further described below and in the TSD, the MPCA developed the proposed wild rice waters from a number of sources, including:

- A 2008 MDNR report to the Minnesota Legislature *;*
- Data and information received following a 2013 MPCA request for relevant wild rice and sulfate information;
- Wild rice surveys completed by Minnesota tribes, mining companies, and the University of Minnesota; and
- Field surveys from MPCA and MDNR biologists and other information from these agencies.

As required by the 2011 law, the MPCA developed and applied criteria to evaluating these multiple sources of information, focusing on the legislative direction to consider history of wild rice harvests, minimum acreage, and wild rice density. Details of the specific sources and how they were evaluated in relation to the three legislative criteria and the history of the wild rice beneficial use subcategory are provided in the following section.

The wild rice beneficial use was established in 1973 and is not being changed by this rulemaking. This rulemaking provides, for the first time, a specific list of those waters that demonstrate the wild rice beneficial use. For that reason, the MPCA is providing in this Statement information about each source used to identify wild rice waters.

The MPCA has received comments suggesting that a use attainability analysis (UAA) is necessary to complete this rulemaking. The MPCA is clarifying an existing beneficial use, not changing it. The MPCA is not adopting new or revised designated uses, or removing designated uses. Rather, the MPCA is using available information to, via rulemaking, identify which waters demonstrate the beneficial use.

Reasonableness of sources and data used to identify Class 4D wild rice waters

The MPCA reviewed data and information from various sources to identify proposed wild rice waters. These sources included various inventories, biological monitoring, and survey databases. The MPCA also publicly requested information and data by publishing a notice in the *State Register* (Exhibit 20) and by asking other state and federal agencies, tribes, and the general public to identify additional information or propose additional wild rice waters to supplement the MPCA's first draft of identified waters.

Table 2 identifies the sources and provides a brief explanation of how the MPCA evaluated the information presented by each source. An essential component of the MPCA's review of the sources was to determine if they demonstrated the use and value of the wild rice beneficial use, as required by 40 CFR 131.10(k)(3). A more complete discussion of general reasonableness of the sources and of the process the MPCA used to evaluate the sources follows this overview of the source materials. Figure 1 is a visual representation of how the MPCA considered the source materials.

Table 2. Sources used for identification of wild rice waters

Exhibit #	Title/Source	Discussion
Exhibit 21	Natural Wild Rice in Minnesota—A Wild Rice Study Report to the Legislature (2008)	This report was submitted to the Minnesota Legislature by the MDNR in 2008 and is considered by many to be the best overview of natural wild rice stands in Minnesota. Although this report was not developed for use in the development of water quality standards, it was the key starting source for the MPCA's list of Class 4D wild rice waters. http://files.dnr.state.mn.us/fish_wildlife/wildlife/shallowlakes/natural-wild rice-in-minnesota.pdf Appendix B of the MDNR report contains an inventory of the location of 1,286 wild rice water bodies. The report includes information about the estimated acreage of wild rice for approximately 60% of the identified waters. The MPCA initially used this inventory as the primary source to identify proposed wild rice waters. However, some waters that were included in the MDNR report are not included in the MPCA's proposed list of wild rice waters and some waters not in the MDNR report are included on the MPCA's proposed list. Waters identified in the MDNR 2008 report with wild rice acreage estimates greater than two acres are included on the MPCA proposed wild rice water list, based on the MPCA's reasonable assumption that two acres is sufficient rice to demonstrate the beneficial use. Other waters on the MDNR list – those where rice acreage estimates were one acre or less or where no reported rice acreage estimates were provided – were further evaluated based on other sources described below. If the MPCA found additional information from other sources to support the existence of the beneficial use, they are proposed as wild rice waters.
Exhibit 22	MDNR Wild Rice Harvester Survey Report (2007)	This is a 2007 MDNR report tabulating the results of a survey of people who purchased a license to harvest wild rice in 2004, 2005, or 2006. This survey of those who purchase a license in 2006 requested identification of the water where wild rice was harvested, but did not request information about the extent of the wild rice present. The MPCA reasonably assumes that successful harvesting of wild rice demonstrates

Exhibit #	Title/Source	Discussion
		the existence of the wild rice beneficial use. The MPCA is proposing to list all waters with reported harvest in 2006, except those waters that cannot be verified with a WID. http://files.dnr.state.mn.us/fish_wildlife/wildlife/shallowlakes/wild rice-harvester-survey-2007.pdf
Exhibit 23	Minnesota Wild Rice Management Workgroup List of 350 Important Wild Rice Waters (2010)	The Minnesota Wild Rice Management Workgroup, a coalition of federal, state, and tribal resource managers and wild rice stakeholders, compiled this list in 2010. This workgroup was convened by a recommendation in the 2008 MDNR *Natural Wild Rice in Minnesota* report. This list identifies 350 of the most important wild rice waters in Minnesota based on harvest and/or ecological, cultural, and historical values, most of which were also identified in the 2008 MDNR report. The MPCA is proposing to include all of these waters on the list of wild rice waters.
Exhibit 24	1854 Treaty Authority List of Wild rice waters	The 1854 Treaty Authority is an Inter-Tribal Natural Resource Management Organization that manages the off-reservation hunting, fishing and gathering rights of the Grand Portage and Bois Forte Bands of the Lake Superior Chippewa in the territory ceded under the Treaty of 1854. Since 1996, this organization has identified wild rice waters based on surveys of lakes and rivers within the ceded territory. Most of the water bodies identified in the 1854 Treaty Authority's March 24, 2016 inventory of wild rice waters, plus three additional waters identified since 2016 exhibit the Class 4D beneficial use and are included in the proposed list of Class 4D wild rice waters. http://www.1854treatyauthority.org/
Exhibit 25	MDNR Aquatic Plant Management Database	MDNR has an Aquatic Plant Management (APM) permitting program that: · Allows the limited removal of wild rice from waters of the state (primarily to allow for boat access from shore to open water). · Issues permits for individuals and organizations who are attempting to restore or introduce wild rice in a given water body. The APM maintains a database with multi-year wild rice permit information. All waters associated with wild rice removal permits listed in the APM permitting database were identified in the proposed list of wild rice waters. Waters associated with permits for restoration were included on the MPCA's proposed list of waters if the MPCA found adequate information regarding the restoration or corroborating support from other sources that showed that they supported the beneficial use.
Exhibit 26	MPCA Biomonitoring Field Sites:	MPCA wetlands and fisheries biologists conduct various types of monitoring and field surveys of Minnesota streams and wetlands. The MPCA has compiled the results from this work in databases. MPCA biologists reviewed these databases and identified streams and wetlands with wild rice, using best professional judgement to identify those waters that support the beneficial use.
Exhibit 27	University of Minnesota/	In the summers of 2011, 2012, and 2013, the MPCA contracted with the University of Minnesota, LacCore/Limnological Research Center to conduct field surveys of water bodies across the state. These surveys measured a suite of parameters in the water column and sediment

Exhibit #	Title/Source	Discussion
	MPCA Wild Rice Study Field Survey Sites	porewater, and sediment samples in connection with wild rice sulfate studies. The 2011 surveys included estimated wild rice plant coverage at the sampling sites. The 2012 and 2013 surveys included both plant coverage estimates as well as wild rice stem counts at the sampling sites. Where a site was identified as having wild rice, the MPCA added it to the proposed list of wild rice waters, with four exceptions (Anka Lake, Big Sucker Lake, Christina Lake, and Dark Lake that had sparse or limited wild rice plants observed).
Exhibit 28	Minnesota Biological Survey Database:	The MDNR's Minnesota Biological Survey (MBS) program maintains a database of surveyed sites with references to plant species observed during the surveys. The MPCA reviewed two versions of the database provided by the MDNR on October 31, 2011 and on February 22, 2017. The MPCA reviewed the narrative descriptions contained in the database for references to the amount of wild rice observed in a particular water body. Water bodies with descriptors such as "thick rice present," "dense stand of wild rice," "ringing the entire shoreline of a lake," or having an "extensive emergent community dominated by wild rice," show the beneficial use is present. Such waters are included on the proposed list of wild rice waters.
Exhibit 29	MPCA Call for Data	During the spring of 2013, the MPCA published a "Call for Data" for locational information on wild rice stands and sulfate analytical results. (Exhibit 21). MPCA received information from MDNR, U.S. Fish and Wildlife Service, United States Geological Survey, Metropolitan Council Environmental Services and Robert Pillsbury from the University of Wisconsin-Oshkosh. Waters identified from this call for data that had estimated wild rice acreage of two acres or more are included in the proposed list of wild rice waters.
Exhibit 30	Permittee Monitoring Reports	Certain NPDES permittees have conducted multi-year field surveys of selected waters in northeast Minnesota that include water quality and wild rice data. The results of these field surveys are contained in a number of reports and summaries that are compiled in Exhibit 30 and are proposed as wild rice waters.
Exhibit 31	WR Waters (7050.0470)	These wild rice waters were first included in the rule in 1998 as selected wild rice waters specifically identified [WR] and listed in Minn. R. 7050.0470, subpart 1. All of these current [WR] waters are included in the proposed list of wild rice waters.
	Waters identified by MDNR in 2015 as Wild rice waters	In 2015, the MDNR provided the MPCA with information about three waters in St. Louis County, not previously identified in the 2008 report, that had sufficient wild rice to demonstrate the beneficial use. Pelican River- 09030002-530 Elbow River- 09030002-602 Rice Lake -69-0803-00
	Waters Identified through MPCA Review of Various Water Surveys	As part of its effort to search for corroborating information on waters identified in the MDNR 2008 report, the MPCA reviewed past MPCA and MDNR records, reports, water surveys, and aerial photographs. Where information was available in these documents to support assignment of

Exhibit #	Title/Source	Discussion
		the beneficial use, those waters were proposed as wild rice waters. The reviewed information included: MDNR fisheries, lakes or stream surveys MDNR game lake surveys MDNR duck reports MDNR plant survey abundance surveys MDNR aquatic vegetation and shoal water substrate report MDNR lake survey correspondence MDNR Minnesota Biological Survey reports on Lakefinder http://www.dnr.state.mn.us/lakefind/index.html MPCA lake survey reports Aerial photographs taken over multiple years

Discussion of why some source information was insufficient to identify Class 4D wild rice waters

While the discussion above describes the sources the MPCA used to identify proposed Class 4D wild rice waters, in some instances information was insufficient to make a determination. In some cases, the MPCA could not identify the location of the water from the information provided. For example, waters in the MDNR 2007 harvester report were listed on a county-by-county basis. For common lake names, multiple waters within a county with the same names were found (for example, Mud Lake, Round Lake, Deer Lake, etc.), and in some cases, the location of the water could not be precisely identified.

In other cases, the MPCA could not correlate the location of a river or stream with a particular WID. Some sources of information listed river and stream locations with only Township and Range data. In these cases, the MPCA reviewed available data (aerial photographs, other sources) to identify the WIDs in that county associated with the river or stream. If multiple WIDs associated with the river or stream were found within the county, and the MPCA was unable to find information to correlate specifically with a single WID where rice was located, the water could not reasonably be included as a proposed wild rice water.

Reasonableness of the use of the MDNR 2008 Report

As a starting point for identifying Class 4D wild rice waters for inclusion in the proposed rules, the MPCA relied on the inventory of wild rice found in the MDNR 2008 report, *Natural Wild Rice in Minnesota* (Exhibit 21). The MPCA's use of this inventory is reasonable as it is widely considered the most comprehensive source of information regarding where rice may be found in Minnesota, and was extensively reviewed. The report was a joint effort of wild rice experts from state, tribal, and federal governments as well as academia and the private sector. It was prepared to fulfill the requirements of Session Law 2007, Chapter 57, Article 1, Section 163, which required:

> *By February 15, 2008, the commissioner of natural resources must prepare a study for natural wild rice that includes:*
>
> *(1) the current location and estimated acreage and area of natural stands;*

> *(2) potential threats to natural stands, including, but not limited to, development pressure, water levels, pollution, invasive species, and genetically engineered strains; and*
>
> *(3) recommendations to the house and senate committees with jurisdiction over natural resources on protecting and increasing natural wild rice stands in the state.*
>
> *In developing the study, the commissioner must contact and ask for comments from the state's wild rice industry, the commissioner of agriculture, local officials with significant areas of wild rice within their jurisdictions, tribal leaders within affected federally recognized tribes, and interested citizens.*

The report looked at current and historical information. Although the MDNR 2008 report is the most comprehensive and current inventory available, it has some limitations with respect to the MPCA's need to identify Class 4D wild rice waters subject to the wild rice sulfate standard. The objectives guiding the report's inventory design and development included: 1) consolidating various information and data on the location (lake, wetland or river segment) of natural wild rice stands in Minnesota and 2) determining the size and natural wild rice coverage for each location. These objectives, as stated in Appendix B of the MDNR report, do not directly correspond to the MPCA's need to establish that the wild rice beneficial use exists in the identified waters. For example, the report does not include density or acreage estimates for all of the rice stands, and contains only limited information about streams with wild rice.

Although the report did not identify stands of wild rice based on the use of the grain as a food source for wildlife and humans, it provided extensive data useful to the MPCA's determination of where that beneficial use may exist. Using this information, the MPCA made reasonable assumptions to determine which of the waters included in the MDNR 2008 report demonstrate the Class 4D beneficial use and therefore would be proposed as wild rice waters.

The MPCA's initial assumption was that water bodies included in the MDNR 2008 report with wild rice acreage estimates of two acres or more meet the beneficial use. The MPCA is proposing to list those waters identified as having at least two acres of wild rice unless information was available to indicate that densities were insufficient to meet the beneficial use. In other words, the MPCA finds that, absent information to the contrary, it is reasonable to assume that a water body included in the MDNR 2008 report that is identified as having at least two acres of wild rice has an existing beneficial use as a wild rice water.

The MPCA recognized that it could not exclusively rely on the two-acre threshold as the sole criterion for evaluating the wild rice beneficial use. For example, some waters in the 2008 MDNR report with either one acre or no acreage estimates were identified through other sources as high quality, harvestable wild rice waters. (See examples in Table 3) MPCA staff searched other sources of wild rice information for corroborating evidence to support inclusion, or exclusion, of waters on the list of proposed wild rice waters. Where there was corroborating evidence from other sources, the MPCA included the water on the proposed list of wild rice waters even if acreage data was unavailable from the 2008 MDNR report.

Table 3. Examples of Waters with Fewer than Two Acres in the MDNR 2008 Report Corroborated with Evidence of Human Harvest from Other Sources

Lake Name	County	Lake ID	Lake Acres	Wild Rice Estimated Acreage	Reported Harvest Trips - 2006
Hickey Lake	Anoka	02-0096-00	41	No estimate provided	5
Little Round Lake	Becker	03-0302-00	565	No estimate provided	7
Hay Lake	Carlton	09-0010-00	103	1	1
Moose Lake	Cass	11-0424-00	92	1	5
Prairie Lake	Itasca	31-0053-00	29	1	31
Lake Sixteen	Otter Tail	56-0100-00	107	No estimate provided	7

Reasonableness of Corroborating Sources

Generally, the MPCA used a weight-of-evidence approach as it reviewed the corroborating evidence from other sources to determine if the wild rice beneficial use exists or has existed in a water. If the 2008 MDNR report identified a water with a one-acre estimate or with no acreage estimate of wild rice, and additional evidence from another source suggested that sufficient wild rice was present in a water to demonstrate the beneficial use, the MPCA is proposing to list it as a wild rice water. Many of the supporting documents used in the MPCA's review do not contain complete information about the density or acreage of wild rice. Therefore, MPCA scientists used their best professional judgement to determine if the available information provided reasonable evidence that the water demonstrated the wild rice beneficial use (or had done so since November 28, 1975).

The sources used as corroborating evidence varied in their level of detail and strength of certainty. MPCA staff used their best professional judgement to make reasonable assumptions about how to use the corroborating sources. For example, where a corroborating source qualitatively identified a water as having "lush" stands of wild rice, the MPCA considered that it met the beneficial use as a wild rice water. Because no single source provided comprehensive or consistent data about the presence of wild rice, the MPCA was not able to apply a strict criterion for what information did or did not reasonably characterize a wild rice water. The MPCA reasonably made the best use of the information from all sources as a basis for professional judgement.

Except for a few waters where the location of the wild rice could not be determined within a specific WID, the MPCA is proposing to include all the waters from the MDNR Wild Rice Harvester Survey Report (2007). The results of the harvester survey reasonably demonstrated the wild rice beneficial use in these waters.

It is also reasonable to include the waters identified in the Minnesota Wild Rice Management Workgroup List of 350 Important Wild Rice Waters. Most of these 350 important wild rice waters were also identified in the 2008 MDNR list. Given the broad expertise of the workgroup that created the list of 350 important wild rice waters, MPCA reasonably relies on this source for demonstrating the beneficial use for these waters since November 28, 1975.

MDNR also has an Aquatic Plant Management (APM) database that contains multi-year wild rice permit information regarding the removal of wild rice or the seeding of wild rice for restoration, including those waters MDNR has targeted for restoration. It is reasonable to assume that waters where rice is dense enough to request an MDNR permit for removal are waters that meet the wild rice beneficial use. The MPCA only included the wild rice waters that received restoration permits for seeding of wild rice if there was supporting evidence that the restoration was successful. The MPCA does not consider the seeding or intention of seeding of wild rice to be a reasonable basis to demonstrate the beneficial use.

The MPCA is also proposing to identify as wild rice waters all of the streams and wetlands from the MPCA's biomonitoring databases that MPCA biologists identified as having sufficient density and acreage to demonstrate the wild rice beneficial use. Since 2013, MPCA field crews began documenting presence and abundance of aquatic vegetation, including wild rice, as part of the qualitative habitat assessment for stream and river monitoring. The MPCA's wetland specialists have collected similar information for wetlands. For this rulemaking, MPCA biologists reviewed the information in their databases and compiled a list of proposed wild rice waters. It is reasonable for the MPCA to propose the waters identified through this process as wild rice waters because the source information was generated and reviewed by knowledgeable experts.

The MPCA included most of the 393 lakes and river segments included on the 1854 Treaty Authority's list of waters with wild rice within the 1854 Ceded Territory (3/24/2016 version). The 1854 Treaty Authority is responsible for co-managing wild rice within the 1854 Ceded Territory, which encompasses northeastern Minnesota. They maintain a list of wild rice waters within the territory, working with partners such as the Fond du Lac, Grand Portage and Bois Forte Bands. The 1854 Treaty Authority has conducted wild rice field surveys in the 1854 Ceded Territory since 1996. Because the 1854 Treaty Authority staff includes wild rice resource managers and biologists who are very knowledgeable about wild rice identification, the MPCA reasonably proposes the identified waters.

The MPCA also reviewed information about sites with wild rice that were sampled from 2011-2013, when University of Minnesota field crews conducted field surveys of waters across the state as part of the wild rice study (Exhibit 27). At each site, crews estimated wild rice coverage or performed wild rice stem counts. The MPCA reviewed the information provided by field crews and chose not to propose sites with no rice, or those that had sparse rice, unless the MPCA has additional evidence from other sources that the water met the wild rice beneficial use. Most of the waters identified in this survey demonstrated that the wild rice beneficial use exists and are proposed as wild rice waters. These waters are reasonably proposed as wild rice waters on the basis of the information gathered during the field surveys.

Some of the sources provided information of varying levels of usefulness for the MPCA's purpose. One example is the Minnesota Biological Survey database, maintained by the MDNR. The database includes information on surveyed sites with references to the plant species present at each site and narrative descriptions that, in some cases, provide additional detail about the extent of the species at the site. MPCA staff reviewed the narrative descriptions in the database for corroborating evidence supporting the wild rice beneficial use. The MPCA considered corroborating evidence to include descriptors such as "thick wild rice present," "emergent aquatic plant community dominated by wild rice," "emergent plant community dominated by *Zizania palustris*," "dense stand of wild rice," and "ringing the entire shoreline of a lake." It is reasonable for the MPCA to determine that the above descriptors demonstrate the beneficial use and, where adequate descriptors were not provided, that this source did not provide corroborating evidence. The MDNR botanists and plant specialists who completed the field surveys are experts in plant identification and knowledgeable about plant communities.

The MPCA also included some of the waters submitted in response to the MPCA's 2013 Call for Data. The MPCA's Call for Data was a widely distributed solicitation requesting information on wild rice waters in Minnesota and ambient sulfide monitoring data. The MPCA reviewed the submissions and added waters to the list of proposed waters where there were at least two acres of wild rice. The MPCA also included some waters identified in the call for data that, although lacking wild rice acreage information, were corroborated by other sources, such as 1854 Treaty Authority, Aquatic Plant Management database, Minnesota Biological Survey, Minnesota DNR 2008 report, and Minnesota Wild Rice Management Workgroup.

In Attachment 2, the MPCA provides a series of tables documenting the source information used as a basis to determine if the beneficial use exists in each proposed wild rice water. An excerpt of the list of waters is provided as an example in Table 4. The tables in Attachment 2 are organized by basin and identify proposed wild rice waters in each major watershed. Waters included in the MDNR 2008 *Natural Wild Rice in Minnesota* report with 2 acres or more of wild rice are identified in Attachment 2 as MDNR 2008a. Although some of the waters identified in Attachment 2 had sufficient wild rice to meet the beneficial use solely on the basis of the MDNR 2008a source, for the sake of completeness the MPCA also identified additional sources of data that reinforced this finding. For example, in Table 4 below, Bluebill Lake included sources MDNR 2008a, 1854 list and 7050.0470. This would indicate that Bluebill Lake was listed in the MDNR report as having 2 acres or more of rice, was also on the 1854 Treaty Authority's March 24, 2016 List, and was listed as a WR water in 7050.0470.

Waters identified in the *MDNR Natural Wild Rice in Minnesota* report with acreage estimates of one acre or without an acreage estimate are identified in the tables as MDNR 2008b. In these cases, additional evidence was required from other sources to determine that wild rice was present in quantities sufficient to demonstrate the beneficial use. For example, Bigsby Lake in Table 4 below has a listing of MDNR 2008b and 1854 List, which indicates that Baker Lake did not demonstrate the beneficial use on the basis of its inclusion in the 2008 report alone, but was included because its listing as a wild rice water was corroborated by its inclusion on the 1854 Treaty Authority's March 24, 2016 Inventory of wild rice waters. Table 5 provides the key for each of the sources used in Attachment 2.

Table 4.Example Excerpt from Attachment 2 of Proposed Wild Rice Waters in the Lake Superior Basin and Sources Used to Demonstrate Beneficial Use

04010101 Lake Superior - North (3/21/2017)

Name	County	WID	Water Type	7050.0470	Source(s)
Baker Lake	Cook	16-0486-00	Lake		1854 List, MPCA 2013
Bigsby Lake	Cook	16-0344-00	Lake		1854 List, MDNR 2008b
Bluebill Lake	Lake	38-0261-00	Lake	[WR]	1854 List, 7050.0470, MDNR 2008a
Bower Trout Lake	Cook	16-0175-00	Lake		1854 List
Brule River	Cook	04010101-502	Stream		1854 List
Cabin Lake	Lake	38-0260-00	Lake	[WR]	1854 List, 2007, 7050.0470, MDNR 2008a, 2010

[WR] indicates wild rice waters identified in rule in 1998.

Table 5. Legend for Sources Listed to Demonstrate Use and Value of the Wild Rice Beneficial Use

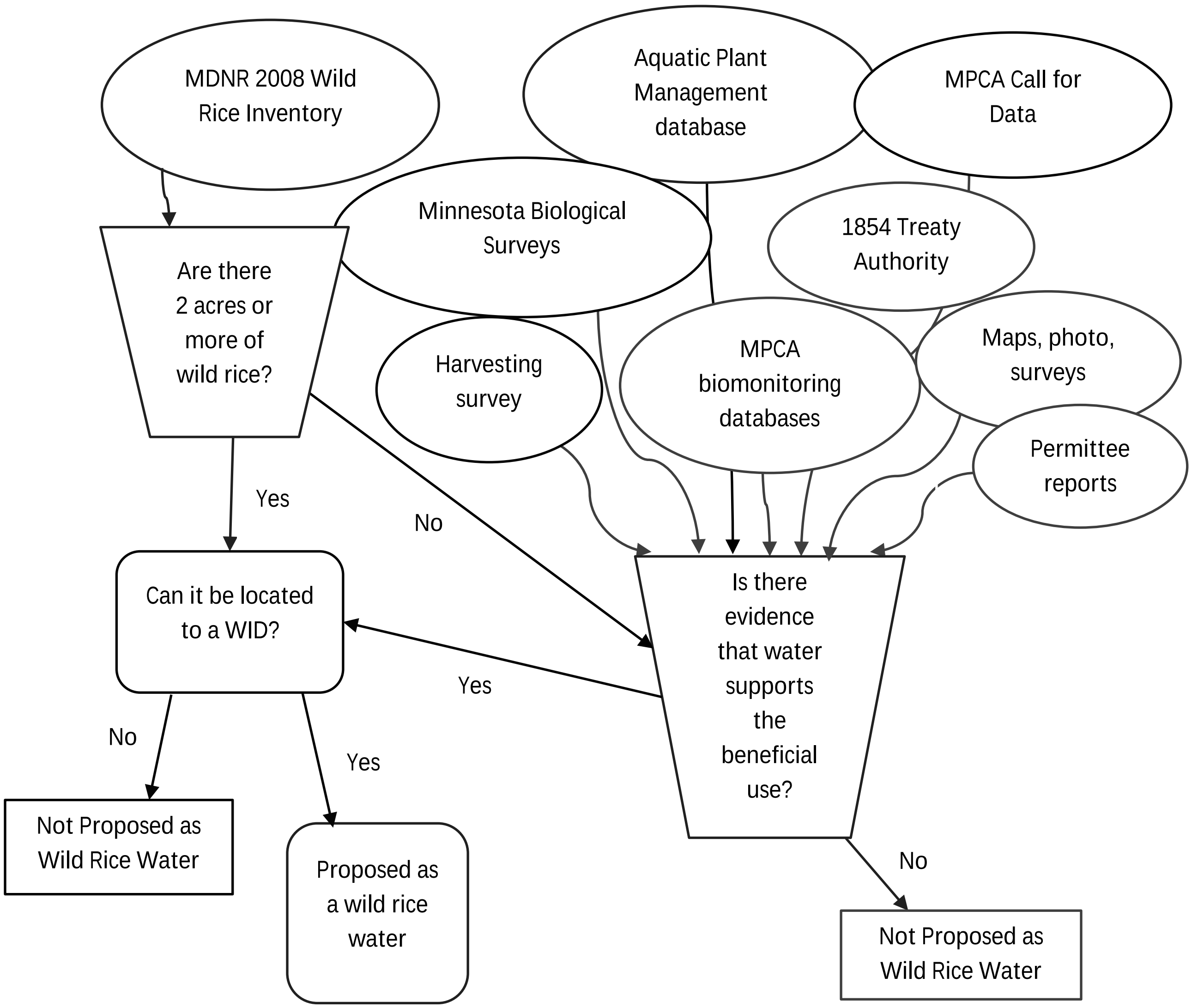
Source	Code used in Attachment 2 for Source
Natural Wild Rice in Minnesota—A Wild Rice Study Report to the Minnesota Legislature 2008	MDNR 2008a, MDNR 2008b
Minnesota DNR Wild Rice Harvester Survey Report	2007
Minnesota Wild Rice Management Workgroup List of 350 Important Wild Rice Waters	2010
1854 Treaty Authority List of Wild Rice Waters (3/24/2016)	1854 List
MDNR Aquatic Plant Management Database	MDNR APM
MPCA Biomonitoring Field Sites	MPCA Biomon
University of Minnesota/MPCA Wild Rice Study Field Survey Sites	U of M/MPCA 2013
Minnesota Biological Survey Database	MBS 2011, MCBS 2017
MPCA 2013 Call for Data	MPCA 2013
Permittee Monitoring	Permittee
[WR] Waters (7050.0470)	7050.0470
Waters identified by MDNR in 2015 as wild rice waters	MDNR 2015
MPCA review of various MPCA and MDNR surveys and records	Survey

MDNR 2008a indicates waters in MDNR 2008 report with greater than or equal to 2 acres of wild rice.

MDNR 2008b indicates waters in MDNR 2008 report with estimates of less than 2 acres of wild rice or without acreage estimates.

Figure 1 is a schematic representation of the generalized process the MPCA followed in using the source information to propose a water body as a Class 4D wild rice water.

Figure 1. Generalized Process for Proposed Class 4D Wild Rice Waters



Note on Waters Within Indian Reservations

The MPCA's list of proposed wild rice waters include waters that are wholly or partially within a federally recognized Indian reservation. The determination of whether waters were wholly or partially within a reservation was made using the same map layers used to develop the 2016 Impaired Waters List.

The proposed wild rice waters list was compiled from a variety of sources including waters identified by tribes and DNR. Draft versions of the proposed list, including these waters within Indian reservations, have been available to the public in a variety of formats during rule development.

The MPCA has the authority to identify and list wild rice waters as 4D waters to which the standard applies for all waters of the state, which includes waters within Indian reservations. The MPCA recognizes that tribes have a shared interest in waters within Indian reservations and that opinions differ as to whether waters wholly within a federally recognized Indian reservation should be specifically identified by the MPCA as a Class 4D wild rice water in Minnesota Rules.

The MPCA is proposing to identify wild rice waters that are partially within Indian reservations as Class 4D waters. It is reasonable to do so to comply with the 2011 legislative requirements and for consistency purposes. Table 6 below, shows the proposed Class 4D wild rice waters that are located partially within Indian reservations.

Table 6 – Proposed Class 4D Waters Located Partially Within Indian Reservations

County	Waterbody Name	MPCA_WID	Tribal Reservation	Waterbody Type
St. Louis	Vermillion (Rice Bay)	69-0378-00	Bois Forte	Lake
Cook	Pigeon River	04010101-501	Grand Portage	Stream
Cook	Swamp Lake	16-0009-00	Grand Portage	Lake
Beltrami	Moose Lake	04-0011-00	Leech Lake	Lake
Beltrami	Pimushe Lake	04-0032-00	Leech Lake	Lake
Beltrami	Turtle River	07010101-510	Leech Lake	Stream
Cass	Boy Lake	11-0143-00	Leech Lake	Lake
Cass	Boy River	07010102-518	Leech Lake	Stream
Cass	Boy River	07010102-520	Leech Lake	Stream
Cass	Inguadona Lake	11-0120-00	Leech Lake	Lake
Cass	Leech Lake	11-0203-00	Leech Lake	Lake
Cass	Mud Lake	11-0100-00	Leech Lake	Lake
Itasca	Dixon Lake	31-0921-00	Leech Lake	Lake
Hubbard	Mud Lake	29-0065-00	Leech Lake	Lake
Itasca	Mississippi River	07010101-756	Leech Lake	Stream
Itasca	Mississippi River above Clay Boswell	07010101-756	Leech Lake	Stream
Itasca	Mississippi River below Clay Boswell	07010101-756	Leech Lake	Stream
Itasca	Natures Lake	31-0877-00	Leech Lake	Lake
Itasca	Rice Lake	31-0876-00	Leech Lake	Lake
Cass	Winnibigoshish Lake	11-0147-00	Leech Lake	Lake
Itasca	Third River	07010101-526	Leech Lake	Stream

County	Waterbody Name	MPCA_WID	Tribal Reservation	Waterbody Type
Itasca	White Oak Lake	31-0776-00	Leech Lake	Lake
Itasca	Whitefish Lake	31-0843-00	Leech Lake	Lake
Aitkin	Big Sandy Lake	01-0062-00	Mille Lacs	Lake
Aitkin	Mallard Lake	01-0149-00	Mille Lacs	Lake
Aitkin	Minnewawa Lake	01-0033-00	Mille Lacs	Lake
Aitkin	Swamp Lake	01-0092-00	Mille Lacs	Lake
Crow Wing	Whitefish Lake	18-0001-00	Mille Lacs	Lake
Mille Lacs	Onamia Lake	48-0009-00	Mille Lacs	Lake
Mille Lacs	Mille Lacs	48-0002-00	Mille Lacs	Lake
Becker	Shell Lake	03-0102-00	Minnesota Chippewa	Lake
Cass	Laura Lake	11-0104-00	Minnesota Chippewa	Lake
Otter Tail	Star Lake	56-0385-00	Minnesota Chippewa	Lake
St. Louis	Big Rice Lake	69-0669-00	Minnesota Chippewa	Lake
St. Louis	Pelican Lake	69-0841-00	Minnesota Chippewa	Lake
Goodhue	Sturgeon Lake	25-0017-01	Prairie Island	Lake
Beltrami	Blackduck River	09020302-513	Red Lake	Stream
Lake of the Woods	Lake of the Woods	39-0002-00	Red Lake	Lake
Pennington	Clearwater River	09020305-647	Red Lake	Stream
Clearwater	Clearwater River	09020305-647	Red Lake	Stream
Becker	Buffalo Lake	03-0350-00	White Earth	Lake
Becker	Flat Lake	03-0242-00	White Earth	Lake
Becker	Indian Creek	07010106-569	White Earth	Stream
Becker	Little Round Lake	03-0302-00	White Earth	Lake
Clearwater	Clearwater River	09020305-517	White Earth	Stream

While some tribes have raised concerns about waters within their reservations being identified as Class 4D wild rice waters in Minnesota Rules, other tribes have specifically requested that their waters be identified and have stated they want to provide information for identifying additional waters as Class 4D waters. Table 7 below shows those waters that the MPCA believes could be reasonably listed as Class 4D waters, because the Class 4D wild rice beneficial use is existing or has existed since November 28, 1975. In keeping with the focus on improving clarity and certainty about where the wild rice sulfate standard applies, the MPCA believes it is reasonable to identify all Class 4D wild rice waters in Minnesota.

However, recognizing the shared state and tribal jurisdiction, the MPCA is proposing not to list waters within tribal reservation boundaries as Class 4D waters, if specifically requested by the tribe. Of the waters listed below, those in the Leech Lake reservation will not be identified in Minn. R. 7050.0471 as Class 4D wild rice waters in accordance with that tribe's request made during consultation discussions. Waters within the boundaries of other reservations are proposed to be identified as Class 4D wild rice waters. If, during the public comment period, a tribe requests that their waters not be identified as Class 4D waters, the MPCA will remove those waters from the final adopted list of Class 4D wild rice waters.

Table 7 – Potential Class 4D Waters Located Wholly Within Indian Reservations

County	Waterbody Name	MPCA_WID	Tribal Reservation	Waterbody Type	* Indicates Proposed 4D Water
Koochiching	Nett Lake	36-0001-00	Bois Forte	Lake	*
Carlton	Bang Lake	09-0046-00	Fond du Lac	Lake	*
Carlton	Cedar Lake	09-0031-00	Fond du Lac	Lake	*
Carlton	Dead Fish Lake	09-0051-00	Fond du Lac	Lake	*
Carlton	Hardwood Lake	09-0030-00	Fond du Lac	Lake	*
Carlton	Jaskari Lake	09-0050-00	Fond du Lac	Lake	*
Carlton	Miller Lake	09-0053-00	Fond du Lac	Lake	*
Carlton	Perch Lake	09-0036-00	Fond du Lac	Lake	*
Carlton	Rice Portage Lake	09-0037-00	Fond du Lac	Lake	*
Carlton	unnamed (FDL1)	09-0178-00	Fond du Lac	Lake	*
Carlton	Wild Rice Lake	09-0023-00	Fond du Lac	Lake	*
St. Louis	Martin Lake	69-0768-00	Fond du Lac	Lake	*
St. Louis	Simian Lake	69-0619-00	Fond du Lac	Lake	*
St. Louis	Side Lake	69-0699-00	Fond du Lac	Lake	*
St. Louis	Twin Lake	69-0695-00	Fond du Lac	Lake	*
St. Louis	Unnamed (FDL2) Lake	69-1454-00	Fond du Lac	Lake	*
Cook	Cuffs Lake	16-0006-00	Grand Portage	Lake	*
Cook	Mount Maud Wetland	16-0914-00	Grand Portage	Wetland	*
Cook	Teal Lake	16-0003-00	Grand Portage	Lake	*
Cook	unnamed (Grd Portage)	04010101-757	Grand Portage	Stream	*
Beltrami	Andrusia Lake	04-0038-00	Leech Lake	Lake	
Beltrami	Big Lake	04-0049-00	Leech Lake	Lake	
Beltrami	Big Rice Lake	04-0031-00	Leech Lake	Lake	
Beltrami	Buck Lake	04-0042-00	Leech Lake	Lake	
Beltrami	Burns Lake	04-0001-00	Leech Lake	Lake	
Beltrami	Cass Lake	04-0030-00	Leech Lake	Lake	
Beltrami	Kitchi Lake	04-0007-00	Leech Lake	Lake	
Beltrami	Little Rice Lake	04-0015-00	Leech Lake	Lake	
Beltrami	Mississippi River	07010101-755	Leech Lake	Stream	
Cass	Big Boy Lake	11-0144-00	Leech Lake	Lake	
Cass	Bullhead Lake	11-0184-00	Leech Lake	Lake	
Cass	Chub Lake	11-0517-00	Leech Lake	Lake	
Cass	Drumbeater Lake	11-0145-00	Leech Lake	Lake	
Cass	Flaherty Lake	11-0492-00	Leech Lake	Lake	

County	Waterbody Name	MPCA_WID	Tribal Reservation	Waterbody Type	* Indicates Proposed 4D Water
Cass	Jack Lake	11-0400-00	Leech Lake	Lake	
Cass	Lomish Lake	11-0136-00	Leech Lake	Lake	
Cass	Long Lake	11-0142-00	Leech Lake	Lake	
Cass	Middle Sucker Lake	11-0317-00	Leech Lake	Lake	
Itasca	Birdseye Lake	31-0834-00	Leech Lake	Lake	
Itasca	Bowstring Lake	31-0813-00	Leech Lake	Lake	
Itasca	Cut Foot Sioux Lake	31-0857-00	Leech Lake	Lake	
Itasca	Egg Lake	31-0817-00	Leech Lake	Lake	
Itasca	Farley Lake	31-0902-00	Leech Lake	Lake	
Itasca	First River Lake	31-0818-00	Leech Lake	Lake	
Cass	Nushka Lake	11-0137-00	Leech Lake	Lake	
Hubbard	Spring Lake	29-0054-00	Leech Lake	Lake	
Itasca	Little Ball Club Lake	31-0822-00	Leech Lake	Lake	
Itasca	Little Cut Foot Sioux Lake	31-0852-00	Leech Lake	Lake	
Itasca	Little White Oak Lake	31-0740-00	Leech Lake	Lake	
Itasca	Lost Lake	31-0900-00	Leech Lake	Lake	
Itasca	Lower Pigeon Lake	31-0893-00	Leech Lake	Lake	
Itasca	Middle Pigeon Lake	31-0892-00	Leech Lake	Lake	
Itasca	Mosomo Lake	31-0861-00	Leech Lake	Lake	
Itasca	Pigeon Dam Lake	31-0894-00	Leech Lake	Lake	
Itasca	Pigeon River	07010101-600	Leech Lake	Stream	
Itasca	Rabbits Lake	31-0923-00	Leech Lake	Lake	
Itasca	Raven Lake	31-0925-00	Leech Lake	Lake	
Cass	Portage Creek	07010102-545	Leech Lake	Stream	
Cass	Portage Lake	11-0134-00	Leech Lake	Lake	
Cass	Portage Lake	11-0204-00	Leech Lake	Lake	
Cass	Rabbit Lake	11-0135-00	Leech Lake	Lake	
Cass	Rat Lake	11-0285-00	Leech Lake	Lake	
Cass	Rice Lake	11-0402-00	Leech Lake	Lake	
Cass	Six Mile Lake	11-0146-00	Leech Lake	Lake	
Cass	Steamboat Bay	11-0491-00	Leech Lake	Lake	
Cass	Steamboat River	07010102-507	Leech Lake	Stream	
Cass	Wabegon Lake	11-0403-00	Leech Lake	Lake	
Itasca	Sand Lake	31-0826-00	Leech Lake	Lake	
Itasca	Simpson Lake	31-0867-00	Leech Lake	Lake	
Itasca	Sioux Lake	31-0907-00	Leech Lake	Lake	
Itasca	Stone Axe Lake	31-0828-00	Leech Lake	Lake	
Itasca	Tuttle Lake	31-0821-00	Leech Lake	Lake	
Itasca	Unnamed Lake	31-0815-00	Leech Lake	Lake	

County	Waterbody Name	MPCA_WID	Tribal Reservation	Waterbody Type	* Indicates Proposed 4D Water
Itasca	Unnamed Lake	31-0860-00	Leech Lake	Lake	
Itasca	Upper Pigeon Lake	31-0908-00	Leech Lake	Lake	
Itasca	Wart Lake	31-0859-00	Leech Lake	Lake	
Itasca	Wilderness Lake	31-0901-00	Leech Lake	Lake	
Mille Lacs	Ogechie Lake	48-0014-00	Mille Lacs	Lake	*
Mille Lacs	Shakopee Lake	48-0012-00	Mille Lacs	Lake	*
Beltrami	Gourd Lake	04-0253-00	Red Lake	Lake	*
Beltrami	Heart Lake	04-0271-00	Red Lake	Lake	*
Clearwater	Second Lake	15-0091-00	Red Lake	Lake	*
Becker	Aspinwall Lake	03-0104-00	White Earth	Lake	*
Becker	Bass Lake	03-0088-00	White Earth	Lake	*
Becker	Big Basswood Lake	03-0096-00	White Earth	Lake	*
Becker	Big Elbow Lake	03-0159-00	White Earth	Lake	*
Becker	Big Rat Lake	03-0246-00	White Earth	Lake	*
Becker	Big Rush Lake	03-0103-00	White Earth	Lake	*
Becker	Big Sugarbush Lake	03-0304-00	White Earth	Lake	*
Becker	Bullhead Lake	03-0312-00	White Earth	Lake	*
Becker	Bush Lake	03-0212-00	White Earth	Lake	*
Becker	Cabin Lake	03-0346-00	White Earth	Lake	*
Becker	Camp Seven Lake	03-0151-00	White Earth	Lake	*
Becker	Carman Lake	03-0209-00	White Earth	Lake	*
Becker	Eagen Lake	03-0318-00	White Earth	Lake	*
Becker	Equay Lake	03-0219-00	White Earth	Lake	*
Becker	Gull Creek	09020108-569	White Earth	Stream	*
Becker	Kneebone Lake	03-0090-00	White Earth	Lake	*
Becker	Little Basswood Lake	03-0092-00	White Earth	Lake	*
Becker	Little Flat Lake	03-0217-00	White Earth	Lake	*
Becker	Little Rice Lake	03-0239-00	White Earth	Lake	*
Becker	Lower Egg Lake	03-0210-00	White Earth	Lake	*
Becker	Many Point Lake	03-0158-00	White Earth	Lake	*
Becker	Mary Yellowhead Lake	03-0243-00	White Earth	Lake	*
Becker	Round Lake	03-0155-00	White Earth	Lake	*
Becker	Spindler Lake	03-0214-00	White Earth	Lake	*
Becker	St. Clair Lake	03-0430-00	White Earth	Lake	*
Becker	Tea Cracker Lake	03-0157-00	White Earth	Lake	*
Becker	Unnamed Lake	03-0786-00	White Earth	Lake	*
Becker	Unnamed Lake	03-0434-00	White Earth	Lake	*
Becker	Unnamed Lake	03-1093-00	White Earth	Lake	*
Becker	Upper Egg Lake	03-0206-00	White Earth	Lake	*

County	Waterbody Name	MPCA_WID	Tribal Reservation	Waterbody Type	* Indicates Proposed 4D Water
Becker	White Earth Lake	03-0328-00	White Earth	Lake	*
Becker	Winter Lake	03-0216-00	White Earth	Lake	*
Clearwater	Wild Rice River	09020108-512	White Earth	Stream	*
Mahnomen	Lone Long Lake	44-0002-00	White Earth	Lake	*
Mahnomen	McCraney Lake	44-0080-00	White Earth	Lake	*
Mahnomen	Roy Lake	44-0001-00	White Earth	Lake	*
Mahnomen	Wild Rice River	09020108-510	White Earth	Stream	*
Mahnomen	Wild Rice River	09020108-510	White Earth	Stream	*
Clearwater	Wild Rice River	09020108-512	White Earth	Stream	*
Clearwater	Wild Rice River	09020108-512	White Earth	Stream	*
Clearwater	Lower Rice Lake	15-0130-00	White Earth	Lake	*
Becker	Tamarac NWR - Egg River	09020103-748	White Earth	Stream	*

It should be noted that, after the adoption of the rule as the MPCA moves to assess waters for compliance with the wild rice sulfate standard, the MPCA will continue to use the assessment and impaired waters listing process developed in conjunction with the Tribes and EPA. Under this process, the MPCA works cooperatively with Tribes during assessment. Also, in preparing the CWA 305(b) National Water Quality Inventory Report and 303(d) Impaired Waters List, the MPCA identifies waters within Indian reservations with the following notes on the Report and Impaired Waters List as appropriate:

- Wholly within – For the 303(d) list, the MPCA lists waters that are lying wholly within Indian reservations (other than the Mille Lacs reservation) in a separate section of the list and includes the following note: "This assessment list was prepared under authority in state law to determine whether waters within the state are impaired. For purposes of the 303(d) list, these assessments are advisory to EPA only because these water bodies are located wholly within a federally recognized Indian reservation and EPA has stated that it does not approve the State's impaired waters listings for waters that are partially or wholly within the boundaries of an Indian reservation."
- Partially within – For the 303(d) list, the MPCA lists waters that are partially within Indian reservations with all other waters but notes that they have partial tribal designation and includes the following note about these bodies of water: "The state and tribe have worked cooperatively on this water quality assessment and agree that the water should be included on the State's impaired waters list. For the purposes of the 303(d) list, the assessment of the portion of the water body within the reservation is advisory to EPA only because EPA has stated that it does not approve the State's impaired waters listings for waters within the boundaries of an Indian reservation.
- Mille Lacs Reservation - The State of Minnesota and the federal government disagree on the boundaries of the Mille Lacs Reservation. As a result, for purposes of the 303(d) list, the

assessment of all or part of any waterbodies within the Mille Lacs reservation is advisory to EPA only because EPA has stated that it does not approve the State's impaired waters listings for waters within the boundaries of an Indian reservation. By identifying this water as within the disputed Mille Lacs Reservation and placing it on the 303(d) list, the State does not concede that this water is within the Mille Lacs Reservation nor that the MPCA lacks jurisdiction to list this water as impaired under 303(d).

4. Reasonableness of the proposed process for future identification of wild rice waters

The MPCA acknowledges that the wild rice waters identified in this rulemaking may not include every water in Minnesota where the wild rice beneficial use has existed since November 28, 1975. Although the MPCA has made reasonable use of the information available to develop and justify the proposed list of Class 4D wild rice waters, there are additional waters that may be wild rice waters but for which there is not yet sufficient information to determine that the beneficial use is demonstrated. The MPCA has therefore developed a list of waters for which there is "insufficient information" at this time to justify including them in the proposed rules. This list was created for informational purposes and future reference, but is not a part of this rulemaking. The MPCA is confident that in the future, additional Class 4D wild rice waters will be identified, either through the MPCA's own assessment and monitoring activities or from outside sources, and there will be a need for future rulemaking to add them to Minn. R. 7050.0471.

Minn. Stat. § 115.44, subd. 2 gives the MPCA authority to conduct rulemaking to classify waters and the MPCA will use this authority to address the future need to amend the list of wild rice waters based on new information. However, given the complexity of identifying wild rice waters, the high level of interest in this resource, and the potential for significant consequences of listing a wild rice water, it is reasonable and prudent to establish a process to provide additional transparency and opportunity for public involvement about these future decisions. The MPCA is proposing in this rulemaking to:

- Formalize a pre-rulemaking process to obtain and review information; and
- Clarify the information the MPCA will consider in making future decisions about adding wild rice waters to Minn. R. 7050.0471.

Reasonableness of conducting a pre-rulemaking solicitation for information through the triennial review process

The MPCA will conduct rulemaking to make all future changes to the list of identified wild rice waters in Minn. R. 7050.0471. Some commenters have suggested that the MPCA establish criteria in rule to identify wild rice waters without rulemaking or adopt a process to "automatically" add wild rice waters without rulemaking. However, the MPCA does not believe that establishing such a process is reasonable. As described in the review of sources used to develop the proposed list of wild rice waters, the types of information available about wild rice require judgement in interpretation and do not lend themselves to specific, determinant criteria. In addition, having a process to add a wild rice water without rulemaking does not allow for the exercise of required judgement or meaningful public participation in determinations having significant consequences.

The decision to identify a water as a wild rice water may have significant consequences for those parties who value wild rice and for dischargers to that water. The rulemaking process ensures that the MPCA demonstrates, through the Statement of Need and Reasonableness, a reasonable justification that the wild rice beneficial use exists based on information specific to a water body and that the public has the benefit of notice and the opportunity to comment on that demonstration.

Amending water quality standards is a complicated, time consuming, and resource-intensive process and a number of factors determine when the MPCA proposes rulemaking. It is reasonable that the MPCA make the best use of its resources to ensure that rulemaking to propose a water as a wild rice water in Minn. R. 7050.0471 is justified and supported by the best information available. Therefore, the MPCA is incorporating an existing process - the federally mandated triennial review of the water quality standards - to provide a pre-rulemaking mechanism to obtain information and provide public notice about potential wild rice waters. The MPCA intends that this pre-rulemaking step provide an additional opportunity to address the unique issues associated with wild rice, but does not intend that it limit either the public or the MPCA's ability to address those issues through other authorities or directives.

The CWA (§ 303 (c)(1)) requires the MPCA to undertake a public review of its water quality standards every three years. To prepare for the triennial review, the MPCA identifies the additions, revisions and amendments to the water quality standards that are needed to carry out its CWA responsibilities to protect, improve, and restore water quality. The MPCA then seeks public comment about these specific issues, as well as inviting general comment on any subject in Minnesota's water quality rules. As part of the triennial review process, the MPCA identifies its priorities and proposed schedules for conducting rulemaking on its Water Quality Standards webpage at https://www.pca.state.mn.us/water/water-quality-standards. While the triennial review process is a key component of developing the MPCA's priorities for water quality rulemaking, inclusion of a standard or topic in the triennial review does not mandate rulemaking or specify any timeframe in which a rule change must be completed.

Although the triennial review process provides the opportunity for public input regarding any beneficial uses, the MPCA is establishing a specific requirement that the commissioner solicit information about potential Class 4D wild rice waters as part of each triennial review. The MPCA believes that the importance of correctly identifying wild rice waters justifies this additional level of scrutiny and that the triennial review provides a reasonable forum for obtaining information from and providing information to the interested public.

Reasonableness of the commissioner's determination regarding the evidence to be considered in future decisions to identify a wild rice water.

In the process of developing the proposed list of wild rice waters, the MPCA reviewed information from a number of sources and made a series of judgements. The MPCA's goal for evaluating source information was to determine whether it provided a basis to determine that wild rice was present in amounts that demonstrated the Class 4D beneficial use (use of the grain as food for wildlife and humans). Different sources provided different types of information to support this determination. Some sources provided information about the extent of wild rice, some provided information about density of certain wild rice beds and some provided information about the history of harvest. In the previous discussion of the sources and the process the MPCA used to develop the list of wild rice waters being proposed in this rulemaking, the MPCA discusses how it combined certain basic assumptions, corroborating information, and best professional judgement to determine which waters should be listed as wild rice waters.

While the circumstances and information available to identify the wild rice waters proposed in this rulemaking may be different from the circumstances and information available to guide the MPCA's future decisions, it is reasonable to require the information to support consideration of future listings to be based on similar principles. The MPCA has an obligation to ensure that it has a consistent basis for identifying a wild rice water before conducting rulemaking to add that water to Minn. R. 7050.0471. Proposed subpart 2 provides examples of the type of information that will provide that support. Although the proposed language does not preclude the submission of other types of information, it identifies three examples of evidence that can demonstrate that the beneficial use exists. The evidence can show:

- A history of human harvest;
- The use of the grain as food for wildlife; or
- At least two acres of wild rice are present.

The first two types of evidence, the history of human harvest and the use of the grain as food for wildlife, are based directly on the wild rice beneficial use in proposed Minn. R. 7050.0224, subpart 5 "the use of the grain of wild rice as a food source for wildlife and humans." With these two examples, the MPCA is reasonably stating that evidence that can demonstrate that humans have harvested the grain or wildlife has used it as a food source is supportive of a beneficial use determination. The third example of evidence that can support a beneficial use determination is to show that at least two acres of wild rice are present. This two-acre requirement is based on a criterion the MPCA used to develop the proposed list of wild rice waters; while it is explained more completely below, the MPCA generally believes that the presence of two acres of wild rice generally will support the beneficial use determination. However, this does not mean that two acres of wild rice must be present to demonstrate the beneficial use—a smaller area of dense wild rice may also support the determination of the beneficial use.

In developing the list of wild rice waters proposed in this rulemaking, the MPCA considered many sources of information to determine whether the beneficial use exists. A fundamental source of information was the MDNR's 2008 Report (Exhibit 21). As noted in previous sections, if the MDNR 2008 report identified two or more acres of wild rice, the MPCA considered that the beneficial use was demonstrated and no further corroboration was required. The MPCA is proposing to reflect that same consideration so that, for future identification of wild rice waters, evidence of two or more acres of wild rice will support a proposed beneficial use determination. It is important to recognize that evidence that there are two acres of wild rice does not automatically identify a water as a wild rice water – rulemaking to include that water in Minn. R. 7050.0471 is still required. This is to ensure that the public has an opportunity to review and comment on the evidence, and present any corroborating or refuting evidence of the beneficial use that the MPCA was not aware of at the time the water was identified as a potential Class 4D wild rice water.

In the course of developing the proposed rules, the MPCA considered a number of alternatives for how to verify the beneficial use. The 2011 legislative directive requires the MPCA to establish criteria for designating waters containing natural beds of wild rice including, but not limited to, "minimum acreage and density of wild rice." As it reviewed information describing wild rice beds, the MPCA struggled with how to consider density and acreage. The variable growth habit of wild rice, plus the variability of when and how wild rice may be present in lakes, rivers, streams, and wetlands, made it very difficult to describe in quantitative terms how much rice over how much area would demonstrate the wild rice beneficial use.

The MPCA considered several options for establishing a "threshold" extent of wild rice in a water that would clearly define the beneficial use. The first consideration in characterizing a wild rice water is that wild rice must be present in sufficient quantities to be used as a "food source for wildlife and humans." Wild rice that is present in only small, scattered beds or thinly distributed over a large area does not provide clear evidence that the beneficial use exists. To meet the beneficial use, wild rice must be present at levels that draw human harvest or that will serve as a food source for wildlife. In a preliminary draft of the rules, the MPCA proposed a threshold of four stems/meter^2 over a water area of at least half an acre or a greater density (eight stems/meter^2) over a smaller area (a minimum of a quarter acre). That equated to the amount of wild rice necessary to sustain two ducks for a one-month period.[10] (Exhibit 32)

The MPCA decided that this concept of establishing a quantitative threshold of density and acreage was unfeasible for a number of reasons. In particular, it was difficult to determine a density and acreage threshold that was appropriate for all types of waters. For example, when attempting to calculate wild rice density in a river or stream, determining where to start and stop the evaluation is critical. If rice is very sparse for a stretch and then quite dense in a small area, the start and stop point may significantly affect the density result. Similarly, the area of a wild rice bed is also difficult to measure, as the edges are irregular and in some waters wild rice gradually diminishes at the edges of a bed rather than abruptly stops.

These examples illustrate how predicating the beneficial use determination on wild rice density could inadvertently lead to the ongoing uncertainty and lack of clarity that this rulemaking is intended to resolve. Therefore, a rigid threshold for acreage or density is not included in the proposed rules. However, the MPCA believes that for future listing decisions, it is useful to establish a minimum acreage that provides clear evidence that the beneficial use exists. The establishment of this minimum acreage does not mean that waters with less extensive stands of wild rice never exhibit the beneficial use; in

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[10] *The relationship of the minimum threshold to wildlife foraging was based on evidence that harvesting by humans requires a greater density and acreage than the levels that support wildlife, specifically ducks.*

those cases, additional evidence may provide a basis to confirm the beneficial use. In any future rulemaking to add wild rice waters to the list, the MPCA will need to demonstrate the reasonableness of the proposed addition(s).

The proposal that two acres of wild rice is evidence of the beneficial use does not require that all the rice be present in one, contiguous two-acre bed. An acceptable demonstration may show wild rice present in scattered acreage that totals two acres. The proposed rule also does not specify the density of wild rice that must be present in the beds that comprise the cumulative two acres. The density of wild rice can vary a great deal over time and across a water body and the MPCA has found that it is not reasonable to limit information about the presence of the wild rice beneficial use to only information that identifies specific density thresholds. Many variables can affect whether the wild rice beneficial use exists. Rice may be present in widely scattered beds, it may be sparse in one year and absent for a period of years, and it may be extremely lush and abundant at other times. As noted above, strict criteria of density and acreage cannot account for this wide variability and accurately characterize whether the beneficial use exists. However, it is reasonable to acknowledge that this type of information is one example of how the beneficial use can be demonstrated.

The proposed rule also identifies four different categories of information that can be used to provide an acceptable demonstration that the beneficial use exists. Although it is certainly preferable to have information in more than one category, the MPCA will consider any of the proposed types of information to be equally reliable and valuable evidence in support of a beneficial use determination.

Proposed item A recognizes the validity of written or oral histories about wild rice in waters. For future rulemaking, the MPCA does not consider it reasonable to limit the information it will consider reliable to only information typically available in state government, such as water assessments, studies and reports. In proposed Minn. R. 7050.0471, subpart 2, item A, the MPCA acknowledges the value of information from oral traditions or personal accounts, particularly given the history of rice harvesting by tribal members. As with all evidence relied upon to support (or refute) the existence of the beneficial use, it is important that information of this type, if available, be scrutinized and weighed during the rulemaking process. The proposed rules reasonably require that this type of information be recognized as acceptable evidence subject to standards of validity, reliability, and consistency.

The MPCA considered whether legal precedent would provide guidance for judging the validity of oral or written histories. To do so, the MPCA conducted a review of court cases relating to the application of oral history in cases involving tribal claims. Although the MPCA does not expect that demonstrations of a history of the beneficial use will be generated solely from tribal members, there is valuable precedent in those court cases for how this type of information has been received and applied by courts.

In Zuni Tribes v. United States, (Exhibit 33) three criteria were established for assessing the usefulness of oral history testimony. The MPCA believes they are as equally valid historical evidence as are written materials and photographs. The criteria are:

- Validity. In order to establish a history of harvest, the evidence must be valid, which requires that the evidence can be corroborated in some way. If a single person's statement about the harvest of wild rice can be corroborated by one or more other statements, it may be considered valid. Similarly, written history may be considered valid if it can be corroborated as occurring at the place and time under consideration.

- Reliability. Consideration of the reliability relates to the repeatability of the information. The MPCA expects that if a water is identified through oral tradition as being harvested, there should be multiple sources identifying the same harvest history.
- Consistency. Consistency is similar to validity in that the information will be considered true if it is consistent with other information. If there are multiple reports of wild rice in a particular stream, and the location of the beds is consistently identified, the information will meet the criteria of consistency.

It is important to state that the relevant time-period for providing historical information only covers the period from November 28, 1975 to the present. As previously discussed, that date establishes the point at which the beneficial uses are recognized as existing uses for purposes of the CWA.

Proposed item B recognizes the value of written records as a source of information to establish that the beneficial use is existing. Written information provided much of the basis of the MPCA's proposed list of wild rice waters and the MPCA believes that it will continue to be a primary source of information for future rulemaking about wild rice waters. Written records may or may not include specific information about acreage, density or history, but they can provide pieces of information that, when combined with other sources, can support future proposals. The MPCA considers that written records from organizations such as tribes, the MDNR, the Board of Water and Soil Resources, U.S Geologic Survey, U.S. Fish and Wildlife Service, colleges and universities, will be a valuable source of information to substantiate future rulemaking.

Proposed item C, photographs or aerial surveys, provides another source of information that is reasonable for the MPCA to consider in documenting the beneficial use. As with written records, aerial surveys and photographs may also have limitations and may require additional corroboration to document the beneficial use sufficient to support rulemaking.

Proposed item D recognizes that additional sources of information that are not otherwise specified may also be relevant. The MPCA recognizes that there may be other sources of information, equally compelling but as yet undetermined, which constitute reliable evidence to support a proposal to include a wild rice water in Minn. R. 7050.0471. The fourth option simply acknowledges that the commissioner can consider any other information which provides a reasonable basis for determining that the wild rice beneficial use is existing. It is reasonable for the commissioner to consider all relevant information sources that may become available in the future.

It is important to clarify that the options provided in items A to D only identify the types of information the MPCA will seek through the triennial review process as evidence of the wild rice beneficial use. They give guidance to people who may want a water identified as a wild rice water as to what information they should provide to the MPCA to support listing additional wild rice waters. They are not criteria that automatically identify a water as a wild rice water. When the MPCA proposes rulemaking to identify a WID as a wild rice water, the MPCA must provide a Statement of Need and Reasonableness that justifies that the beneficial use exists in that WID, or has existed at some point after November 28, 1975. This justification may require additional information to verify the beneficial use to supplement the information provided through the triennial review.

5. Reasonableness of identifying the Class 4D wild rice waters in a new rule part

The water quality standards currently identify waters that have a specific designated use in Minn. R. 7050.0470. The MPCA considered a number of alternative ways to incorporate the large number of new waters being identified in the proposed rules as Class 4D wild rice waters. The MPCA is reasonably proposing to identify all Class 4D wild rice waters in a separate new rule part, (Minn. R. 7050.0471) even though many wild rice waters are waters that have other use classifications already identified in Minn. R. 7050.0470. Adopting a separate part to identify wild rice waters is reasonable because wild rice waters are identified by a different identification system than used in 7050.0470. Minn. R. 7050.0470 currently identifies waters by name within major water basins and for rivers and streams, describes the extent of the designated use mainly by the public land survey (PLS) descriptors (e.g. township, range, section) and follows the description with a list of the designated uses of that water. For example: *Amity Creek, (T.50, R.13, S.5, 6; T.50, R.14, S.1; T.51, R.13, S.31, 32; T.51, R.14, S.26, 27, 28, 35, 36): 1B, 2A, 3B;*

The MPCA is reasonably using a different system based on an assigned water identification number (WID), to identify the wild rice waters being proposed. Although many of the proposed wild rice waters are already listed in Minn. R. 7050.0470 for other designated uses, many other waters are not already listed. Adding the wild rice waters to 7050.0470 would mean that in some cases the PLS system would be used, in some cases a WID would be used, and for the already listed waters both types of identifiers might be used. This resulting mixed system of identifiers would be extremely confusing. Although there may be some initial confusion about the same waters being identified for different designated uses in two separate rule parts, the proposed approach clarifies what each rule part includes. The long-term advantages to clarity and usability outweigh the potential for initial confusion. Identifying the wild rice waters in a separate rule part is reasonable because it does not affect the designated uses of the waters currently listed in 7050.0470 and will provide specific clarity as to where the wild rice standard applies.

Currently, waters with specific designated uses are listed alphabetically in Minn. R. 7050.0470 according to major basin and watershed within each major basin. To accommodate requests from interested parties, the MPCA is proposing to use the same organization for the wild rice waters identified in Minn. R. 7050.0471.

In addition to identifying wild rice waters in Minn. R. 7050.0471, the MPCA will also make information about wild rice waters available through an interactive tool organized by basin and major watershed. The MPCA will identify waters by name for each major watershed, and a map will display the location of wild rice waters within the watershed. For each proposed wild rice water, the tool will display the name of the water, county, WID, and the sources the MPCA used to determine if the beneficial use was demonstrated. This interactive search tool also includes a tab that allows users to view all the wild rice waters in a county. This will be helpful for users who wish to look up a water but who do not know the name of the watershed in which it is located. In addition to providing information about proposed wild rice waters, the tool will also include information about waters for which the MPCA has some information about wild rice but not enough to propose the waters in this rulemaking. These waters are labeled in the tool as insufficient information (II) waters.

E. Revision of the numeric standard

A key goal of this rulemaking is to revise the numeric wild rice sulfate standard to incorporate the latest science and information. In this Statement, the MPCA summarizes the scientific information and data analysis, which is explained in more detail in the MPCA's TSD (Exhibit 1), and provides a general overview of the key aspects of the proposed new standard. Some of those key aspects address the averaging time of the standard (duration), and the frequency, meaning how often the magnitude may be exceeded before the standard is considered to be violated.

The number itself is the magnitude of the standard. The current wild rice sulfate standard sets a very clear magnitude (10 mg/L). The existing 10 mg/L standard was derived based largely on data collected in the 1930s and 1940s, which showed a correlation between areas where wild rice grew and areas with lower levels of sulfate in the water. The legislature directed the MPCA to review the standard, including conducting scientific study and data analysis. Based on the results of that effort, it is reasonable to revise the standard to incorporate the new information about how, when and to what extent sulfate affects the ability of wild rice to thrive.

A water quality standard requires a number of elements in order to protect the beneficial use. It is not enough to determine the toxicant and the number at which there is an effect. Clear and effective implementation of a water quality standard also requires defining how the standard applies, where the standard applies and in the case of an equation, how it is calculated.

1. Reasonableness of identifying sulfide in sediment porewater as the toxicant

The existing standard is based on the observed relationship between sulfate concentrations in Minnesota water bodies and the presence and extent of wild rice in those water bodies. Studies in the 1930s and 1940s found that dense wild rice stands were mainly found in water bodies with lower concentrations of sulfate in the surface water. However, sulfate on its own is usually not a particularly harmful substance, at least for humans. The EPA drinking water standard for sulfate is 250 mg/L, but is a "secondary" standard set to prevent a salty taste and other non-health effects, rather than any health issues.[11] Stakeholders have noted that beer frequently has sulfate concentrations above the existing 10 mg/L standard, up to and over 200 mg/L.

An early objective of the research funded by the Legislature was to further explore the correlation between wild rice presence and sulfate levels to better understand the way in which sulfate affects wild rice. MPCA staff had a hypothesis, stated in the study protocol informed by researchers, tribes and

[11] https://www.epa.gov/dwstandardsregulations/secondary-drinking-water-standards-guidance-nuisance-chemicals#table

stakeholders, (Exhibit 7) that sulfate exerts negative effects on wild rice when it is converted to hydrogen sulfide, which is much more toxic than sulfate. In mucky low-oxygen environments, such as those favored by wild rice (which roots in the sediment of aquatic habitats), the respiration of sulfate-reducing bacteria in the sediment converts sulfate diffusing into the sediment from the overlying water into hydrogen sulfide in the sediment porewater. Hydrogen sulfide can take several forms when dissolved in water, depending on pH; the sum of these forms will be called "sulfide" in the rest of this document.

The sulfide concentration in the porewater, the water in the sediment between solid particles, is key because it is the porewater that is in contact with the roots of wild rice. The wild rice study and research supported the MPCA staff's hypothesis, showing that the pollutant that harms wild rice is sulfide in the sediment porewater. The sediment of wild rice habitats typically contains no oxygen because of the low solubility of oxygen in water, combined with the consumption of oxygen by the bacteria exploiting the organic matter of decaying plants. As a result, anaerobic bacteria that respire ("breath") sulfate, rather than oxygen, dominate decomposition if sulfate is available, "breathing out" sulfide. If the sulfide is exposed to oxygen, the resulting reaction (oxidation) detoxifies the sulfide by turning it back into sulfate.

The MPCA's Final TSD (Exhibit 1) explains the role that physical and chemical conditions of the sediment and surface water play in the presence and absence of wild rice among water bodies. Based on findings of the wild rice study, it is reasonable for the MPCA to identify porewater sulfide as a significant controller of the ability of wild rice populations to persist and thrive.

2. Reasonableness of the protective level of sulfide

As a result of the above conclusion, a key part of revising the standard to protect wild rice became the determination of the protective level of sulfide. The MPCA's research and data analysis show that a reasonable protective level of sulfide is 120 µg/L. Wild rice is more likely to thrive – both in terms of presence and amount of wild rice – in water bodies where the porewater sulfide remains below this level. This Statement provides a summary of the MPCA's work to establish a reasonable protective sulfide value; the scientific and technical data are provided in detail in the Final TSD (Exhibit 1).

Developing the Protective Level of Sulfide

Determining the degree of sulfide toxicity to wild rice is a relatively new line of scientific inquiry. Most available information on sulfide toxicity speaks to the effect of sulfide on aquatic life – fish and bugs – and EPA has a national criterion for sulfide in surface waters to protect aquatic life that is very low (2.0 µg/liter). Although the scientific literature has long identified rooted aquatic plants as vulnerable to sulfide toxicity (Lamers et al., 2013), at the start of the MPCA-sponsored research effort there was no published information specific to the effect of sulfide on wild rice. There was some information on the toxicity of sulfide to white rice (*Oryza sativa*), which is related to wild rice and inhabits similar environments. However, it is unclear how applicable data from white rice is to wild rice. Furthermore, many of the studies identified toxic levels of sulfide to a variety of plants, whereas the MPCA needed to identify a protective level of sulfide for wild rice specifically.

Ultimately, multiple lines of evidence, derived from field studies, container (mesocosm) studies, and laboratory hydroponic studies, support the MPCA's decision that the protective level of sulfide for wild rice is 120 µg/L. EPA has consistently recommended "a 'weight-of-evidence' approach that considers all relevant information and its quality, consistent with the level of effort and complexity of detail appropriate in establishing and refining water quality standards." Information can be found in EPA's document entitled *Weight of Evidence in Ecological Assessment*. (Exhibit 34).

In the initial analysis of the study data, the MPCA proposed identifying a protective sulfide level based on a specific "effect concentration." Protective concentrations of a chemical are often identified by exposing organisms to a range of concentrations of that chemical and then calculating the concentration at which some minimal effect is observed, such as a 10% or 20% adverse effect on growth. Effect concentrations are described based on percentage reduction in growth or some other biological response – so a concentration at which there is a 10% reduction is an EC10; a concentration at which 50% are affected is an EC50, etc.

In its preliminary analysis (Exhibit 6, MPCA, 2014), the MPCA had proposed identifying a protective sulfide concentration based on the EC20 and the hydroponic lab experiments; EPA's general guidelines on effect concentrations recommend use of an EC20 or EC25 to protect aquatic communities (i.e. assemblages of species) from chronic exposure to a chemical. Looking at an EC50 (generally interpreted to characterize a concentration that has an adverse impact) and an EC20 (sometimes interpreted as a level of no effect), the MPCA initially suggested that a sulfide concentration greater than 300 µg/L is harmful to wild rice. (Exhibit 6 pp 15-16)

The preliminary analysis was peer reviewed by a panel of experts, whose conclusions are presented in the *Summary Report of the Meeting to Peer Review MPCA's Draft Analysis of the Wild Rice Sulfate Standard Study* (Exhibit 9). While all the peer review information was important to the further development of the standard, two key points were critical to the development of the proposed protective sulfide concentration. First, the peer review panel recommended that the MPCA look at a more conservative protective concentration, such as EC10 or EC5. Secondly, the panel suggested that the MPCA make more use of the field survey data.

In regards to the chosen effect concentration, the panel felt that using the more conservative EC10 or EC5 was more appropriate because the goal of the standard is to protect a single key species – wild rice – rather than an ecological community where multiple species may fill the same ecological niche or role. In other words, the EPA guidance is designed to protect 95% of a community's species, and to preserve the ecological functioning of the community, not to protect an individual species. The peer reviewers recommended a lower effect concentration is appropriate when identifying a protective concentration of a toxin for a single species, in contrast to an ecological community. The EPA guidance itself notes that it may be desirable to modify the general guidance to reflect an ecologically important species.

The MPCA therefore calculated EC10 values from the hydroponic studies, combining data from multiple experiments. EC10 estimates were made for three different representations of sulfide exposure (initial concentration, arithmetic average, and geometric average) yielding EC10 values of 251, 106, and 39 µg/L, respectively. Based on an understanding of sulfide oxidation, of these three estimates the EC10 of

106 µg/L is most defensible. Additional discussion of the MPCA's selection of EC10 is provided in the TSD.

The MPCA also calculated EC10 values from the mesocosm experiments described in Pastor et al., 2017, which yielded two statistically-significant effects of sulfide on wild rice, (1) percent filled, or viable, seeds and (2) number of plants that emerged in the spring. Calculation of EC10 values from linear regressions yields EC10 values of 228 and 121 µg/L, respectively. All of these point estimates of EC10 concentrations have confidence intervals within which the true EC10 value is likely to fall. For the mesocosm data in particular, the 95% confidence intervals are relatively wide.

The peer review panel (Exhibit 9, page 6) also noted that "the field survey provides some of the best data that the MPCA has available to investigate the relationship between wild rice and surface water sulfate levels. These data also offer a means of determining sulfide levels that are protective of wild rice. Much more analysis should be done on this data set." One particular member of the panel also noted (Exhibit 9, pp. F36-37) that a visual estimate of the field survey data "indicates that the cover of wild rice declines at porewater sulfide concentrations above about 0.1 mg/L (100 µg/L)".

The MPCA therefore evaluated the field data in order to derive a protective sulfide concentration. The field data comes from a survey of 108 water bodies, of which 96 water bodies had sufficient water transparency to support wild rice. In order to develop the protective level of sulfide, the MPCA looked at the porewater sulfide concentrations and the presence or absence of wild rice. Most of the data analysis was done on the 96 water bodies with appropriate water clarity, since it is not reasonable to calculate a protective sulfide concentration with data from sites that would not support wild rice no matter how low the sulfide concentration is. [12]

Following the observation from the peer reviewer, the MPCA did a simple visual analysis of the data, looking for a sulfide level at which there was a noticeable reduction in the proportion of sites with wild rice present. The data were examined for such a threshold by calculating the average proportion of sites with rice above any given sulfide concentration, and the pattern examined without any statistical analysis. This showed that the percentage of sites with wild rice declines as sulfide increases, but the decline is relatively slow until the sulfide concentration exceeds 120 µg/L, where there is a notable drop in the percentage of sites with wild rice present. While a small uptick in the proportion of sites with wild rice occurs between 130-150 µg/L, the percentages never return to the 60% or greater that are observed below 120 µg/L. This can be seen with reference to Figure 2 from the TSD.

[12] *Note: Although wild rice was not present at all 96 sites, the MPCA included them in the survey because elevated sulfide could be the reason for the absence of wild rice.*

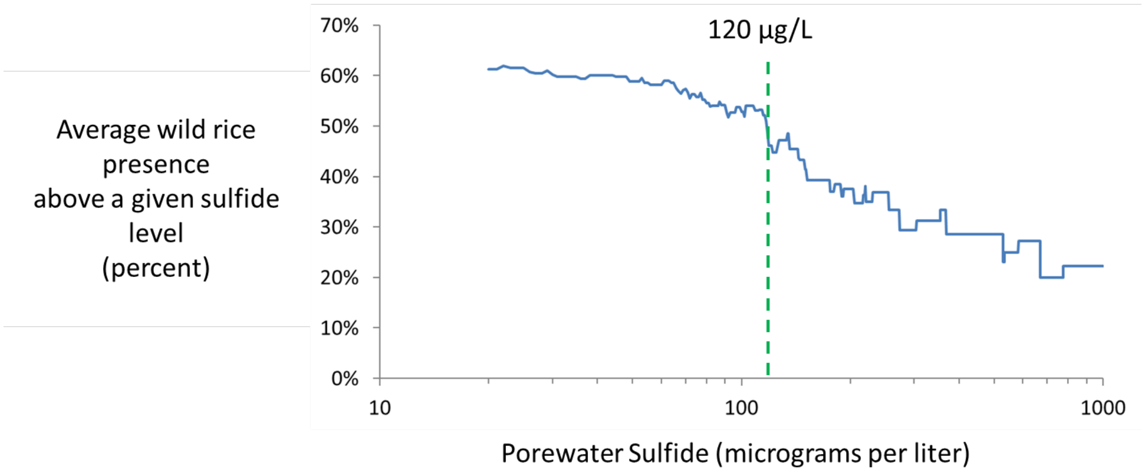


Figure 2. Empirical examination of the average proportion of sites with wild rice above or below a given porewater sulfide concentration (sites excluded with transparency < 30 cm). (TSD)

A change-point analysis completed on this data – a statistical method to find where the density of wild rice changed – showed a change at a sulfide level of 112 µg/L with a 95% confidence interval of 25 – 368 µg/L.

The MPCA also calculated an EC10 value from the field data. In this case, the EC10 was derived from a binary logistic regression relating porewater sulfide to the presence or absence of wild rice at any of the field sites. The calculated EC10 for the field data has a high degree of uncertainty, resulting in a point estimate of 93 µg/L sulfide with a 95% confidence interval that ranges from 14 – 239 µg/L.

As shown in Figure 3, the MPCA considered multiple lines of evidence and data analysis, including others described in the TSD but not summarized here. Nearly all of the lines of evidence have wide confidence intervals, but cluster towards the lower sulfide levels. This supports the MPCA's proposal to set the protective level of sulfide at 120 µg/L (0.120 mg/L).

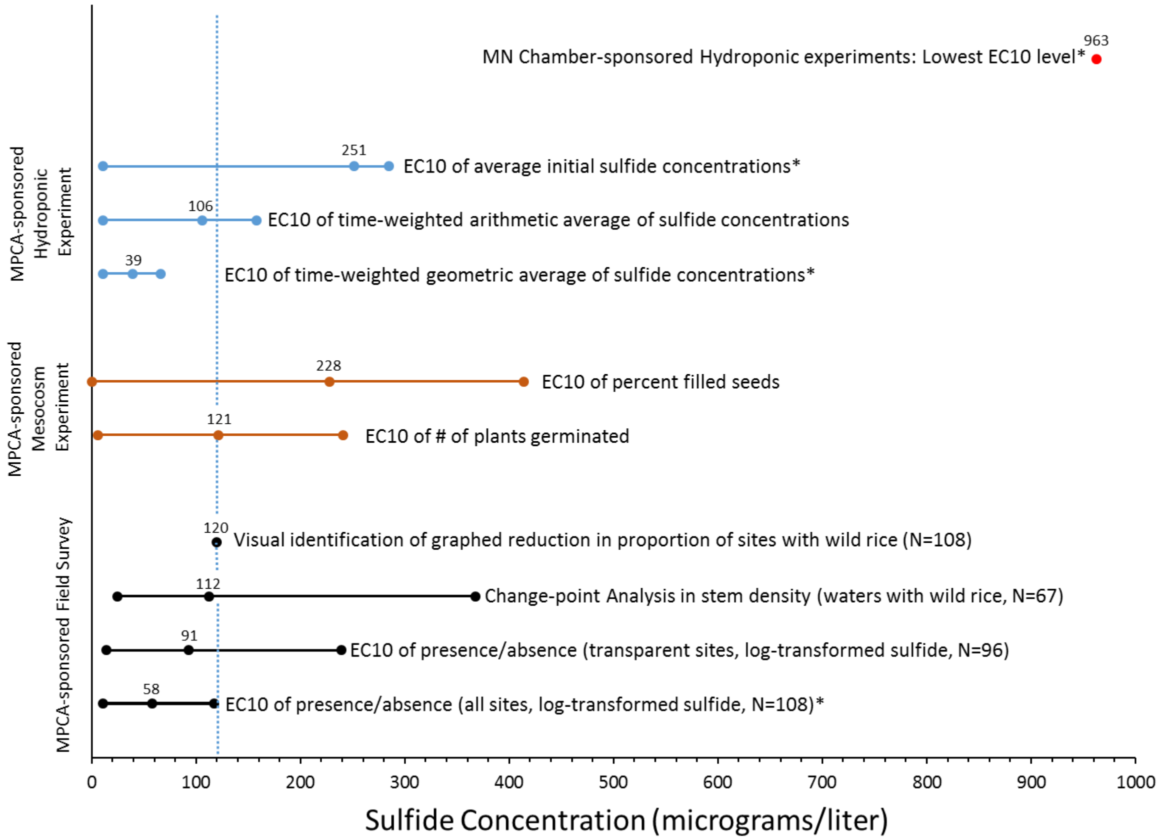


Figure 3. Estimates of protective sulfide concentrations for biological endpoints from hydroponic, mesocosm, and field data, based on EC10 estimates, change-point analysis, and visual examination of trends. (TSD) [13]

A noticeably different estimate in this figure is an EC10 of 963 µg/L, calculated by Minnesota Chamber of Commerce (2015), from the data provided from a 21-day hydroponic study conducted by the Fort Environmental Laboratory (Fort Environmental Laboratory, 2015; Fort et al., 2017). In this study, wild rice seeds from a Minnesota lake were germinated in solution with a range of sulfide concentrations. In contrast, the hydroponic growth tests conducted by Pastor et al. (2017) yielded EC10s ranging from 39 to 251 µg/L, where the most defensible EC10 was identified as 106 µg/L (TSD).

The potential advantage of hydroponic experiments is that the sulfide concentration can be controlled, in contrast to growing wild rice in sediment. But, it is difficult to design a hydroponic experiment that can fully mimic the natural environment, and especially mimic sulfide exposure during the few weeks of growth after seed germination. Germinating wild rice seeds may be buried several inches in anoxic sediment that may develop elevated sulfide, through which the seedling must grow before reaching the overlying water. Surface water is likely low in sulfide. Pastor et al. (2017) exposed the entire 3-day old

[13] *Estimates marked with an asterisk (*) received less weight in the weighing of multiple lines of evidence due to limitations of the experiment or analysis. See TSD (Exhibit 1) for further discussion*

seedling to sulfide over the ensuing 10-day experiment. In contrast, seedlings in the Fort et al. (2017) experiment were able to grow above the surface of the sulfide-enriched water, into aerobic conditions over a 21-day experiment.

Neither experimental design is necessarily more correct than the other design. The hydroponic design of Pastor et al. (2017) perhaps mimicked the exposure of seeds buried several inches in sediment, whereas the design of Fort et al. (2017) perhaps mimicked the exposure of seeds germinating lying on the surface of the sediment. However, under natural conditions, 21-day old wild rice plants would not have access to the atmosphere because the stems would not yet have elongated sufficiently to reach the water surface. Therefore, it is unlikely that 3-week old plants would have access to sufficient oxygen to detoxify such high levels of sulfide.

Since the MPCA's responsibility is to protect wild rice from elevated sulfide under normal conditions, the EC10 of 963 µg/L is not given great weight among the multiple lines of evidence. It is unknown how often in nature wild rice seeds germinate and grow from a depth of several inches in anoxic sediment which is the scenario that Pastor et al.'s hydroponic design may be mimicking. But, the resulting EC10 of 106 µg/L, and its 95% confidence limit of <11 to 158 µg/L overlaps with EC10s and associated 95% confidence limits derived from the mesocosm experiment and field survey. The overlap in confidence limits reinforces the conclusion that a protective concentration of sulfide lies in that region, and not near the EC10 of 963 µg/L derived from the Fort et al. study (TSD).

Aside from the EC10s derived from hydroponic experiments, the most defensible metrics of wild rice growth and reproduction are:

1) the percent of filled seeds in the mesocosm experiment (EC10=228),

2) the number of plants that germinated in the mesocosm experiment (EC10=121),

3) the occurrence of wild rice in the transparent sites of the field survey (EC10=91), and

4) the density of wild rice in the field survey (change-point of 112).

Given that these estimates have 95% significant confidence intervals that range from zero to 414 µg/L, it is defensible to conclude that these estimates of protective sulfide concentrations broadly agree with each other.

Based on the analysis of the multiple lines of evidence, it is reasonable for the MPCA to propose that the sulfide in the sediment porewater of wild rice waters be maintained at or below 120 µg/L to protect the wild rice beneficial use. Not only is 120 µg/L at a visual break in the proportion of sites with wild rice, but it is within the range of the other most defensible estimates of protective sulfide concentrations:

- 106 µg/L (from hydroponic experiments);
- 91 µg/L (the field survey EC10 based on wild rice presence);
- 112 µg/L (the field survey change-point based on wild rice density);
- 121 µg/L (EC10 based on mesocosm plant germination); and
- 228 µg/L (EC10 based on mesocosm seed viability).

While the EC10 value based on mesocosm seed viability is the value most different from 120 µg/L, 120 µg/L remains within the relatively wide confidence interval of 0 to 414 µg/L. This further supports the MPCA's proposal of 120 µg/L as the protective sulfide level.

3. Reasonableness of variables that impact sulfide

In essence, establishing a protective level of sulfide of 120 µg/L (0.120 mg/L) is akin to setting a water quality standard for the sediment porewater in which wild rice grows. However, there are difficulties in relying upon a standard for porewater sulfide to protect wild rice. First, levels of sulfide in the porewater are more difficult to measure than surface water sulfate; secondly, the pollutant that is discharged and leads to elevated sulfide is sulfate.

There is a documented relationship between surface water sulfate and porewater sulfide. In the sediment of water bodies, sulfate in the overlying water can diffuse into the underlying sediment and be converted by bacteria to sulfide. Numerous lake studies have shown that the production of sulfide in a given water body is a function of the sulfate concentration (Urban et al., 1994).

Therefore, it is reasonable to establish a method for deriving a numeric standard for sulfate in the surface water to maintain sediment porewater sulfide concentrations at or below 120 µg/L. Setting a surface water standard is more consistent with other water quality standards and allows for the calculation of effluent limits to control sulfate discharges from specific sources. Absent establishing a method for "translation" of a sulfide threshold in sediment porewater to a surface water sulfate standard, the MPCA would be compelled to complete such a translation on a case-by-case basis for permitting or other actions, and permit applicants would be required to incur costs to collect sediment data to be used in developing such translations. Relating the sulfide endpoint to a numeric sulfate standard via rulemaking is more reasonable because it enhances transparency, clarity, and certainty.

In order to set up this "translator," it is important to understand the factors that impact the development of porewater sulfide. As noted in the TSD, while one might expect porewater sulfide concentrations to be simply correlated to sulfate concentrations in the surface water, the relationship is not a direct correlation, but is complicated. When sulfate is low, sulfide is also low. However, when sulfate is high, sulfide can range anywhere from low to high. This shows that there are clearly additional factors at play beyond just sulfate in the overlying water.

A key research finding, further explained in the TSD, and published in Pollman et al. (Exhibit 35), is that the concentration of porewater sulfide is controlled by three variables:

1) The average sulfate concentration in the surface water;

2) The TEFe in the sediment where wild rice grows; and

3) The TOC in the sediment where wild rice grows.

Most importantly for the MPCA's proposed approach, these three variables assert almost <u>equal</u> control over the levels of sulfide in the porewater.

The MPCA, informed by study results collected over a three-year period, developed a statistical model of these control variables. This model, called a Structural Equation Model (SEM), provided a method to use the collected field data to test important hypotheses. The conclusion of the SEM provided strong evidence for surface water sulfate, and sediment organic carbon and TEFe acting as causal agents in the production of sulfide in porewater.

The two sediment variables vary among water bodies but are relatively unchanging within a given water body. These sediment variables are a function of the natural environment; they are determined by the local geology, ecology, and hydrology, and available evidence suggests they do not change rapidly over time. Sulfate levels, on the other hand, can be greatly affected by human activities that discharge elevated concentrations of this chemical into water bodies. Given that the sediment variables are primarily determined by natural processes, sulfate discharge is the means by which porewater sulfide is affected by human activities. Therefore, sulfate is the variable that must be addressed to protect wild rice from elevated sulfide in the sediment porewater.

4. Reasonableness of developing an equation to derive a numeric sulfate standard

Given the relationships noted above, it is reasonable to develop a method to determine how much sulfate can be in a given wild rice water and still maintain the sediment porewater sulfide concentration at or below 120 µg/L. Furthermore, given that sulfate is the environmental variable affected by human activities, it is reasonable to rely upon that sulfate level as the numeric standard for the protection of the wild rice beneficial use from excess sulfide. The MPCA has developed a method to determine the protective level of sulfate based on the sulfide threshold of 120 µg/L and the natural levels of extractable iron and organic carbon observed in each wild rice water.

Sulfate is converted at varying efficiencies into the actual toxic chemical, porewater sulfide. Because the conversion efficiency among water bodies varies by a factor of over 100, *there is no single sulfate concentration that would appropriately protect all wild rice waters*. This observation is a critical component in the MPCA's proposal to replace the current 10 mg/L sulfate standard.

The range in conversion efficiency can be observed in the ratio of sulfate in surface water to sulfide in the porewater of the 108 different waters surveyed in the MPCA-sponsored field survey (mg sulfate per liter: mg sulfide per liter). The 5th percentile is a ratio of 5.2, and the 95th percentile is a ratio of 533, a 103-fold range. Systems where wild rice grows in low-iron, high-organic sediment are particularly efficient at converting sulfate to sulfide, and therefore need a sulfate standard that is relatively low. Wild rice also grows in waters that are relatively inefficient at converting sulfate to sulfide (waters with high-iron, low-organic sediment, such as the Mississippi River backwaters) and will not need a low sulfate standard. An equation-based approach accounts for varying conversion efficiencies.

The idea of tailoring a water quality standard to particular environmental conditions is not new. The water quality standards include equations to calculate appropriate standards for metals and for ammonia. Outside the world of water quality standards, use of an equation to calculate water body-specific protective sulfate concentrations is analogous to recent initiatives in "precision medicine" or "individualized medicine." Individualized medicine means a situation where medical treatments are tailored to the individual characteristics of each patient or their disease. It does not mean the creation of drugs that are unique to a patient, but rather the ability to classify individuals into subpopulations that differ in their susceptibility to a particular disease or treatment.

Similarly, a tailored water quality standard is designed, based on a model of the environment, to be appropriate for the specific characteristics of a given water body. This results in a water quality standard that, when compared to a fixed number, more accurately identifies the level of a chemical that is protective of the beneficial use.

A fixed number is an appropriate standard when the ratio of the concentration of a pollutant to its effect is constant—for instance, when a chemical is directly toxic to organisms, and the toxicity is not modified by the nature of the water body or any other chemicals within that water body. In a case where the effect is indirect and variable, such as the effect of sulfate on wild rice, it is more appropriate to tailor the standard to take into account those variable effects. In this case, the MPCA is proposing to do so by employing an equation that accounts for the variable efficiency in the conversion of sulfate to sulfide.

It is important to reiterate that the toxicant that is ultimately being addressed is sulfide in the sediment porewater. Establishing the magnitude of that toxic effect does not rely on an equation – MPCA is proposing that to be 120 µg/L based on recent scientific studies; this conclusion is further discussed in the TSD. The proposed equation is instead a means for translating the protective sulfide level into a surface-water sulfate concentration in light of the controlling influence exerted by not just sulfate, but also iron and carbon, on sulfide levels in the porewater.

The MPCA proposes to replace the existing 10 mg/L sulfate standard to protect wild rice with rule language that 1) specifies the protective level of sulfide for all wild rice waters, and 2) provides an equation that allows the calculation of a numeric sulfate standard for each wild rice water that maintains the sulfide at a protective level (below 120 µg/L). Some resulting numeric sulfate standards would be less than the existing 10 mg/L and some greater, since the varying iron and carbon conditions among water bodies affect how the sulfate is converted to sulfide.

Prior to this reassessment of the existing standard, questions had arisen as to the importance of regulating sulfate, given that wild rice populations had been observed growing in waters significantly greater than 10 mg/L. The recent studies have revealed that sulfate can harm wild rice, but only when other variables favor the development of elevated sulfide in the sediment. A numeric standard based on the porewater sulfide level and its relationship to surface water sulfate implicitly provides an explanation for field observations of viable wild rice populations in waters where sulfate concentrations substantially exceed 10 mg/L.

Because of natural variability in how aquatic ecosystems respond to pollutants, no water quality standard is perfect, but the use of MPCA's proposed approach to protect wild rice from elevated sulfide has multiple advantages over the application of the existing sulfate standard of 10 mg/L:

- The proposed approach better applies current scientific knowledge, and offers a path to address the fact that not all wild rice waters respond similarly to sulfate.

- The proposed approach to establishing a numeric sulfate standard would be more accurate than any fixed sulfate standard, including that of 10 mg/L.
  - About half the time, a fixed standard of 10 mg/L would be unnecessarily low to protect the wild rice beneficial use. Because of the greater accuracy of the equation-based standard, there would be fewer instances of unnecessary investment in sulfate control equipment and ongoing operation.
  - About half the time, a fixed standard of 10 mg/L would not be low enough to be protective of the wild rice beneficial use. Because of the greater accuracy of the equation-based standard, there would be fewer instances of failure to control sulfate in sulfate-sensitive wild rice waters where control is actually necessary.

Although the complexity of implementing the proposed equation approach requires more monitoring resources than would a fixed sulfate standard, adoption of the equation is nevertheless reasonable in light of the above-described advantages and because the cost of data collection will be much less than the cost of treatment.

Because the cost of treating wastewater to remove sulfate is extremely high, it is reasonable and very important to minimize the possibility of applying a standard that is more stringent than necessary to protect the wild rice beneficial use. The equation-based standard also, when compared to a fixed standard of 10 mg/L, would result in approximately half the rate of false negatives, reducing the frequency of harm to wild rice populations and the potential for future need to remediate wild rice water bodies that are harmed by a build-up of sulfide

5. Reasonableness of the specific equation

As described above, the equation calculates a concentration of sulfate based on values of iron and carbon in the sediment to keep sulfide below 120 µg/L, which protects the wild rice from harm. This concentration of sulfate is the “magnitude” of the standard and must be met in the water body.

The 2014 external peer review panel recommended that the MPCA not only rely heavily on the field data for the identification of a protective sulfide concentration, but also to use the field data to develop an equation that relates the protective sulfide concentration (now identified as 120 µg/L) to the associated sulfate concentrations in each wild rice water.

To accomplish this task, the MPCA first used the structural equation model to identify the variables that control porewater sulfide (sediment iron, sediment TOC, and surface water sulfate). The MPCA then relied on a multiple binary logistic regression (MBLR) to develop the proposed equation. Logistic regression is a predictive analysis; in this case the MBLR regression predicts the probability that sulfide is greater than 120 µg/L. The inputs to the regression are the field survey data from 108 different sites for the observed sediment iron, sediment TOC, surface water sulfate and porewater sulfide (the Class B data). The Class B data set was used for the regression on which the equation is derived because this data set is the best available approximation of a random sample of potential wild rice waters (see TSD), to maximize the validity of probabilities drawn from the equation (e.g., the probability that the equation correctly relates sulfate to sulfide).

Note that it is not necessary to exclude sites with low transparency, since what is being modelled is the chemical relationship between sulfate and sulfide. Water transparency may affect the probability of wild rice presence in a given water body, but would not affect the chemical relationship between sulfate and sulfide.

The mathematical model produced by the MBLR regression has the following general form, (the actual MBLR model looks more complicated, and is presented in the TSD):

> The ***Probability that sulfide is greater than 120 µg/L*** is a function of ***Sulfate***, ***Sediment Iron***, and ***Sediment TOC***

The proposed equation was created by converting the probability to a constant value (by setting the probability to 0.5) and re-arranging the model to solve for the protective sulfate concentration. Use of a probability of 0.5 maximizes the probability that a sulfate concentration will be calculated that is most likely to produce the protective sulfide concentration of 120 µg/L, given the water body-specific sediment concentrations of iron and TOC. Once re-arranged, the equation that predicts a sulfate concentration corresponding to the protective sulfide concentration of 120 µg/L has the general form:

> The ***Protective Sulfate Concentration*** is a function of ***Sediment Iron*** and ***Sediment TOC***

The TSD demonstrates that using a probability of 0.5 produces sulfate values that most accurately predict the sulfide concentrations that were observed during the field survey. Probabilities that porewater sulfide is greater than 120 µg/L other than 0.5 are either over-protective (less than 0.5) or under-protective (greater than 0.5).

Use of a probability of 0.5 produces this proposed equation, as described in the TSD:

$$Calculated\ Sulfate\ Standard\ = 0.0000121\ \times\ \frac{Iron^{1.923}}{organic\ carbon^{1.197}}$$

Other regression techniques can be used to calculate protective sulfate concentrations from iron, carbon and sulfide, but they are less accurate than MBLR. Based on the 108-site Class B data set, MBLR has an overall misclassification rate of 16% (the sum of false positives and false negatives out of all sites). Multiple linear regression (MLR) has a misclassification rate of 23%, and structural equation modelling (SEM), a rate of 26%. When the MBLR-based equation is applied to an independent data set for validation, the misclassification rate is 19%, which is still appreciably better than the other regression techniques.

Although the proposed equation produces fairly balanced false positives and false negatives (7% and 9% in Class B data, and 5% and 14% in Class V data), there is a smaller proportion of false positives (5 to 7%) than false negatives (9 to 14%), which means that the potential for requiring sulfate control where none is needed to protect wild rice will occur in 5 to 7% of the wild rice waters assessed. It is important to point out that using a fixed sulfate standard, has less accuracy than a calculated sulfate standard. The lowest misclassification rate of potential fixed sulfate standards is 32%, which occurs at 5, 10, and 26 mg/L. The misclassification rates of a fixed sulfate standard of 10 mg/L are evenly split between false positives and false negatives (16% of each). A fixed standard of 5 mg/L would be over-protective (24%

false positives, 8% false negatives), and 26 mg/L would be under-protective (28% false negatives, 4% false positives).

The state of Vermont recently adopted, and EPA approved, fixed phosphorus standards to protect aesthetic use in lakes and aquatic biology in streams. Numeric standards were derived in a way to minimize false positive and false negative rates (Smeltzer et al., 2016). The MPCA is not aware of any other state or tribe that has analyzed false positive and false negative rates as part of the development of a water quality standard, although McLaughlin (2012) points out that such an approach is consistent with EPA guidance and can minimize decision errors. In Vermont, eleven different phosphorus standards were developed, depending on the applicable tiered water use objective. The misclassification rates varied from 17 to 40%, with a median of 35%--about the same as the best misclassification rate, 32%, for possible fixed sulfate standards to protect wild rice. The proposed equation has a lower maximum misclassification rate (19%) than 10 of 11 of these fixed phosphorus standards.

The proposed equation is reasonable because:

- It incorporates the variables demonstrated to control sulfide: sulfate, iron, and TOC.
- It incorporates a protective sulfide concentration of 120 µg/L, which not only is protective of wild rice presence, but also is protective of greater wild rice density (120 µg/L is close to the statistically-determined change-point in wild rice stem density--wild rice density is significantly greater when sulfide is lower than 112 µg/L).
- It had a low rate of false positives and false negatives (16% total misclassification rate) in the data set in which it was developed, and only a slightly higher misclassification rate (19%) in an independent data set used for validation.
- It more accurately predicts whether sulfide exceeds the protective concentration of 120 µg/L than equations developed with other statistical techniques (MLR or SEM) (16% to 19% misclassified, compared to 23% or 26%, respectively).
- It results in approximately balanced false positives and false negatives, but with fewer false positives than false negatives.
- Under the proposed equation, the proportion of false positives is 5% to 7% of wild rice waters, which corresponds to the potential for identifying an exceedance of a calculated sulfate standard when porewater sulfide is in fact not elevated above 120 µg/L. Under the current sulfate standard of 10 mg/L, the proportion of false positives is 16%.
- It more accurately predicts whether sulfide exceeds the protective concentration of 120 µg/L than the current standard, 10 mg/L (19% misclassified, compared to 32%).

Further details about the development of the equation can be found in the TSD (Exhibit 1).

<u>Corroborating evidence for a protective sulfide level of 120 µg/L and the equation: More about false positives and negatives</u>

Once a protective sulfide concentration is identified, and an equation incorporating that value is developed, there will always be some water bodies for which the calculated sulfate concentrations are either under-protective or over-protective. Tools such as site-specific standards, discussed later in this Statement, help address this. With that said, a key consideration in developing this revised water quality standard is the standard's accuracy. Accuracy is defined as the rates of false positives and false negatives. A false positive occurs when a sulfate concentration is greater than the standard, but porewater sulfide is actually less than the protective level of sulfide in sediment porewater; in this case the numeric standard is overly stringent. A false negative occurs when a sulfate concentration is less than the standard, but porewater sulfide is actually greater than the protective level; in this case the numeric standard is not sufficiently protective of the wild rice beneficial use.

Sometimes the calculated sulfate standard will be exceeded but the beneficial use still protected (sulfide is less than 120 µg/L), or the water body might be meeting the sulfate standard but the beneficial use is not protected (sulfide is greater than 120 µg/L). In other words, the equation sometimes produces sulfate concentrations that are in error when looking at the toxicant of concern; sulfide in the porewater. The reasonableness of the proposed process for establishing an alternate standard or a site-specific standard is discussed in Part E.9.

The equation would have about 60% of the rate of false positives and false negatives as a 10 mg/L fixed standard. The sum of false positives and false negatives yields a misclassification rate of 32% for the fixed standard of 10 mg/L, compared to rate of 19% for the equation. (A validation data set yielded a misclassification rate of 19% for the equation; the dataset used to develop the equation yielded a misclassification rate of 16%. This is further described in the TSD).

A look at the error rates in the Class B data set (which approximates a probabilistic sample) associated with a range of potential protective concentrations of sulfide provides additional support for the chosen level of 120 µg/L. (More information is provided in Part 1-6 and Appendix 10 of the TSD.) MPCA staff used the field data set to evaluate potential protective sulfide levels against both the accuracy of the equation and the protection of wild rice presence and density. A goal was to take a balanced approach, looking for sulfide levels where the chance that the water body is above the calculated sulfate standard when the water body is actually not impaired (false positive rate) is approximately equal to the chance that the water body is below the standard when the water body is impaired (false negative)—while making sure that a sulfide concentration is chosen that actually protects wild rice presence and density.

Looking at the range of protective sulfide values from various EC10 and other analyses (as shown in Figure 3), balanced errors were found between 60 and 130 µg/L and between 350 and 400 µg/L. These values were compared to wild rice presence and density. For sites with sulfide levels above 350 µg/L, while 25% had wild rice present, only 13% of sites had denser wild rice (density greater than 25 stems/m^2). Because low-density stands provide less grain for wildlife, are less desirable for harvesting by people, and may be less likely to persist over the long term (TSD), picking a protective sulfide level that would result in less dense wild rice is under-protective. (A density of 25 stems/m^2 is chosen for illustration purposes; other densities could have been chosen.) The other end of the range of protective sulfide values, 60 µg/L, appears to be over-protective. Overall, many sites with denser wild rice are seen with sulfide levels both above and below 60 µg/L. In fact, the data show that there are almost twice as many sites above 60 µg/L sulfide with wild rice denser than 25 stems/m^2 as below (28 vs 15).

Of sites with porewater sulfide less than 90 µg/L, 55% of sites have wild rice density greater than 25 stems/m^2. In the range of the protective sulfide level proposed by the MPCA, the data show that only 42% of the sites with sulfide in the range of 90 to 130 µg/L have denser wild rice than 25 stems/^{2}, indicating that a reduction in density occurs in that range. A majority of sites have densities greater than 25 stems/m^2 up to a sulfide concentration of 120 µg/L, above which the density decreases. Between 120 and 350 µg/L, only 26% of sites have wild rice densities above 25 stems/m^2. Consistent with the visual investigation, sulfide concentrations greater than 120 µg/L is also where the percent of sites with wild rice present begins to decline. In this zone of balanced false positives and false negatives, 120 µg/L and 130 µg/L have the lowest total error rates of 16%, and, between the two of them, 120 µg/L is the most balanced. The balanced error rates and review of density therefore provides additional support for and further demonstrates the reasonableness of the MPCA's proposal to identify 120 µg/L as the protective sulfide level to be implemented in the equation. Based on the foregoing, the MPCA's proposal of 120 µg/L is reasonable.

6. Reasonableness of the requirements for determining whether the standard has been met.

An important part of implementing any water quality standard is determining when the standard is met, both directly in the waterbody through the assessment process and for setting permit limits that support meeting the standard. The magnitude, duration, and frequency of the standard are the bases for determining how water bodies are assessed against the standard and inform permit requirements that ensure the standard is met. The proposed rule language therefore sets out the basic framework for determining how to apply the standard.

The proposed rule revisions provide greater clarity on the magnitude, duration and frequency of the wild rice sulfate standard, which will aid in implementation.

Reasonableness of applying the standard as an annual average (duration)

An essential step in implementing any numeric standard is determining the duration or averaging time of the standard. The duration needs to reflect the available information about the timeline of impact to the beneficial use. For example, a standard to protect against acutely toxic conditions may be expressed as a "never to exceed" duration, whereas one that protects against impacts over the longer term may be expressed as an annual or even multi-year average.

The MPCA is proposing that the numeric standard to protect wild rice from sulfide impacts, which is expressed as a sulfate standard, will apply as an annual average. This means that on any given day the sulfate values in a wild rice water may be higher than the numeric sulfate standard, as long as the value averaged over the whole year is below the numeric sulfate standard.

This averaging period is appropriate and reasonable for two reasons. First, because the conversion of sulfate by bacteria to sulfide is not instantaneous but depends on certain chemical and physical factors and occurs over time. EPA recommends incorporating maximum (i.e., "never to exceed") pollutant concentration levels into water quality standards only if the pollutant is directly toxic to aquatic plants or animals. Where the pollutant is directly toxic, "EPA currently recommends a 4-day averaging period for most chronic criteria (long term impacts on growth or reproduction) and a 1-hour period for most acute criteria (short term lethal impacts)." (Kansas Dept. of Health). Fort et al. (2014) and Pastor et al. (2017) demonstrated that sulfate is not directly toxic to wild rice at the ambient concentrations encountered in Minnesota's surface waters. Rather, sulfate can contribute over the long term to the buildup of toxic porewater sulfide in the sediment in which wild rice germinates and roots. Therefore, the effect of elevated sulfate is indirect and setting the standard as a maximum concentration that can never be exceeded in the water body is overly restrictive.

A longer-term duration, such as the proposed annual average, is more appropriate because the transformation of sulfate to sulfide is relatively slow. Sulfate to sulfide conversion is a multi-step process. Sulfate needs to enter the sediment from the overlying water, generally through diffusion from areas of high concentrations to areas of low concentration. Diffusion is a relatively slow process, particularly under colder conditions. Diffusion is also a reversible process. If sulfate concentrations in the overlying water decline, sulfate will move from the sediment into the surface water.

Once sulfate has entered anoxic sediment the conversion to sulfide is completed by bacteria that respire sulfate instead of oxygen. If the bacteria population size is limited by sulfate availability, sulfide production is proportional to the sulfate concentration, but bacterial growth takes time. Bacterial growth and respiration are also affected by temperature, occurring more slowly under colder conditions.

The time it takes for the conversion of sulfate to sulfide was observed in a multi-year mesocosm experiment where sulfate was added at relatively high concentrations (treatment sulfate concentrations of 0, 50, 100, 150, and 300-mg/L additions) to a situation where the numeric sulfate standard would be 34 mg/L if calculated using the proposed equation. In this case, it was not until the third year of the experiment that wild rice growth and reproduction was significantly affected by the 100 mg/L treatment (Pastor et al., 2017). This mesocosm experiment conducted by Pastor et al. (2017) demonstrated that porewater sulfide is directly proportional to the long-term (annual) average sulfate concentration (Myrbo et al. Exhibit 36).

Second, the annual average is consistent with the data and empirical statistical relationships upon which the equation is based. The equation relates average, not maximum or minimum, sulfate concentrations to sulfide. The sulfate data used to develop the equation were from single grab samples of surface water that were then related to sediment organic matter and iron via the binary logistic regression. The grab samples were taken in a fashion that approximated random samples of the water bodies, and therefore, approximated the average sulfate concentration .

The equation was developed by analyzing data from natural water bodies, under the reasonable assumption that the variables that are known to control porewater sulfide (sulfate, sediment organic carbon, and sediment iron) are in steady state (that is, there are no significant changes in concentrations over time). The vast majority of the study sites did not receive point source discharges that would cause significant fluctuations in sulfate concentrations over time. An analysis of repeated samples from 15 different natural wild rice sites showed no significant time trends in sediment TOC or sediment TEFE, and a barely significant seasonal increase in sulfate (Myrbo et al. Exhibit 18). It makes sense that the sediment parameters show no change over time, and that sulfate concentrations might vary seasonally.

Sediment parameters would be expected to remain stable in most aquatic systems as there is not much sediment or other dissolved material added or removed very quickly. There are some exceptions, but most aquatic sediment systems are stable. Sulfate concentrations have the potential to respond to changes in surface water concentrations as there is more mixing occurring in the water, and increases or decreases in sulfate concentration would occur more quickly.

There is a slight increase in sulfate over the ice-free season that was attributed to spring dilution from snowmelt (Myrbo et al. Exhibit 18). Sulfate in surface water can be attributed to three primary sources:

1) within the lake or stream watershed from dissolution (i.e., rocks and/or degradation of plant matter) that are present within the system. (These sources would not be expected to increase or decrease the surface water concentration greatly.)

2) groundwater input that might be natural (dissolution of rocks) or anthropogenic (flow from a dewatering effort).

3) direct discharge of sulfate effluent.

The latter two sources have the potential to have the most control on surface water sulfate concentrations.

It is reasonable to apply the sulfate standard as an annual average because (1) the transformation of sulfate to sulfide is relatively slow, and (2) the equation that produces the calculated sulfate standards is essentially based on average sulfate data. Application of the sulfate standard as a maximum that should not be exceeded would be over-protective, because the resulting porewater sulfide concentrations would be lower than needed to protect wild rice.

Discussion of the concept of seasonality

The existing 10 mg/L sulfate standard applies during times when the rice is susceptible to damage by sulfate. This has generally been interpreted as meaning that the standard applies only during the wild rice growing season and was due to the earlier assumption that it was sulfate itself that was impacting wild rice. The affirmation of the MPCA's more recent hypothesis that elevated sulfate can lead to sulfide, and that it is the sulfide that is impacting wild rice, required a re-examination of this assumption. This re-examination led the MPCA to propose that it is more appropriate for the numeric standard to apply year-round since the conversion of sulfate to sulfide also occurs year-round.

Although movement into the sediment and sulfide production are likely slower in colder weather, porewater sulfide is nonetheless produced throughout the year (Derocher and Johnson, 2013). Therefore, at all times sulfate can contribute to the production of sulfide – the pollutant that is harmful to the wild rice in toxic concentrations.

Myrbo et al. (Exhibit 18) also showed that there is no significant seasonal trend in porewater sulfide over the wild rice growing season. If there is an annual cycle in porewater sulfide, it is likely that sulfide is lower in the winter, as studies have found lower sulfide concentrations in the winter (Leonard et al., 1993; Urban et al. 1994), which is attributed to greater oxygen penetration, lower sulfate diffusion rates, and decreased bacterial growth rates. However, the MPCA lacks sufficient scientific information to quantify the lower winter diffusion rates and thereby develop a ratio or other numeric approach to allow higher sulfate levels in the winter. The MPCA also does not know if an approach that allowed higher sulfate levels in the winter would be protective over the long term. Because of this, is it reasonable to have a standard that applies all year, not just seasonally.

Reasonableness of applying a one in ten year frequency

A paper by the Kansas Department of Health provides a useful description of frequency in the context of water quality standards. “Water quality criteria were not intended to be instantaneous values never to be exceeded. Concentrations exceeding criteria values beyond the designated duration are referred to as ‘excursions.’ Frequency is the number of times an excursion can occur over time without impairing the aquatic community or other use.” (Kansas Dept. of Health, 2011)

The MPCA proposal specifies a one in ten-year frequency for the wild rice sulfate standard. As discussed below, the impact of sulfate on wild rice is not immediate – it is chronic and mediated by a biological process – and as a result, it takes more than one year for elevated sulfate to produce adverse effects. This means that over ten years, the annual average sulfate concentration in the water body may exceed the numeric sulfate standard once without the water body being considered impaired.

Developing the frequency of a standard requires understanding how a beneficial use is impacted by short-term levels of pollution above that expressed by the magnitude and duration of the standard. In the case of wild rice, two key findings from the research have informed the MPCA’s development of the proposed reasonable approach to the frequency of the proposed numeric standard.

First, levels of porewater sulfide are based on the balance between sulfide production and loss. Not all sulfate that diffuses into sediment is converted to sulfide (TSD). Ultimately, elevated porewater sulfate and sulfide concentrations are reversible once the sulfate concentration in the surface water declines, partly because elevated concentrations of chemicals diffuse toward areas of lower concentrations. If temporary higher sulfate in the surface water causes more sulfate to diffuse into the sediment, much of that sulfate is likely to diffuse back into the surface water once the surface water sulfate levels decline. Porewater sulfide concentrations will not be maintained at higher levels in the sediment if sulfate availability declines. Elevated porewater sulfide concentrations also have a tendency to diffuse into the overlying water, where it would usually be oxidized back into sulfate. In addition, over time oxidants such as oxygen and ferric iron will be mixed into the surface sediment, decreasing an elevated concentration of porewater sulfide.

Second, sulfate added at a level 2.5 times greater than the calculated standard in the experiment of Pastor et al. (2017) did not affect wild rice until the third growing season. Because sulfide production requires the diffusion of sulfate into the sediment, it makes sense that there is a lag time in the impacts and that higher levels of sulfate in the surface water would not adversely affect wild rice if they do not persist for long. It is unlikely that one year of elevated surface water sulfate will result in a sustained increase in sulfide levels in the sediment porewater. Therefore, it is reasonable to have some limited allowable excursion above the standard.

Furthermore, the available scientific evidence supports that even a one-year elevation in sulfide levels in the sediment porewater above 120 µg/L would not have a long-term negative effect on wild rice growth and reproduction, so long as sulfide concentrations do not remain elevated above 120 µg/L for multiple sequential years. Relatively poor reproduction in one year out of five or ten years is extremely unlikely to have a long-term negative effect on the persistence of a wild rice population because wild rice populations build up a seed bank in the sediment so that only a portion of dormant seeds germinate in any given year. In fact, wild rice is infamous for having large swings in plant density from year to year under natural conditions. The existence of the seed bank allows wild rice to recolonize a water body even if all growing plants are eliminated by an environmental disturbance in a given year (Exhibit 21). For example, a June 2012 precipitation event completely eliminated wild rice in Kettle Lake (Carlton County), but the following year the density of wild rice was above average (55 stems per square meter, compared to a 10-year average of 41 stems per square meter, not counting two years of zero density, 2012 and 2016) (Vogt, 2017).

A waterbody's wild rice population will be able to persist at a high average stem density if the annual average sulfate concentration does not exceed the calculated standard very often. The MPCA had to define what "very often" means in order to define the allowable excursion frequency. Because of the limitations of available environmental knowledge, the severity of an excursion cannot be rigorously related to the impact on a wild rice population. Nevertheless, MPCA expects that a wild rice population will not be significantly harmed by an exceedance that occurs only once in ten years, because that frequency will allow the environmental chemistry and wild rice population to recover between exceedances, thereby providing a high degree of protection. In addition, a one in ten-year exceedance frequency is roughly equivalent to the MPCA's proposed use of a protective receiving water flow rate of $365Q_{10}$ when evaluating the need for an effluent limit to protect wild rice from elevated sulfate. A flow of $365Q_{10}$ is exceeded by 90% of historical annual flow rates. Therefore, flows would only be less than the $365Q_{10}$ flow about once every ten years.

Based on the foregoing, the one in ten year frequency is reasonable.

Implementing the proposed duration and frequency

From a permitting perspective, the MPCA's experience has shown that the lack of clear conditions (such as duration and frequency) for determining compliance complicates the implementation of standards. The MPCA expects that by clarifying how the standard is met, the proposed rule will facilitate compliance for permittees and aid the MPCA in the process of determining compliance.

In the assessment process, the MPCA monitors and evaluates conditions in water to compare them to applicable standards. Waters that do not meet the standard are "impaired" and must be restored so that they will fully support the beneficial use(s). Clarity on the duration and frequency of the sulfate standard will assist MPCA in the assessment process.

7. Reasonableness of the required data gathering and analysis

In order to calculate the numeric sulfate standard from the equation, organic carbon and iron data must be obtained or, if an alternate standard is being developed (see the discussion in Part E. 9.), sediment porewater must be sampled and analyzed for sulfide. Obtaining this information requires collecting sediment and porewater samples and then analyzing them according to specific protocols. Typically, the

MPCA will conduct sediment sampling and analysis on the established timeline for routine watershed assessment. For new or expanding discharges, the discharger must conduct the sediment sampling and analysis as part of their responsibility to characterize the impact of the facility. The MPCA is proposing to incorporate by reference a document called *Sampling and Analytical Methods for Wild Rice Waters*. Incorporating a document by reference means that the adopted document has the same effect as adopted rule language and any future changes must be made through the rulemaking process. It is a process used to address concepts that are not easily communicated through the conventions of rule language or to address procedures that are often excerpted for practical applications. Examples are analytical methods and building codes. The document *Sampling and Analytical Methods for Wild Rice Waters* proposed to be incorporated by reference identifies the required procedures for sediment sample collection, TOC and TEFe analysis, and porewater sampling and analysis.

Incorporation of procedural documents into rule is not reasonable or necessary in all cases because procedures guide the agency's response to varying fact-specific situations that arise during the implementation of a rule that applies generally. However, for this rulemaking there is a specific need for sediment and porewater to be collected and analyzed in order to set a numeric standard. Because the data collected via sampling is required to set the numeric standard, it is important that the sampling and analysis be conducted in exactly the same way as it was during the research that forms the basis for the proposed standard. Given that the sampling and analysis procedures are integral to setting the numeric standard, as compared to guiding the implementation of a standard once it is established (i.e., the procedures precede the standard setting rather than follow the standard setting during implementation of the standard), MPCA finds that it is needed and reasonable to incorporate the sampling and analysis procedures into the rule itself. .

It is reasonable to identify a standard sampling procedure to:

- accurately characterize the iron and carbon concentrations in the sediment where the wild rice is growing;
- duplicate to the sediment sampling conditions on which the equation is based; and
- reproduce the same sediment sampling conditions if re-sampling is required.

The methods describe how many sediment samples are needed, where samples should be taken, and what other data should be collected. The MPCA is developing an implementation plan to collect sediment samples and other data through the intensive watershed monitoring process. However, the MPCA expects that applicants for new or expanded permits will need to collect the data themselves, if they or the MPCA have not already done so, and that others may also want to collect data to establish the numeric standard or if they have questions about the MPCA sampling. Therefore, the MPCA believes it is reasonable to identify the data gathering and analytical methods in rule.

Identifying areas of wild rice habitat within a wild rice water

First, the sampling method establishes a priority ranking of the conditions that identify wild rice habitat. The MPCA recognizes that there is great variability in wild rice waters and that the sampling method must be flexible enough to accommodate that variability but still provide the most accurate characterization of the sediment in the wild rice growing areas of each wild rice water. Part 1 of the proposed sampling method establishes a hierarchy of likely wild rice habitat, ranging from areas where rice is clearly present to areas where there are no other indicators other than a water depth suitable for wild rice growth.

The highest priority for sediment sampling (#1) are those areas where there is wild rice present or evidence of recent wild rice growth. Obviously, sampling the sediment in areas of active wild rice growth will most clearly demonstrate the conditions where wild rice grows, so those areas are the highest priority. However, wild rice is an annual plant and =can fluctuate widely in amount and density from year to year. There are documented cases of normally productive wild rice waters where, occasionally, wild rice plants cannot be found in late summer, most commonly due to a sudden rise in water level earlier in the summer. The highest priority areas for sediment sampling therefore also include areas where there is physical evidence of the recent presence of wild rice. A wild rice bed may have flourished in the previous year, but because of the timing of the sampling, weather, or grazing by wildlife, actively growing wild rice may not be observable at the time of sampling. However, if there is evidence that wild rice was recently present, these locations, together with areas of actively growing wild rice, are the highest priority for sediment sampling.

Within a priority hierarchy, the next potential sampling area category (#2) would be locations within the wild rice water where the presence of wild rice has been documented. In this rulemaking, the MPCA is identifying wild rice waters in Minn. R. 7050.0471 based on evidence that the wild rice beneficial use exists or has existed in that water. The information the MPCA used to make this determination, or other similar types of information, may provide useful direction for the selection of sampling areas. If it is not possible to observe wild rice in a wild rice water, it is reasonable to sample in areas where there is information available about the past location of wild rice. This type of information may include survey notes indicating where the rice beds are located or information that wild rice was harvested along the south shore of a lake or upstream of a landmark.

The next sampling areas in the hierarchy (#3 and #4) are those areas where there are plant communities that require habitat similar to wild rice (TSD; Pillsbury and McGuire, 2009). Wild rice habitat identifier #3 is based on the observation that white and yellow waterlilies require habitat similar to wild rice. In lieu of actual wild rice beds, sampling waterlily beds will provide the best approximation of the conditions that support wild rice. Identifier #4 is based on the observation that aquatic plants other than waterlilies also grow in areas suitable for wild rice. The conditions that support communities of floating-leaved or emergent plants also reasonably approximate the conditions that support wild rice, although this relationship is not documented to the same extent as waterlilies. Examples of the types of floating-leaved or emergent plants that will approximate the conditions for wild rice growth are pondweeds, watershield, pickerelweed, and arrowhead. The exception to selecting a sample area based on this type of aquatic vegetation is the presence of species that develop dense stands that exclude other species, such as cattails, phragmites, purple loosestrife, and reed canary grass. These species are not a valid indicator of the conditions that support the growth of wild rice.

Where either waterlilies or other aquatic plants are used as alternatives for the presence of wild rice, the sample areas must also be confined to the water depth at which wild rice can grow. Waterlilies and other aquatic plants can potentially grow at greater depths than would support wild rice growth. The sampling hierarchy requires that the water depth of either of water lilies or alternate aquatic plants must not exceed 120 cm under normal conditions. This means that although a bed of water lilies may seem to be a reasonable choice, if the waterlilies are growing at a depth of more than 120 cm, it is not a valid sediment sampling location. In that case, the sampler must either find a sampling area with waterlilies or aquatic plants growing within the 120 cm limit or find an area that is of a lower priority. However, if water depths are abnormally deep when sediment sampling occurs, then it is permissible to sample in the deeper water if the aquatic plants associated with wild rice are growing at that depth.

The next priority habitat identifier includes those areas where satellite or aerial photographs show potential wild rice or associated plant communities (#5). However, when satellite or aerial photographs are used, the same condition about the water depth applies. Images of waterlilies or floating-leaved vegetation are not valid if they are associated with water depth greater than 120 cm, unless the water is abnormally deep at the time of the sampling.

The lowest priority for sampling are those areas where there is no other evidence of wild rice, but the water depth is conducive to the growth of wild rice (between 30 and 120 cm). Water depth is a significant controlling factor for wild rice growth and, in the absence of any other information, is a reasonable basis for selecting the sediment sampling sites in a wild rice water.

Selection of sediment sample areas

The process of selecting the sediment sample areas can be very complex in a natural setting. Wild rice waters will differ a great deal in size, shape, and the variability and extent of habitat. Wild rice can cover an entire water body or it may be present in only a small area. The sampler must use best professional judgement to select sample areas that accurately characterize the wild rice water.

Identification of sampling transects

The sediment sampling procedure requires that after a sample area has been selected, a transect of that area must be established so that cores can be collected and the core sites documented. The sediment sampling procedure identifies the conditions for establishing a transect in each sample area so that cores are taken in a consistent manner from areas that best represent sediment conditions. It is reasonable to require consistent procedures and recordkeeping to ensure that if necessary, the sample collection process can be reproduced.[14]

Sample collection

The sampling method specifies that sediments must be sampled using a coring device that removes a 10 cm deep section of sediment. Requiring a 10 cm depth is reasonable because the data obtained must comport with the method used to develop the equation, which used data from the top 10 cm of

[14] It may be necessary to sample porewater at the same location as the initial sediment sample location in order to establish an alternate standard, as proposed in Minn. R. 7050.0224, subpart 5, item C.

sediment. The 10 cm depth was chosen for the MPCA wild rice research because 10 cm represents the primary zone of wild rice root growth and where there is exposure to porewater sulfide.

The sediment sampling method requires collection and compositing of five sediment cores from each of five sample areas, for a total of five composite samples derived from 25 sediment cores. Composite samples provide a way to integrate the conditions in the sediment where wild rice grows without the need to analyze individual core samples. The MPCA has determined that 25 cores is sufficient to capture the natural variability of both sediment organic carbon and iron given a reasonable amount of effort and resources devoted to field collection and laboratory analysis.

The MPCA examined the reasonableness of using 25 cores to characterize the sediment of wild rice waters by comparing how increasing number of cores affected the variability of the data around the mean concentration of sediment iron and sediment carbon. As described further in the TSD, the variability decreases as sample size increases, as depicted by a narrowing of the confidence interval around the mean. The rate of narrowing of the confidence interval leveled off at a sample size of about 20 to 25. This suggests that the additional cost for sampling more than 25 cores will not improve the quality of the data.

Data Reporting

The sediment sample method requires that specific information be provided for each wild rice water. An example of a reporting form is provided in the Sampling and Analytical Methods for Wild Rice Waters document, although the details of this form may vary according to sampler and over time. Any similar format that provides the necessary information will be acceptable.

8. Reasonableness of chemical analysis for organic carbon and iron in sediment samples

Once collected, the sediment samples need to be analyzed in a laboratory to determine their TOC and TEFe content. The methods used to analyze sediment samples for TOC and TEFe are proposed to be incorporated by reference into the rule in the document *Sampling and Analytical Methods for Wild Rice Waters*.

The incorporated documents require that the TEFe concentration be determined through the specific method of sediment analysis that was used to produce the sediment data that were used to develop the equation. The MPCA method for determining extractable iron in sediment requires the extraction of iron from the sediment with a specific strength of hydrochloric acid (0.5 N) for a specific length of time (30 minutes), at a specific temperature (80 degrees Centigrade). Any deviations from these specifications would extract less or more of the iron contained in the sediment, which would result in an erroneous sulfate standard being calculated via application of the equation. It is therefore reasonable for the MPCA to require that the equation be implemented only with iron data produced in conformance with the MPCA method.

Through the analysis of the field study data and an understanding of sulfur chemistry, it became clear that iron in the sediment had the potential to mitigate sulfide produced by removing sulfide from solution as an iron-sulfide precipitate. Not all iron found in sediment is in a form that is available to potentially react with sulfide—some iron is bound inside minerals and would not react with sulfide. Because many researchers have had the need to quantify just the sediment iron that is biologically or chemically available, various methods have been proposed in the scientific literature to quantify "reactive iron" which is referred to as "extractable iron" in this Statement. Most often, researchers have used either 0.5 N or 1.0 N hydrochloric acid (N stands for Normal, a measure of concentration) to extract the iron from the sediment prior to analysis. Consistent with the goal to only extract potentially reactive iron, the MPCA chose an iron extraction method using the 0.5 N acid concentration. The list of references to this Statement provides a number of peer-reviewed research studies that also used 0.5 N hydrochloric acid to quantify potentially reactive iron (Azzoni et al., 2005, Fredrickson et al., 1998, Gilmour et al., 2007, Giordani et al. 2008, Kennedy et al., 1999, Kenneke and Weber, 2003, Kostka and Luther, 1994, Liu et al., 2014 and Zhu et al., 2012).

The proposed method requires that the organic carbon concentration input into the equation be determined through standard laboratory methods based on EPA Method 9060A.

9. Reasonableness of using the lowest calculated sulfate concentration as the numeric standard

To protect the wild rice beneficial use, a numeric sulfate standard needs to be determined for each wild rice water. As noted above, the first step in this effort is to measure the TOC and TEFe in five composite sediment samples from the wild rice water. The next step is to plug the resulting pairs of iron and carbon data into the equation to calculate the protective sulfate concentration for that iron-carbon data pair, resulting in a total of five sulfate concentrations. Finally, the proposed rule specifies that the numeric sulfate standard is the lowest sulfate concentration calculated from the paired sediment data.

The purpose of sampling sediment in the wild rice water is to capture the variability of the sediment concentrations of TEFe and TOC to ensure that the sulfate standard selected from the group of five representative sulfate values calculated is protective of the wild rice beneficial use in that wild rice throughout the wild rice water. A commenter suggested that the numeric sulfate standard should be the average of calculated sulfate concentrations, rather than the lowest. There are two reasons why it is not reasonable to use the average. First, the goal of developing a sulfate standard to protect wild rice is to allow wild rice to grow in all suitable habitat in a water body, not just a subset. Use of an average would protect only a portion of the beneficial use, given that use of an average implies that about half of the habitat would need a lower numeric sulfate standard to ensure that wild rice would not be exposed to high porewater sulfide concentrations. Second, the suggestion of using an "average" might sound like it would protect half of the wild rice areas, but in fact, protection might be far less than half. The reason that "average" does not necessarily protect half is that calculation of averages is vulnerable to extreme values, for example, if one of the five calculated potential sulfate standards were extremely high, the average could actually be higher than four of the five values. In such a case, the use of an average as the numeric sulfate standard could conceivably protect only a very small proportion of the wild rice water body where wild rice grows. For the above reasons, use of the lowest calculated sulfate concentration is much more defensible and reasonable than use of a calculated average concentration. Additional explanation is provided in Chapter 3 of the TSD.

The MPCA compared the lowest composite value from each site to the percentile ranks (Table 8) and observed that they all fall within the 10th and 30th percentiles of the individual, non-composited, samples for the six sites. Since the goal is to protect virtually all of the wild rice from elevated sulfide, selecting the lowest value addresses the need to protect for sensitive conditions where sulfide may accumulate, and is a reasonable decision for protecting wild rice. In addition, selecting a value calculated from the observed, measured TOC and TEFe concentrations provides a direct application of the measured sediment concentrations to the calculated sulfate value.

Table 8. Lowest calculated sulfate value of composite samples compared to sulfate values at various percentiles calculated from the 25 individual samples analyzed from each water body of the pilot study

Water body	Lowest calculated sulfate value from composites (mg/L)	Sulfate values at various percentiles calculated from individual samples (mg/L)				
		10th	30th	50th	70th	90th
Bowstring River	2.1	2.0	3.3	3.6	3.9	5.3
Clearwater River	22.3	19.7	23.5	24.4	32.3	50.1
Hesitation WMA	104.3	85.7	112.7	142.2	217.2	469.4
Mission Creek	240.1	203.1	247.6	294	312.8	397.1
Monongalia Lake	6.6	5.1	6.8	8.6	10.7	13.8
Mississippi River	5.6	4.6	6.0	6.9	9.3	12.8

10. Reasonableness of providing for alternate and site-specific standards

Using an equation to derive the numeric sulfate standard from the protective sulfide porewater concentration is designed to respond to the specific environmental conditions of any given water body. However, there will be still be situations where this approach does not accurately protect the beneficial use in a specific wild rice water. This is true of any standard – given the wide diversity of natural systems and the limitations of scientific knowledge despite regular advances, no standard of general applicability can accurately reflect all the diversity seen in the natural environment. In the case of wild rice and sulfide, the MPCA's proposed approach of employing an equation to determine the numeric sulfate standard needed to maintain the protective sulfide level in a given water body is the most accurate approach evaluated, but it is not accurate in every situation. Providing a process for establishing an alternate standard is reasonable because it responds to known scenarios that have been observed in the study data.

Establishing an alternate sulfate standard in a wild rice water will be appropriate when the average ambient sulfate concentration exceeds the calculated equation-based standard and porewater sulfide concentrations are demonstrably below the protective concentration of 120 µg/L. The ability to set an alternate standard responds to concerns about false positives (where surface water sulfate above the calculated standard does not elevate porewater sulfide) that potentially could cause investment in sulfate control that is not needed to protect wild rice. The MPCA is aware of sites where the relationships established by the equation do not hold true; that is, where sulfate does not convert to expected levels of sulfide based on the equation. This is usually due to circumstances specific to the water body, such as groundwater flow that counteracts the diffusion of surface water sulfate into the sediment.

A water body that consistently exhibits porewater sulfide less than 120 µg/L when the equation predicts sulfide greater than 120 µg/L is most likely experiencing the upward movement of groundwater through the sediment. To respond to this scenario, the MPCA is proposing a process for establishing an alternate numeric standard where the porewater sulfide concentration remains below 120 µg/L even though the surface water sulfate concentration is higher than the calculated numeric standard. This approach is grounded in the understanding that if the porewater sulfide is below 120 µg/L, the ambient level of sulfate is sufficiently protective of the wild rice beneficial use. In such cases, the proposed rule allows the commissioner to establish an alternate numeric sulfate standard for that water body. The alternate standard may be the current average ambient sulfate level or it is also possible that the alternative standard could be higher than the current ambient sulfate level. A standard higher than the current ambient sulfate level could be justified if the porewater sulfide levels are considerably less than 120 µg/L and an evaluation of the conditions provides a reasonable assurance that porewater sulfide concentration will remain below 120 µg/L.

The proposed process for establishing an alternate sulfate standard as described above is not the same as the process for establishing a site-specific standard. Establishing a site-specific standard requires detailed analysis, public notice and comment, and EPA approval, activities that are beyond the analysis and approval associated with determining the protective sulfate numeric value when porewater sulfide is below the protective threshold proposed in this rulemaking. Instead, the proposed process for an alternate sulfate standard is analogous to the procedures found in Minn. R. 7050.0217 to 7050.0219 for calculating site-specific human health criteria.

When establishing an alternate standard, the MPCA must consider the factors that are contributing to the concentration of porewater sulfide, to ensure that the conditions will maintain the sulfide at or below the protective levels and protect the wild rice beneficial use. The unique conditions present in a water body, the health of the wild rice population, the effect of dischargers, and environmental conditions must all be evaluated. There may be other reasons, in addition to the influences of groundwater flow, for why sulfide is low and wild rice is prospering despite high levels of sulfate in the surface water. In order to justify an alternate standard, the MPCA will need to consider factors that may be influencing the conditions. In particular, the MPCA must consider whether the addition of sulfate to the water body has achieved a steady state condition between sulfate and sulfide. In order to determine whether the observed porewater sulfide levels accurately reflect the ambient sulfate levels, there cannot have been new discharges to that water body for a period of years. The MPCA is reasonably providing an option for establishing an alternate standard, but cautions that the evaluation that will be needed to establish an alternate standard will be complex.

The MPCA recognizes that there may be situations not yet encountered where the proposed approach to the numeric standard, whether calculated or alternate, will not be protective of wild rice, or will be over-protective of wild rice. This may occur based on the specifics of a particular site, or because the relationship between sulfate and sulfide varies in a way that has not yet been seen or anticipated. In such a case, a more classic, site-specific standard analysis would be needed, which the MPCA can provide under existing authority for site-specific standards. As noted in the rule language, the site-specific standard must still protect wild rice beneficial use. The proposed rule language reasonably refers to the rules governing site-specific standards to ensure that readers are aware that a site-specific standard can be developed if warranted.

It is reasonable to base the alternate standard on porewater sulfide information because, as discussed previously, the MPCA has determined that sediment porewater sulfide is the toxicant of concern, and 120 µg/L in the sediment porewater is the concentration needed to protect the wild rice beneficial use. It is also reasonable to derive a numeric sulfate standard from the porewater sulfide concentration because sulfate is a predominant form of sulfur that is discharged via human activity.

11. Reasonableness of the porewater sampling procedures

As discussed above, there may be situations where the calculated sulfate level in a wild rice water is lower than the measured concentration of sulfate in the surface water and the porewater sulfide concentration is below 120 µg/L . In those cases, proposed Minn. R. 7050.0224, subpart 5, item B, subitem (2) provides the option of establishing an alternate sulfate water quality standard based on the actual levels of sulfide in the porewater, which must be sampled and analyzed according to specific procedures. The MPCA is proposing to incorporate by reference a document that describes the procedure and methods for sampling and analyzing sediment porewater for sulfide. It is reasonable to require that porewater sulfide concentrations be obtained in conformance with specific methods so that the sulfide concentrations are comparable to the MPCA-sponsored field study that obtained the data on which the proposed sulfate standard and protective sulfide level are based.

The porewater sampling procedures build upon the sediment sampling procedures required for analysis for TOC and TEFe. Sediment sampling procedures are being incorporated by reference in the document *Sampling and Analytical Methods for Wild Rice Waters*. The proposed sediment sampling procedures require careful documentation of the location of the core sample sites. Porewater samples must be obtained from a subset of the previously sampled core sites. Those previously selected and sampled core sites represent the sediment conditions where wild rice is or may be growing. The porewater sampling procedure requires the collection of samples from fewer sites than are required for sediment sampling. For sediment sampling, 25 cores samples are required. For porewater sampling, ten porewater samples are required, from randomly selected core sample sites (two in each of the five previously determined sediment sampling transects).

It is reasonable to collect ten porewater sulfide samples rather than collecting and compositing five sulfide samples from each transect as required for sediment sampling. The process of collecting porewater samples is complex and the MPCA considers that ten samples is a sufficient number to characterize porewater sulfide in a wild rice water, and that obtaining more than ten samples in a wild rice water would be burdensome. In addition, in order to make a porewater composite, samples would need to be removed from the individual serum bottles and mixed, which might expose them to oxygen. Oxygen exposure could degrade the sulfide, producing erroneously low sulfide concentrations and compromising assurance that the samples are strictly comparable to the samples obtained in the MPCA's field study.

It is reasonable to randomly select from the previous core sampling locations because:

- According to statistical theory, randomly selected sites are more likely to represent the true environmental conditions than consciously selected sites or sites selected from a regular pattern; and
- The pre-selection of the random sites removes any discretion in site selection that might bias the samples. The sampling document identifies which core sample sites should be selected for porewater analysis and those sites were determined using a random-number generator.

The porewater sampling methods also specify the appropriate depth for obtaining a porewater sample. The concentration of sulfide in porewater has been shown to vary with sediment depth, so it is important to extract the porewater from the sediment in a uniform way so that the degree of dilution by shallower and deeper low-sulfide water is similar to that in the MPCA-sponsored field study. For instance, use of a smaller-diameter coring tube than that specified in the methods proposed to be incorporated by reference could change the concentration of sulfide.

The incorporated document provides specific detail about the equipment specifications and the procedures to be used to collect porewater samples. The equipment and procedures ensure consistency with the data on which the 120 120 µg/L protective threshold is based, and are based on standard procedures.

F. Reasonableness of where the standard applies

As described previously, the MPCA is proposing to identify approximately 1,300 specific WIDs as wild rice waters. This discussion explains the reasonableness of the MPCA's proposal that the calculated sulfate standard applies to the entire identified WID.[15]

It is important to be clear about the difference between "where the standard applies", in terms of the water bodies to which it is applicable, and "where the standard applies" in the sense of what facilities receive a related permit limit. The MPCA generally, and in this SONAR specifically, speaks to "where the

[15] An exception to the WID-wide application of the sulfate standard is proposed in the amendment to Minn. R. 7053.0406. In subpart 1, the MPCA proposes that no effluent limit is required if the commissioner makes a determination that, based on site-specific conditions, the discharge will not affect the wild rice beneficial use.

standard applies" to mean defining those waters that must be protected for the beneficial use; in this case, those waters where sulfate must remain below the numeric sulfate standard in order to protect the wild rice beneficial use. Permitted facilities are reviewed to determine if they may cause or contribute to a violation of the standard in the waters where the standard applies; if so, they receive an applicable discharge limit to avoid causing or contributing to a violation.

Further discussion of how the MPCA determines effluent limits is provided in Part G.

The question of where the standard will apply in identified wild rice waters is extremely complex. A number of factors affect the presence, location, and density of wild rice beds; the complexity of river hydrology further complicates the issue. The fundamental issue the MPCA sought to resolve was how to protect the beneficial use in an identified wild rice water yet acknowledge those situations where there is no reasonable potential for a discharge to affect the beneficial use.

1. Application of the standard to lakes, wetlands and reservoirs

The MPCA's decision about how to apply the standard to lakes, wetlands and reservoirs identified as wild rice waters was relatively straightforward. Most lakes, reservoirs and wetlands are identified by a single WID. For most lakes, reservoirs and wetlands, water moves and mixes through the entire water body. Even though a lake, reservoir or wetland may not have uniform conditions to support the growth of wild rice in all areas, the standard reasonably applies to the entire water body because, due to mixing, a discharge to any part will affect sulfide production in every part.

The MPCA recognizes that in limited situations, a lake will have a hydrologically separate area, such as a bay, which does not mix with the main lake waters (i.e. water does not flow from the main basin to the bay). If a bay is determined to be hydrologically separate from the main basin, a unique WID will represent that bay. Where a part of a lake is hydrologically separate and assigned a unique WID, the MPCA will conduct a separate determination of whether it is a wild rice water. In few situations, the wild rice beneficial use may be demonstrated only in certain bays within a lake or reservoir. In these situations, if the bay of the lake has been determined to be hydrologically separate from the main basin, the MPCA proposes to identify only that bay as a wild rice water. Conversely, if the wild rice beneficial use was demonstrated in the main lake basin, and not in a bay(s), only the main basin will be identified as a wild rice water. As an example, the main basin of Swan Lake is WID #31-0067-02 and the southwest bay of Swan Lake is WID #31-0067-03. The southwest bay has a separate WID because water that enters the main basin does not go into the southwest bay. The MPCA is proposing to list the southwest bay of Swan Lake as a wild rice water, which is where the wild rice beneficial use has been demonstrated, and not the main basin.

2. Application of the standard to rivers and streams

The question of where to apply the standard in rivers and streams is considerably more complex than that of lakes/reservoirs/wetlands. The MPCA considered many alternatives and issues relating to the application of the standard in rivers and streams before deciding on the proposal. The MPCA's goals were to:

- Protect the wild rice beneficial use.

- Acknowledge that wild rice growth is extremely variable; it may change locations within a water and even be absent for a period of years before reappearing.
- Acknowledge that downstream discharges may not have an effect on wild rice located upstream.
- Limit the need for case-by-case determinations of where the standard should apply.
- Acknowledge the limitations of the MPCA's database of wild rice locations.
- Acknowledge the variability of the physical conditions of some WIDs.
- Provide a degree of certainty for dischargers to wild rice waters.
- Avoid treatment costs that do not contribute to protection of wild rice.

The MPCA is proposing to identify rivers and streams as wild rice waters based on the documented presence of the wild rice beneficial use at some point in the identified WID and to have the standard applicable to the entire WID. After much discussion, application of the standard at the WID level is the most clear and administratively feasible way to apply the standard.

As discussed previously, the MPCA uses the WID identification system throughout its permitting, water assessment, and monitoring programs.

3. Alternatives considered for rivers and streams

The following discussion of the alternatives considered identifies the issues and complexities the MPCA considered in proposing how the standard will apply to rivers and streams.

Apply the standard within a range of where the wild rice beneficial use is present or has been documented.

Initially, the MPCA focused on having the standard apply around the locations of wild rice beds in each wild rice water. In early drafts of the proposed rule revisions, the MPCA suggested that the standard apply 800 meters upstream and downstream from the point where there is a documented presence of wild rice since November 28, 1975. However, further investigation into the information supporting the identification of wild rice waters showed a lack of evidence detailing the exact location of wild rice beds. In some cases, this is because of how the data was collected, but it is also because wild rice beds are known to move around within waters. (The transient nature of wild rice beds is one of the reasons that the MPCA initially considered applying the standard some distance up and downstream of each wild rice bed.) The magnitude of the effort associated with documenting the past, present, and future location of every wild rice bed that indicates the beneficial use is beyond the capabilities of the MPCA. Furthermore, consideration of this option quickly led to questions about how the wild rice bed locations would be documented – in rule or elsewhere – and how frequently and through what process that information would be updated. The MPCA anticipated a state of constant change as the location of existing wild rice beds moved and new beds were identified. Given these questions and uncertainties, the MPCA determined that pursuing this option would not meet the objective of clarifying where the wild rice sulfate standard applies, would be administratively burdensome, and would not reasonably protect the beneficial use.

Base the identification of where the standard applies in wild rice waters on the presence of suitable conditions to support the beneficial use of wild rice.

Similar to comments that the MPCA should not identify specific waters but instead identify the habitat that will support the growth of wild rice and apply the standard wherever those conditions exist, the MPCA could have chosen to have the standard apply to parts of each wild rice water that have habitat that would support wild rice. Again, this approach would be difficult to implement. These suggestions do not take into consideration the variability of the conditions for wild rice growth or the presence of other factors that limit the growth of wild rice (e.g. it will not grow where water levels vary too widely.) The assumption that the rule can broadly characterize wild rice waters based on certain physical conditions mistakenly assumes a complete understanding all of the variables affecting wild rice and the complex relationships between them.

Establish wild rice waters at a level smaller than the WID.

The MPCA considered whether it would be possible to subdivide the current WID system to identify the specific areas where it has documented the wild rice beneficial use and to exclude those specific areas that have not been documented. However, there are significant administrative obstacles to changing the process for assigning WIDs.

In order to refine the current WID system, the MPCA would need to either sub-divide WIDs in a manner consistent with the above-mentioned factors, or create a new and separate system of sub-divided WIDs specific to wild rice waters. Stream WIDs are sometimes changed or divided as part of the MPCA's assessment process. The MPCA uses a rotating watershed approach for data collection and watershed assessment, completed over a 10-year cycle. The MPCA has established a schedule for intensively monitoring each major watershed over a 2-year period, once every 10 years. Following this two-year intensive water quality data collection period, watersheds are assessed to determine if they meet the beneficial uses associated with these waters. Sometimes during the monitoring or assessment cycle for a particular watershed, a proposal is made to split a stream WID, often when water quality data indicate the need for a beneficial use class change within the WID. The MPCA has a process for splitting stream WIDs to reflect these changes in use class.

While it would be possible to request WID splits to better identify where wild rice might be present within an existing stream WID, it is not reasonable to do so. The WID is used by the MPCA as the main administrative designation used to assess whether a stream reach meets a variety of beneficial uses and a stream reach may be impaired for a variety of parameters such as dissolved oxygen, sulfate, nutrients, and various toxic substances. While a series of smaller WIDs might better represent the location of wild rice, smaller WIDs would likely make it more difficult for the MPCA and others to collect representative samples to characterize conditions for other parameters. Increasing the overall number of WIDs would also create additional administrative and monitoring burdens.

A separate system of sub-divided WIDs specific to wild rice waters would also result in a significant and unreasonable administrative burden for maintenance and program coordination for the MPCA and for other entities that rely on MPCA water quality data. Additionally, further refining the size of a wild rice water WID will not necessarily result in a more accurate identification of where the wild rice beneficial use exists.

Exceptions to the proposed approach

The MPCA recognizes that there will be exceptions to the MPCA's assertion that the presence of wild rice beneficial use at some point justifies the application of the standard to the entire WID. The nature of wild rice growth and physical properties of rivers and streams are extremely variable, and discharges at various locations will have different potentials to affect wild rice. There may be situations where, depending on the location of the discharge relative to the wild rice and other qualities of the water body, there is no reasonable potential for the discharger to affect the wild rice. The MPCA is proposing a means of addressing this situation via an amendment to Minn. R. ch. 7053. The reasonableness of the proposed mechanism for addressing these exceptional situations is discussed in Part 6.H, with the amendments to Minn. R. ch. 7053.

G. Reasonableness of implementation provisions (Minn. R. ch. 7053)

Minn. R. ch. 7053 sets forth provisions for effluent limits and treatment requirements for discharges to waters of the state. Effluent limits – limitations on the amount of pollution that a point source (facility) can discharge – are a key component of ensuring that water quality standards are met in the waters to which the standard applies. Once developed, effluent limits become part of a facility's permit. The process of setting an effluent limit begins with a review to determine if a facility has a reasonable potential to cause or contribute to an exceedance of a water quality standard. If so, the facility receives a limit intended to control the discharge of the pollutant to a level that ensures that the facility will not cause or contribute to an exceedance of the water quality standard.

It is important to provide an overview of the process for setting effluent limits to demonstrate the reasonableness of the proposed changes to Minn. R. 7053 associated with the Class 4D sulfate standard, particularly for the proposed $365Q_{10}$ flow rate.

1. Effluent limit reviews

Conducting effluent limit reviews requires adequate data. In the case of the wild rice sulfate standard, that data includes: sediment data to calculate the sulfate standard (or porewater sulfide data to establish an alternate standard), surface water sulfate data, and effluent sulfate data. When these data are available, MPCA staff conducting effluent limit reviews will take the following steps.

- Review downstream waters to determine where potentially affected wild rice waters are located relative to the discharge. Note that the wild rice water or waters may be many miles downstream of the facility.
- Collect sediment data to calculate the applicable numeric sulfate standard or, in the case of an alternate standard, collect porewater data to identify the applicable numeric sulfate standard.

- Examine ambient surface water sulfate concentrations to determine whether sulfate in the wild rice water is meeting or exceeding standards or if additional data are needed.
- Examine effluent data to determine whether discharge levels are causing or contributing to an exceedance of the standard, or have the potential to do so.

It takes time to collect and evaluate data in order to calculate sulfate limits and establish effluent limits. It is reasonable to recognize that the implementation of an effluent limit must be based on sufficient data that accurately characterizes the conditions in the wild rice water and effluent.

2. Setting water-quality based effluent limits

The MPCA must develop an appropriate water quality based effluent limit (WQBEL) if a discharger shows the potential to cause or contribute to an exceedance of the sulfate standard. Figure 4 shows the general process for setting a WQBEL with a more detailed explanation below.

Figure 4. General process to determine applicable WQBEL from water quality standard.

<u>Water Quality Standard</u>

The process begins with a water quality standard that is protective of a specific water body to ensure the beneficial uses are protected. The sulfate standard protects the wild rice beneficial use in wild rice waters. Each wild rice water has its own unique sediment and water chemistry that contributes to the formation of porewater sulfide. As a result, the water quality standard for sulfate will be specific to each wild rice water.

<u>Reasonable Potential</u>

Reasonable potential is a term used to describe the analysis for determining whether a WQBEL is necessary for a permitted wastewater discharger. The term is taken from federal regulations, which require that effluent limits must control all pollutants or pollutant parameters which are or may be discharged at a level that will cause, have the reasonable potential to cause, or contribute to an excursion above any state water quality standard. Federal regulations require that all discharges with reasonable potential to cause or contribute to the exceedance of a state water quality standard receive a WQBEL (40 CFR §122.44).

Generally, a facility will have reasonable potential for sulfate if it discharges sulfate upstream of a wild rice water at concentrations in exceedance of the numeric standard and if the surface water sulfate concentration in the wild rice water exceeds the standard. If the facility does not have a reasonable potential, future routine effluent monitoring may be recommended to ensure protection. If a facility has reasonable potential, a wasteload allocation (WLA) is derived from the amount of pollutant load the facility can discharge without causing or contributing to an exceedance of the standard in a downstream wild rice water.

Wasteload Allocation

Before a WLA can be set, there must be reasonable potential that a facility has the ability to cause or contribute to a downstream impairment. A WLA is the amount of a pollutant (in this case, sulfate) that an existing or future facility may discharge. WQBELs for point source discharges are developed from WLAs. Neither EPA nor MPCA guidance requires a WLA to be calculated a specific way when setting effluent limits. However, a WLA should be based on: 1) the pollutant load that would meet the standard, and 2) the pollutant load that is currently present in the receiving water. When calculating a WLA, the MPCA has developed pollutant-specific practices that account for the unique chemistry of each pollutant. For example, an ammonia WLA might account for the fact that ammonia can decay biologically whereas a mercury WLA would account for mercury bioaccumulation in fish and other organisms.

Assimilative Capacity

The calculation of the sulfate WLA considers the assimilative capacity of the receiving water. The assimilative capacity of the receiving water is the difference between current loading and the highest load that still allows the water quality standard to be met. As long as the current loading is less than the load required to meet the water quality standard, there is adequate/remaining/available assimilative capacity. If the current loading is greater than the load that will meet the water quality standard, there is no available assimilative capacity and reductions are needed for the water body to meet its beneficial use.

The following mass balance equation (Equation 1) calculates a WLA in units of concentration for a single or multiple facilities. The WLA is dependent on the variables in the mass balance equation. The value for either the calculated standard, alternate standard, or site-specific standard (all referred to as WQS in the equation) must be known before a WQBEL can be determined for a wild rice water.

Equation 1. General mass balance equation for WLA

$$WLA = \frac{WQS * Q_s + WQS * \sum_{i=0}^{n}(Q_e) - Q_s * C_s}{\sum_{i=0}^{n} Q_e}$$

WQS =numeric sulfate standard

Q_s = Protective receiving water flow rate ($365Q_{10}$)

Q_e = Individual point source effluent flow rate. (70% of AWWDF for municipal WWTPs, MDF for industrial dischargers)

C_s = Background concentration of pollutant in receiving water (see background concentration section)

Protective Flow Rate ($365Q_{10}$)

Water quality standards are defined by a duration and frequency, as described previously. The MPCA is proposing an annual average duration, and one-in-ten year frequency for the wild rice sulfate standard.

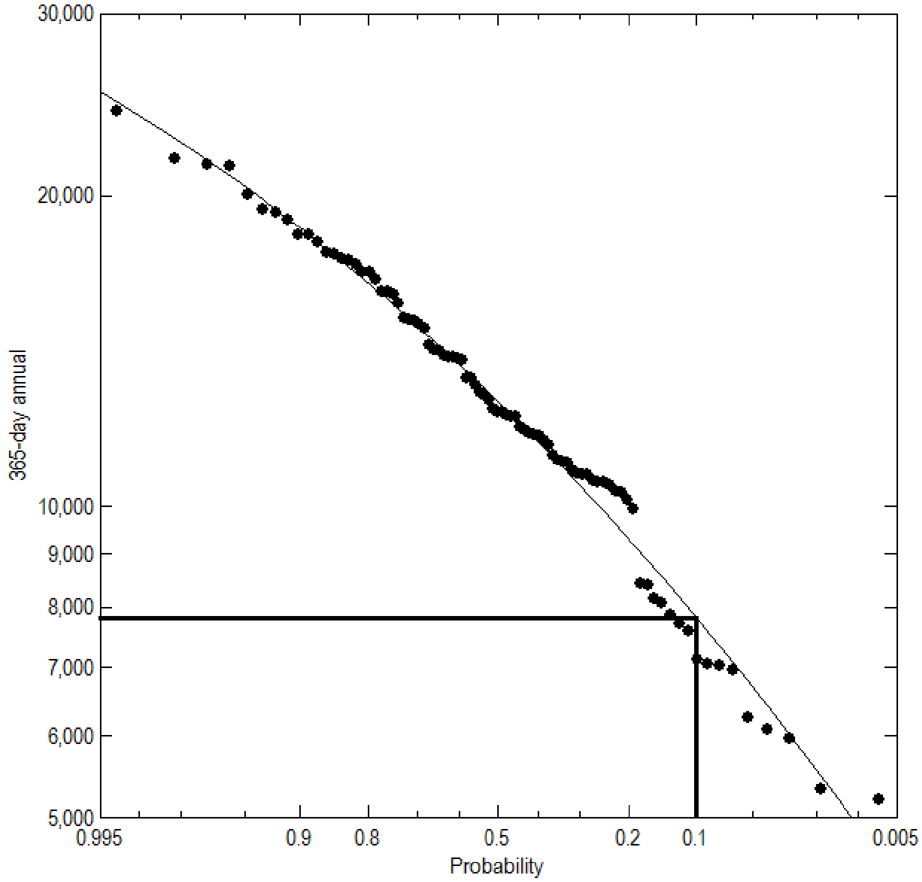
In order to ensure that the effluent limit developed protects the water quality standard at the specified duration and frequency, an appropriately protective stream flow rate must be determined. The flow rate is used for streams and loading to lakes fed by streams. The flow rate defines the critical flow condition, which is then used in the effluent limits calculation. Low flows are a potential concern because there is less water available in the receiving water to dilute the effects of sulfate discharges.

Based on the annual duration and one-in-ten year frequency, the MPCA is proposing a one-in-ten year annual low flow statistic ($365Q_{10}$) to define the critical in-stream condition. The “365-day ten-year low flow” or “$365Q_{10}$” means the yearly average flow with a one-in-ten year recurrence interval. The $365Q_{10}$ is comparable to the recurrence interval used for other water quality standards, such as general toxics ($7Q_{10}$) and ammonia ($30Q_{10}$) in the sense that a one-in-ten year recurrence interval is used; however, the averaging period is expanded to an annual (365 day) period to reflect the annual average duration proposed for the wild rice sulfate standard. A $365Q_{10}$ is derived using the same methods to derive a $7Q_{10}$, and the guidelines regarding period of record for flow data and estimating a $7Q_{10}$ apply equally to determining a $365Q_{10}$ as described in part 7053.0135, subp. 3. The $365Q_{10}$ calculation methodology would apply to streams and rivers. A one-in-ten year flow recurrence interval or equivalent value calculated using site-specific water modeling would apply to lakes, wetlands, and reservoirs. Because of the lack of flow through the water body, an isolated water body without inflows or outflows would have a one-in-ten year flow of zero.

The $365Q_{10}$ flow rate is a reasonable choice because it is protective of both the annual average duration and the one-in-ten year recurrence interval of the proposed standard. The flow rate will be calculated using calendar-year time intervals to be protective of the annual average duration of the standard. A recurrence interval of one-in-ten years will be used to be protective of the standard’s acceptable frequency of exceedance.

A graphical illustration of the $365Q_{10}$ calculation for flow gauge 05133500 on the Rainy River is provided in Figure 5. The straight line at the 10^{th} percentile shows that the $365Q_{10}$ for this gauge is 7800 cfs.

Figure 5. Calculation of 365Q10 on Rainy River



Station: 05133500, fitted line based on the log-Pearson type III method

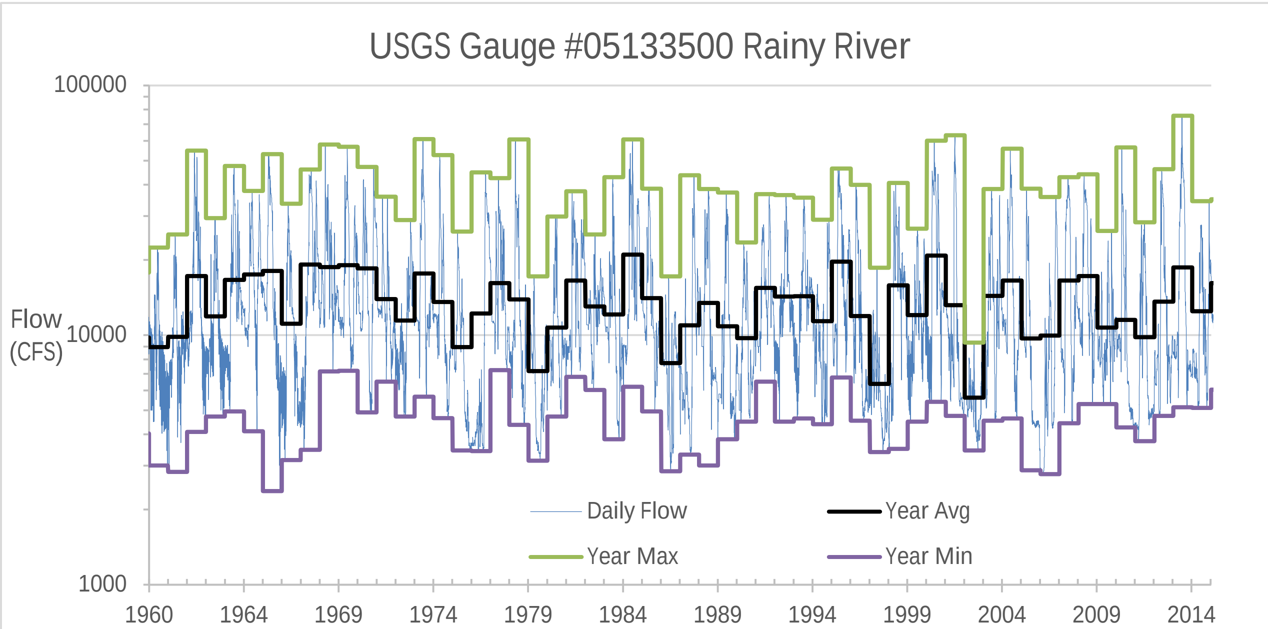
The MPCA examined historical flow records for selected major Minnesota rivers (Mississippi, Minnesota, Rainy, Red, St. Louis, Crow Wing, Redwood & Zumbro) to determine the likelihood of successive low flow years (see example in Table 9). The occurrence of a 10th percentile or less annual average flow rate occurring consecutively in Minnesota is indicated by "Yes" in the "Low Flow In A Row" column in Table 9. When considering the probability of low flow for a given river, the MPCA assumes each flow year is independent from the prior and subsequent year. The exception to this is that during the "dustbowl" era 1930's, the Rainy River and other Minnesota rivers had consecutive low flow years (i.e. less than the 365Q10) one after the other. This was during the unique "dustbowl" climate period in U.S. history, where poor soils management and La Niña conditions caused reductions in precipitation in the Midwest (Cook et al., 2008).

Table 9. Occurrence of annual average flow rates at 10th percent low flow or less. Records measured at USGS gauge 05133500 Rainy River (1928-2016 record).

Year	Rank	Annual Average Flow (CFS)	Annual Max Flow (CFS)	Annual Min Flow (CFS)	Low Flow In A Row
1931	1/89	4636	11900	1700	Yes
1930	2/89	5445	19600	1600	Yes
2003	3/89	5609	9340	3450	No
1998	4/89	6373	18600	3400	No
1958	5/89	6479	11200	3120	No
1980	6/89	7175	17200	3140	No
1932	7/89	7309	15700	3200	Yes
1940	8/89	7650	30300	3400	No
1987	9/89	7728	17200	2850	No

The analysis also found that Minnesota river flows are highly variable over the course of a year (high intra-annual variability) and that hydrologically rivers rarely flow at their "low flow" conditions for an extended period of time. Low flows are of concern because there is less water to dilute the sulfate loading from wastewater treatment plants (WWTP) and other permitted facilities. There can be periods of drought or low flow during a calendar year but every river in Minnesota has high flow periods during the spring that are at least an order of magnitude greater than low flow periods of the summer and fall. This pattern is evident by looking at the hydrograph of the Rainy River in Figure 6 (the period of record visualized was shortened from 1960 to 2016 to allow for better visualization). Even within low flow years, intra-annual flow variability will provide periods of relief from high sulfate concentrations, especially if the water has point source contributions.

Figure 6. USGS Flow for Rainy River



Effluent Limit

Where the MPCA determines an effluent limit is needed to protect a wild rice water, it will derive a WQBEL from the wild rice water's WLA for each facility discharging to the water body. For wild rice waters that have multiple facilities discharging to them, the gross WLA is split into several individual WLAs for the individual facilities. The WLA then determines effluent limits that are protective of the water quality standard using the method below.

Point Source Effluent Flow Rate

The facility effluent flow rate used in effluent limit reviews should be protective of the water quality standards critical condition. Municipal WWTPs must treat all the water flowing into the facility (inflow). Once treated, the discharge (effluent) flows into the receiving water. The maximum capacity of a municipal facility to treat wastewater is known as the average wet weather design flow (AWWDF). The AWWDF is comprised of the everyday base wastewater flow plus the additional flow reaching the plant because of inflow and infiltration in the wastewater collection system during storm events. During dry periods when precipitation and thus infiltration is much lower, the flow a wastewater plant is designed to treat is referred to as the average dry weather design flow.

Average dry weather design flow for municipal WWTP and maximum design flow (MDF) for industrial WWTPs have traditionally been used to calculate effluent limits for toxic parameters. For toxics, the critical condition is an extreme low flow; one can reasonably expect municipal facilities discharge at the average dry weather design flow at this time because of lack of inflow and infiltration. However, the wild rice sulfate standard has an annual duration, and seventy percent of AWWDF represents the approximate maximum level at which a municipal treatment can operate at over a longer duration of time. Likewise, it is reasonable to assume that industries will discharge at the MDF, although given the complex nature of some industrial facilities, the MPCA may in some cases use a facility-specific flow rate.

The 70th percentile of the average wet weather design flow (AWWDF) for municipal WWTPs and maximum design flow (MDF) for industrial WWTPs should be used in effluent limit calculations to be protective of the wild rice sulfate standard. Municipal facilities operating at over 70% AWWDF on a long-term average basis are likely at or exceeding full AWWDF during storm events and will need to expand the size of their treatment plants. For many facilities, 70% AWWDF is near average design flow capacity. The MPCA will likely continue the practice of using the 70th percentile of the AWWDF for municipal WWTPs and MDF for industrial WWTPs as it does for the river eutrophication standard -based effluent limit setting. Using the 70th percentile AWWDF for municipal facilities allows staff to analyze the potential impact from a WWTP under flow conditions considered at maximum capacity without needing to expand the facility. For industrial facilities the MPCA will use the full MDF unless an alternative flow condition is considered more appropriate given the unique nature of their process.

Estimating Sulfate Background Concentrations

The MPCA has a long-standing practice of using background concentrations to account for receiving water dilution as part of the effluent limit review process. "Background," in the context of effluent limits, is the level of water quality in the wild rice water of interest without facility impacts. MPCA staff typically use parameter-specific practices when determining background concentrations for a specific parameter of concern. For many water quality standards, the immediate receiving water is the water of interest. In these circumstances, samples collected upstream of the discharge provide for a reasonable background estimation. Implementation of the wild rice sulfate standard will be different because the water of interest may be many miles from the discharge. In this circumstance, a sample collected upstream of the discharge may not provide a suitable background value. The upstream water may be significantly different from the downstream water of interest because of multiple factors, some of which include: size of facility, size of area draining to wild rice water, biological community complexity, and biochemical diversity.

Methods for determining background concentrations are ranked below in terms of preference when site-specific data are not available. The MPCA prefers using site-specific data but may rely on other methods to determine background concentrations.

1. Subtraction
   This is the process where the current actual point source loading is subtracted from ambient river loading. This approach allows the MPCA to account for the different contributions from point and non-point sources.
2. Substitution
   This is the process of using watersheds or water bodies with similar characteristics to predict background receiving water concentrations in the receiving water of interest. The MPCA tends to use the average or median of site-specific data as the background concentrations when setting effluent limits.
3. Water Quality Model
   This is the process of using mathematical techniques to simulate and predict water quality. A typical water quality model consists of a collection of formulations representing physical mechanisms that determine position and behavior of pollutants in a water body.

Allocating Load Among Point Sources Once a WLA Is Established

Once a gross WLA has been calculated for a water body, then individual WLAs must be divided among facilities discharging to that water body. Table 10 identifies 19 separate ways a WLA could be allocated (U.S. EPA 1991), demonstrating that there may not be a single way to distribute WLAs amongst sources.

Table 10. WLA Methods (Table from U.S. EPA TSD for Water Quality Based Toxics Control, 1991)

1. Equal percent removal (equal percent treatment)
2. Equal effluent concentrations
3. Equal total mass discharge per day
4. Equal mass discharge per capita per day
5. Equal reduction of raw load (pounds per day)
6. Equal ambient mean annual quality (mg/l)
7. Equal cost per pound of pollutant removed
8. Equal treatment cost per unit of production
9. Equal mass discharged per unit of raw material used
10. Equal mass discharged per unit of production

11a. Percent removal proportional to raw load per day

11b. Larger facilities to achieve higher removal rates

12. Percent removal proportional to community effective income

13a. Effluent charges (dollars per pound, etc.)

13b. Effluent charge above some load limit

14. Seasonal limits based on cost-effectiveness analysis
15. Minimum total treatment cost
16. Best availability technology (BAT) (industry) plus some level for municipal inputs
17. Assimilative capacity divided to require an "equal effort among all dischargers"

18a. Municipal: treatment level proportional to plant size

18b. Industrial: equal percent between best practicable technology (BPT) and BAT, i.e., Allowable wasteload allocation:

$$(WLA) = BPT - \frac{x}{100}(BPT - BAT)$$

19. Industrial discharges given different treatment levels for different stream flows and seasons. For example, a plant might not be allowed to discharge when stream flow is below a certain value, but below another value, the plant would be required to use a higher level of treatment than BPT. Finally, when stream flow is above an upper value, the plant would be required to treat to a level comparable to BPT.

Many dilution-based WLA equations will be based on multiple facilities contributing to a water body of concern. The MPCA will work with permittees to determine if all facilities' effluent limits should be based on identical concentration WLAs when multiple facilities discharge upstream of a wild rice water and demonstrate reasonable potential.

Limit Expression

In an NPDES permit, WQBELs for sulfate to protect the wild rice beneficial use will typically be expressed as a 12-month moving total mass. Concentration-based limits will also be included in the permit if need is demonstrated. As an example, there may be some situations where a mass limit is not protective enough given that it allows for various flow and sulfate concentrations (mass = flow x concentration; as flow goes down, concentration can go up and vice versa to equal same mass). If the wild rice water demonstrates that the beneficial use may not be protected because of various flow and corresponding sulfate concentrations, the limit will be expressed as a concentration. The sulfate concentration will likely be calculated by taking the calculated 12-month moving total mass and dividing by the discharge effluent flow from the facility. This calculation will result in a concentration, milligram per liter (mg/L), effluent limit.

The targeted mass limit would be calculated to be protective of the water quality standard as a 12-month moving total. The MPCA's process for calculating of a 12-month moving total requires the following steps:

1. Calculate the "Calendar Month Total" (kg/mo) value: for the discharge, multiply the total volume of effluent flow in million gallons (mg) by the monthly average sulfate concentration value and a 3.785 conversion factor to get the kg/mo value for each individual facility. Add all of the individual kg/mo values together to get the combined kg/mo "Calendar Month Total" value.
2. Calculate the "12-Month Moving Total" (kg/year or kg/yr) value: start with the combined kg/mo "Calendar Month Total" value (as described above) for the month of the current reporting period and add the last twelve months of the combined kg/mo "Calendar Month Total" values.
3. For the first 11 months after this limit is effective, report the total kg/yr of sulfate discharged from the permitted WWTPs from the first month the limit is effective through the 11th month after this limit became effective. Starting with the 12th month after this limit became effective and thereafter, calculate the "12-Month Moving Total" sulfate value as outlined above.

H. Reasonableness of allowing a determination that no effluent limit is required

The discussion above described the process of setting effluent limits and the reasonableness of the critical flow condition proposed. However, there may be some specific cases where a sulfate effluent limit is not needed to protect the wild rice beneficial use.

Proposed Minn. R. 7053.0406, subpart 1 allows the commissioner to make a determination that a discharger will not affect the wild rice beneficial use in a wild rice water. In Part 6.F, the MPCA discusses the complexity of applying the sulfate standard to rivers and streams. In those situations, a number of factors can influence the effect of a discharge on the health and growth of wild rice within the wild rice waters. In that part, the MPCA discusses the various options it considered before proposing that the standard will apply to the entire WID. In general, this means that all dischargers to that WID may need an evaluation of reasonable potential and a sulfate effluent limit. However, in recognition that there will be circumstances where this is not appropriate, the MPCA is proposing subpart 1, which allows the commissioner to determine that under certain circumstances no sulfate effluent limit will be necessary.

Proposed subpart 1 recognizes that there are specific conditions that would prompt the commissioner to determine that an effluent limit is not required. These conditions generally relate to the location of a discharger within the wild rice water and the documented location of wild rice within the wild rice water. There may be situations where the location of the discharge point will ensure there is no reasonable potential for an impact on the wild rice beneficial use.

The specific situations are likely to occur where the discharge from a facility impacts only the part of a wild rice water WID where there is no wild rice. For instance, a situation may occur where the discharge is at the downstream end of a stream WID and the only location where the wild rice beneficial use has been demonstrated is upstream of the discharge point. Another reason may be that there are specific hydraulic or substrate conditions in the part of the WID the discharge affects that prevent the growth of wild rice regardless of sulfate levels. In those situations, the commissioner would base the decision to not require an effluent limit on specific physical conditions of the water body that preclude the wild rice beneficial use. Examples of the hydraulic or substrate conditions the MPCA expects could preclude attainment of the beneficial use, regardless of sulfate discharge, are:

- Lack of sediment that allows germination and sustained growth;
- Rapid flow that prevents the establishment of seedlings; or
- Deep water that prevents the sprouted grain from reaching maturity.

Note that the conditions on which the commissioner will base such a determination are limited to "hydraulic or substrate conditions" and do not include factors relating to water quality, biological influences, or cultural conditions. If there is no reasonable potential for impact on the wild rice beneficial use, it is reasonable not to establish an effluent limit.

I. Reasonableness of variance requirements specific to wild rice waters

Water quality standards must be set based solely on the scientific conclusions of what conditions are necessary to support the specified beneficial use. Facilities then receive effluent limitations as needed to ensure that the water quality standards are protected in the water body. If meeting an effluent limit is not technically or economically feasible, the CWA provides certain tools to deal with that infeasibility.

An important tool to address the infeasibility of meeting a water quality standard or effluent limit is a variance. A water quality variance is an exemption from meeting otherwise applicable water quality standards and their associated WQBELs. Variances are intended to be temporary and apply to a specific pollutant. Situations can arise in which a permittee (e.g. municipal wastewater treatment facility, industrial facility) cannot currently meet a water quality-based effluent limit due to economics, technology, or limited other factors. In such cases, the permittee may apply for a variance.

Once a WQBEL is determined, a permittee can apply for a variance using the MPCA's Variance Request Form. As part of the process, the permittee must first review all possible alternatives, including treatment technology and source reduction, to reduce levels of the relevant pollutant. The variance request must also include information on the facility design, water quality data, and treatment alternatives. Also, the permittee must demonstrate the adverse economic impacts that are likely to occur if the permittee is required to comply with the limit. The MPCA uses EPA guidance, the Interim Economic Guidance for Water Quality Standards Workbook, to evaluate whether the economic impacts are such as to justify a variance. If the MPCA agrees, the MPCA may then grant preliminary approval to the variance, and any related permit requirements, including an interim effluent limit. Variances must go through a public process, including a public notice and public meeting, and must be approved by EPA before they are finalized and included in the facility permit.[16]

Once approved and included in a permit, variances must be periodically reviewed to determine if the conditions have changed such that meeting the limit or standard has become feasible. As noted above, variances must include provisions for meeting an alternate limit that is feasible and makes progress in reducing the relevant pollutant. The general premise is that while a standard or limit may not be feasible to meet in the present, economic or technological changes in the future will make meeting the limit or standard possible; that is why variances are considered temporary.

Although variances have not been a commonly used tool in the past in Minnesota (there are only five active variances), this is likely to change. In the case of wild rice and sulfate, the MPCA recognizes that sulfate treatment is currently prohibitively expensive for many dischargers, and therefore when the proposed rule revisions are adopted, dischargers (industrial and municipal) may apply for variances from the standard until economically feasible treatment systems can be designed and constructed. It is important to recognize that a variance is temporary, it must be approved by the MPCA and EPA, and the discharger must make progress toward achieving the standard. It is also important to recognize that a variance is not necessarily an "all or nothing" alternative to meeting the standard or WQBEL. A variance may include requirements to minimize sulfate in the influent and reduce sulfate discharges through alternative management until full compliance can be achieved. An important aspect of variances is progress toward the goal of meeting the standard or WQBEL. In this way, it is an improvement over the status quo of uncertainty in applying the sulfate standard.

Existing rules provide the administrative mechanism for obtaining variances from either a treatment standard or an effluent limit based on a water quality standard. The proposed rule reasonably cites to those existing variance requirements.

- Minn. R. 7000.7000 establishes the MPCA's general variance process;
- Minn. R. 7050.0190 establishes the specific process to obtain a variance from a water quality standard;

[16] *More information on the variance process can be found on the MPCA's Water Quality Variance web page at http://www.pca.state.mn.us/water/water-quality-variance*

- Minn. R. 7052.0280 establishes specific requirements for a variance from a water quality standard in the Lake Superior Basin; and
- Minn. R. 7053.0195 establishes the process to obtain a variance from an effluent limit or treatment requirement.

Minn. R. 7050.0190, subpart 4(A)(6) requires the commissioner to consider whether a variance can be granted because meeting the standard is not feasible due to "substantial and widespread negative economic and social impacts." Therefore, in addition to citing to these existing requirements, the proposed rule incorporates by reference an EPA document on which the commissioner must base the determination of widespread economic and social impacts. This document is the EPA Interim Economic Guidance for Water Quality Standards Workbook. The MPCA uses this same document to guide the review of economic considerations for current variance requests. However, until this time this EPA document has not been incorporated into the state rules by reference. The MPCA expects to receive a number of requests for variances from the sulfate standard and believes that the usefulness of this document to the MPCA's economic review warrants incorporating it, and subsequent amendments to it, into the rule. Because the incorporation by reference includes all subsequent amendments to this document, the MPCA and permittees requesting a variance review, can be assured that the most current version of the EPA economic assessment tools will be used.

Although the factors considered and the process for conducting the review vary somewhat, the MPCA must consider the economic and social impacts in the review for variance applications from either public or private entities. The required economic analysis is different for a public versus a private entity. For example, if the entity is publicly-owned (e.g. a municipal sewage treatment plant), the households in the community may bear the cost either through an increase in user fees, an increase in taxes or a combination of both. A discussion of the use of a Municipal Preliminary Screener to estimate eligibility for variance is provided in Part 10.5 of this Statement. If the entity is privately-owned (e.g. a manufacturing facility), the analysis should consider factors such as the entity's ability to secure financing and the degree to which it will be able to pass the cost of treatment on to its customers in the form of higher prices.

Entities, either public or private, seeking a variance must demonstrate that compliance would create widespread socioeconomic impacts on the affected community, and can do so by following the referenced economic guidance. This analysis takes into account indicators such as increases in unemployment, losses to the local economy, changes in household income, decreases in tax revenues, indirect effects on other businesses, and increases in sewer fees for remaining private entities. Although the economic analysis is different for private and public applicants, the MPCA must use a similar process and the same EPA guidance manual to determine if a facility is eligible for a variance.
The process for obtaining a variance from a water quality standard and its associated effluent limit is complex and requires consideration of many factors. In addition, a variance must be approved by EPA before it can be effective. To ensure consistency in the MPCA and EPA's review, it is reasonable to standardize the elements of the variance review process to the extent possible, by identifying the documents the MPCA and EPA will rely on for their review.

In making this review of economic and social impacts, the MPCA uses the same guidance document for its calculations and considers the same factors as EPA. The proposed rule reasonably identifies and incorporates by reference the federal guidance manual used to conduct the review of economic and social impact. The current guidance manual is dated 1995, but is being incorporated by reference "as amended" to ensure that the document the MPCA uses for its review remains consistent with the most current edition used by EPA. EPA has used this document since 1995 and has relied on it to explain when and how finances play a role in determining pollution treatment.

The proposed rule also provides an exemption from the variance fees for municipal facilities seeking a variance from a wild rice sulfate standard or effluent limit. This fee rate established in rule is based on the amount of MPCA effort expected to review variance requests. The MPCA is proposing to waive the variance fee for municipalities for several reasons.

- The MPCA expects to receive numerous variance requests from municipalities when data are available to calculate the applicable numeric standard and evaluate reasonable potential. The MPCA is developing, specifically for the sulfate standard, a streamlined application and review process. Because this process will allow the MPCA to more efficiently complete municipal variance reviews, the MPCA believes each individual application will not require the level of staff effort normally required for a variance review. It is reasonable to reflect this reduced need for MPCA resources in the fees charged.
- For a municipal variance request, much of the information needed by either the municipality in developing the application or the MPCA in reviewing the application is already known (e.g. type and cost of treatment). Other necessary information, such as is required in the federal economic guidance, is public and accessible. Only a few pieces of information may be needed to complete the application and finalize the variance decision. These remaining steps involve only a small portion of the process and therefore, limit the MPCA's review time and cost.
- By waiving the fee for the MPCA's review of the variance request, the MPCA is acknowledging the economic constraints under which many small municipalities operate.

7. Specific reasonableness

The discussion in Part 6 provides the MPCA's justification for major concepts and general topic areas of the proposed revisions that required extensive discussion. The following discussion identifies each of the proposed rule amendments and either provides a justification for it or directs the reader to the part of the rule where the MPCA provides a more complete discussion of the reasonableness of that requirement.

7050.0130 Definitions

1. **Proposed change.** *Subp. 2a.* ***Annual Average ten-year low flow" or "365*** Q_{10} *means the lowest average 365-day flow with a once in ten-year recurrence interval. A 365*Q_{10} *is derived using the same methods used to derive a 7*Q_{10}*, and the guidelines regarding period of record for flow data and estimating a 7*Q_{10} *apply equally to determining a 365*Q_{10}*, as described in part 7050.0130, subpart 3.*

   Justification. The flow rate is being defined to provide clarity about how to implement the standard consistent with its duration and frequency. Other flow rates, such as the 7Q_{10} and 122Q_{10} that are important for implementing standards are defined in 7050.0130 and 7050.0150. Therefore, it is reasonable to also provide a definition of the 365Q_{10}. A discussion of why 365Q_{10} is the appropriate flow rate for implementing the wild rice sulfate standard and, therefore, why the proposed definition is reasonable is provided in the discussion of general reasonableness in Part 6. G. 2, relating to how the MPCA sets effluent limits.

2. **Proposed change.** *Subp. 3a.* **Cultivated wild rice water** means a contained area where water levels are artificially manipulated for producing wild rice.

   Justification. The term "cultivated wild rice water" is used in the definition of wild rice water, which specifically excludes cultivated wild rice waters. It is reasonable to define cultivated wild rice waters in order to provide clarity about where the standard will not apply. In the discussion of general reasonableness in Part 6. C. 3, the MPCA provides a discussion of why it is not reasonable to apply the sulfate standard to cultivated waters and therefore, not reasonable to include cultivated wild rice waters on the list of wild rice waters.

3. **Proposed change**. Subp. 3b. Existing use has the meaning given in part 7050.0255, subp.

   Justification. Although "existing use" is not specifically used in the proposed rule language, it is inherent in the listing of wild rice waters. The MPCA's intent in identifying wild rice waters is to have a completing listing of those waters where the wild rice beneficial use is an "existing use" and it will be these waters where the wild rice based sulfate standard will apply. Existing use is a key concept in the CWA that helps define how waters are to be protected.

   Although wild rice has been present and harvested in Minnesota for generations, November 28, 1975 is the date by which the existing wild rice use must be present, in alignment with the effective date EPA promulgated the initial federal water quality standards related to existing uses. The term "existing use" is defined in 40 CFR § 131.3 (e) as "those uses actually attained in the water body on or after November 28, 1975, whether or not they are included in the water quality standards." Any beneficial use that a water body supported on that date, or at any time thereafter, is a use that must be maintained; the beneficial use of wild rice would be such a use. The MPCA believes it is reasonable to reflect the requirements of the CWA regarding existing uses in this rulemaking and its implementation of its CWA delegated program. November 28, 1975 is therefore a reasonable date by which the historical beneficial use and standards are established and approved under the CWA.

The proposed definition of existing use refers to a definition adopted in 2016 (Minn. R. 7050.0255). The adopted definition, which only applies to the antidegradation requirements in parts 7050.0250 to 7050.0335, includes the federal date that establishes the existing use. However, because the concept of the existing use also applies to the wild rice waters identified in the proposed revisions, it is reasonable to provide a definition that consistently applies to all of Minn. R. ch. 7050.

4. **Proposed change.** *Subp. 6a.* ***Water Identification number (WID)*** *means a unique identifier used by the agency to identify a surface water. For rivers and streams, a WID is an eight-digit hydrologic unit code, followed by three digits that further define the reach of water being identified. For lakes, wetlands, and reservoirs, a WID is a two-digit county identification code, followed by a four-digit unique lake number, followed by a two-digit basin identification code. For purposes of part 7050.0224, a WID identifies a specific water body or reach of a river or stream.*

   Justification. The identification of wild rice waters and the determination of where the wild rice sulfate standard applies is based on a standard format used by the MPCA to identify a water body. Although the MPCA uses this terminology frequently, it has not previously been defined in rule. Because the MPCA will be identifying wild rice waters based on the WID, it is reasonable to provide a definition. The MPCA's discussion of the reasonableness of using a water identification number (WID) to identify wild rice waters is provided in Part 6.D. 2.

5. **Proposed change.** *Subp. 6b.* ***Wild rice*** *means plants of the species Zizania palustris or Zizania aquatica.*

   Justification. The term wild rice is used throughout the proposed rules and it is reasonable to establish the scientific nomenclature to correctly identify the plant being protected. The two species identified in the definition are the only two species of wild rice found in Minnesota. (A third North American species, *Zizania texana*, is not found outside of Texas.)

6. **Proposed change.** *Subp. 6c.* ***Wild Rice Waters*** *are those water bodies that contain natural beds of wild rice as defined by Laws, 2011 First Special Session, ch. 2, article 4, section 32, paragraph (b) and are identified in part 7050.0471. Wild rice waters do not include cultivated wild rice waters.*

   Justification. The law enacted by the Minnesota Legislature in 2011 forms the legal basis for the MPCA's proposed rule amendments. This law includes a definition of "waters containing natural beds of wild rice." Reliance on this definition is therefore reasonable and justifies the exclusion of cultivated wild rice waters. A further discussion of the exclusion of cultivated wild rice waters is provided in Part 6.C. 3.

7050.0220 Specific Water Quality Standards by Associated Use Classes

7. **Proposed change.** *Subp. 1.**Purpose and scope.***

A. The numeric and narrative water quality standards in this chapter prescribe the qualities or properties of the waters of the state that are necessary for the designated public uses and benefits. If the standards in this chapter are exceeded, it is considered indicative of a polluted condition ~~which~~ that is actually or potentially deleterious, harmful, detrimental, or injurious with respect to designated uses or established classes of the waters of the state.

B. All surface waters are protected for multiple beneficial uses. Numeric water quality standards are tabulated in this part for all uses applicable to four common categories of surface waters~~,~~ so that ~~all~~ applicable standards for each category are listed together in subparts 3a to 6a. Some of these waters may also be Class 4D wild rice waters identified in part 7050.0471. The four categories are:

A. (1) cold water sport fish (trout waters), also protected for drinking water: classes 1B~~,~~; 2A~~,~~; 3A or 3B~~,~~; 4A, and 4B~~,~~; 4D when applicable to a wild rice water listed in part 7050.0471; and 5 (subpart 3a);

B. (2) cool and warm water sport fish, also protected for drinking water: classes 1B or 1C~~,~~; 2Bd~~,~~; 3A or 3B~~,~~; 4A and 4B~~,~~; 4D when applicable to a wild rice water listed in part 7050.0471; and 5 (subpart 4a);

C. (3) cool and warm water sport fish, indigenous aquatic life, and wetlands: classes 2B, 2C, or 2D; 3A, 3B, 3C, or 3D; 4A and 4B ~~or~~ 4C; 4D when applicable to a wild rice water listed in part 7050.0471; and 5 (subpart 5a); and

D. (4) limited resource value waters: classes 3C~~,~~; 4A and 4B~~,~~; 4D when applicable to a wild rice water listed in part 7050.0471; 5~~,~~; and 7 (subpart 6a).

Justification. Minn. R. 7050.0220 identifies the standards that apply to four major categories of waters. The categories are based on the type of fish and aquatic life they support (cold water sport fish, also classified for drinking water use; cool and warm water sport fish, also classified for drinking water use; cool and warm water sport fish, indigenous aquatic life and wetlands; and limited resource value waters). Minn. R. 7050.0220 does not establish any standards; it only provides an accessible way to see applicable standards for waters with multiple use classes. The goal of part 7050.0220 is to allow the reader to easily review the applicable standards and find which standard is the most stringent. Because the wild rice based sulfate standard was originally included as a subclass of the 4A use class, it was not separately listed there; instead, the Minn. R 7050.0220 tables that listed standards include a note saying "wild rice present."

Because the MPCA is proposing a new rule part, Minn. R. 7050.0224, subpart 5, to house the sulfate standard applicable only to wild rice waters listed in Minn. R. 7050.0471, it is reasonable to reference that change. The MPCA proposes to do so by amending Minn. R. 7050.0220, subpart 1 to identify the fact that the new Minn. R. 7050.0224 subpart, (subpart 5, Class 4D waters) is applicable to various classes of waters that are also wild rice waters identified in Minn. R. 7050.0471. The addition of language about wild rice in the subpart 1 rule language clarifies that any of these waters may also be wild rice waters to which the proposed Class 4D sulfate standard applies.

Several minor formatting and grammatical changes are also proposed.

The introductory paragraph is divided into items A. and B. at the suggestion of the Revisor of Statutes to more clearly address specific and separate topics. This is only a clarification and does not change the meaning.

In item A, the Revisor of Statutes has recommended to change the term “which” in item A, to “that.” This change does not change the effect of the rule and is only for grammatical purposes.

In item B, “all” is being deleted because the phrase being added to subitems (1) to (4) in this rulemaking about 4D is qualified by “when applicable.” Because the term “when applicable” does not mean “all”, it is no longer appropriate to state that “all” applicable standards are identified for each category and it is therefore reasonable to delete “all.”

In subitems (1) to (4), the Revisor of Statutes has suggested a series of punctuation changes. A comma has been replaced by a semicolon to more clearly separate the identified use classes. These changes serve to more clearly group the identified use classes. These changes do not affect the application of the identified use classes.

8. **Proposed change.** *Subp. 3a.* ***cold water sport fish, drinking water and associated use classes.*** *Water quality standards applicable to use classes 1B, 2A, 3A or 3B, 4A and 4B, 4D when applicable to a wild rice water listed in part 7050.0471; and 5 surface waters.*

A. MISCELLANEOUS SUBSTANCE, CHARACTERISTIC, OR POLLUTANT

--	***--***	***--***	***--***	***--***	***--***	***--***	***--***
2A	***2A***	***2A***	***1B***	***3A/3B***	***4A***	***4B***	***5***
CS	***MS***	***FAV***	***DC***	***IC***	***IR***	***IR***	***AN***

*(31) Sulfates, in a wild rice water ~~wild rice present,~~ ~~**10** mg/L~~*

See part 7050.0224, subp. 5

Justification. In each of subparts 3a, 4a, 5a and 6a, the MPCA proposes to delete the references to “wild rice present” and “10 mg/L” and adds a cross reference to Minn. R. 7050.0224, subpart 5, the subpart establishing the proposed numeric sulfate standard for wild rice waters. Because the MPCA is revising the sulfate standard to include an equation approach, it is not possible to provide a specific numeric standard in this rule in place of the existing 10 mg/L standard. Providing a cross reference to the part of the rule where the sulfate standard is established is comparable to how Minn. R. 7050.0220 already refers to the rules where similar standards for total suspended solids or eutrophication are established. When a standard is based on a calculation or equation, it is reasonable to direct the reader to where the more detailed information regarding that standard can be found.

The existing reference to "wild rice present" was intended to differentiate between the standards applicable to all Class 4A waters and those applicable to the class 4A subclass of "water used for production of wild rice." The revised sulfate standard will no longer use the term "water used for production of wild rice" and will only apply to the wild rice waters identified in Minn. R. 7050.0471. Because of this change, the applicability of the revised sulfate standard will depend on whether a water has been identified as a wild rice water in Minn. R. 7050.0471. In this rulemaking, the phrase "water used for production of wild rice" is being replaced with "wild rice water," so it is reasonable to also replace the reference to "wild rice present" and replace it with a reference to "in a wild rice water."

9. **Proposed change.** *Subp. 4a**. cool and warm water sport fish, drinking water, and associated use classes.** Water quality standards applicable to use classes 1B or 1C, 2Bd, 3A or 3B, 4A, 4B, <u>4D when applicable to a wild rice water listed in part 7050.0471;</u> and 5 surface waters.*

A. MISCELLANEOUS SUBSTANCE, CHARACTERISTIC, OR POLLUTANT

--	--	--	--	--	--	--	--
2Bd	***2Bd***	***2Bd***	***1B/1C***	***3A/3B***	***4A***	***4B***	***5***
CS	***MS***	***FAV***	***DC***	***IC***	***IR***	***LS***	***AN***

(30) Sulfates, <u>in a wild rice water</u> ~~wild rice present,~~ ~~***10*** *mg/L*~~

<u>See part 7050.0224, subp. 5</u>

Justification. See discussion in section 8 above.

10. **Proposed change.** *Subp. 5a. **cool and warm water sport fish and associated use classes.** Water quality standards applicable to use classes 2B, 2C, or 2D; 3A, 3B, or 3C; 4A, 4B, 4D <u>when applicable to a wild rice water listed in part 7050.0471;</u> and 5 surface waters. See parts 7050.0223, subpart 5; 7050.0224,subpart 4 and 7050.0225, subpart 2, for class 3D, 4C, and 5 standards applicable to wetlands, respectively<u>. See part 7050.0224, subp. 5 for standards applicable to wetlands that are also Class 4D wild rice waters</u>.*

A. MISCELLANEOUS SUBSTANCE, CHARACTERISTIC, OR POLLUTANT

--	--	--	--	--	--	--
2B,C&D	***2B,C&D***	***2B,C&D***	***3A/3B/3C***	***4A***	***4B***	***5***
CS	***MS***	***FAV***	***IC***	***IR***	***LS***	***AN***

(19) Sulfates, <u>in a wild rice water</u> ~~wild rice present,~~ ~~**10** mg/L~~

See part 7050.0224, subp. 5

Justification. See discussion in section 8 above.

11. **Proposed change.** *Subp. 6a.* ***Limited resource value waters and associated use classes.***

A. WATER QUALITY STANDARDS APPLICABLE TO USE CLASSES 3C, 4A, 4B, <u>4D when applicable to a wild rice water listed in part 7050.0471</u>5, AND 7 SURFACE WATERS

--	***--***	***--***	***--***	***--***
7 LIMITED RESOURCE VALUE	***3C 1C***	***4A 1R***	***4B LS***	***5 AN***

(14) Sulfates, <u>in a wild rice water</u> ~~wild rice present,~~ ~~***10*** *mg/L*~~

See part 7050.0224, subp. 5

Justification. See discussion in section 8 above.

7050.0224 Specific Water Quality Standards for Class 4 Waters of the State; Agriculture and Wildlife.

12. **Proposed change.** *Subp. 1.* ***General.*** *The numeric and narrative water quality standards in this part prescribe the qualities or properties of the waters of the state that are necessary for the agriculture and wildlife designated public uses and benefits. ~~Wild rice is an aquatic plant resource found in certain waters within the state. The harvest and use of grains from this plant serve as a food source for wildlife and humans. In recognition of the ecological importance of this resource, and in conjunction with Minnesota Indian tribes, selected wild rice waters have been specifically identified [WR] and listed in part <u>7050.0470</u>, subpart 1. The quality of these waters and the aquatic habitat necessary to support the propagation and maintenance of wild rice plant species must not be materially impaired or degraded.~~ If the standards in this part are exceeded in waters of the state that have the class 4 designation, it is considered indicative of a polluted condition ~~which~~ <u>that</u> is actually or potentially deleterious, harmful, detrimental, or injurious with respect to the designated uses.*

Justification. The MPCA is reasonably deleting or moving each of the following sentences in subpart 1:

- *Wild rice is an aquatic plant resource found in certain waters within the state.* This language was originally included to provide background about wild rice. However, it does not have any regulatory meaning and is reasonably deleted.
- *The harvest and use of grains from this plant serve as a food source for wildlife and humans.* This phrase establishing and describing the beneficial use is slightly rephrased and re-stated in new subpart 5, so that it is logically grouped with the remainder of the information related to wild rice.
- *In recognition of the ecological importance of this resource, and in conjunction with Minnesota Indian tribes, selected wild rice waters have been specifically identified [WR] and listed in part 7050.0470, subpart 1. The quality of these waters and the aquatic habitat necessary to*

support the propagation and maintenance of wild rice plant species must not be materially impaired or degraded. These sentences have been moved, essentially unchanged, to new subpart 6. Establishing the narrative standard in a separate subpart is reasonable because the narrative standard for wild rice narrowly applies only to a select number of wild rice waters in the Lake Superior basin and is not "general," or applicable to all Class 4 beneficial uses. The narrative standard is not applicable to all waters being proposed as wild rice waters. This narrative standard is specific to certain wild rice waters and is appropriately addressed in a separate new subpart. This revision corrects what the MPCA considers an error in the original placement of the language specific to wild rice. This clarifying change does not alter the meaning. The language of the narrative standard is not being changed; it is only being moved from subpart 1 to subpart 6.

- The Revisor of Statutes has suggested some minor changes to clarify this phrase. Moving these sentences out of the original paragraph requires that small changes be made to provide additional context. These minor changes are discussed in section 20.*If the standards in this part are exceeded in waters of the state that have the class 4 designation, it is considered indicative of a polluted condition ~~which~~ that is actually or potentially deleterious, harmful, detrimental, or injurious with respect to the designated uses.* The Revisor of Statutes has recommended the use of "that" for grammatical reasons. This amendment does not change the effect of this sentence.

The changes to this subpart are reasonable because they add clarity and internal consistency.

13. **Proposed change.** *Subp. 2.* ***Class 4A waters.*** *The quality of class 4A waters of the state shall be such as to permit their use for irrigation without significant damage or adverse effects upon any crops or vegetation usually grown in the waters or area, including truck garden crops. The following standards shall be used as a guide in determining the suitability of the waters for such uses, together with the recommendations contained in Handbook 60 published by the Salinity Laboratory of the United States Department of Agriculture, and any revisions, amendments, or supplements to it:*

Substance, Characteristic, or Pollutant	*Class 4A Standard*
Bicarbonates (HCO_3)	*5 milliequivalents per liter*
Boron (B)	*0.5 mg/L*
pH, minimum value	*6.0*
pH, maximum value	*8.5*
Specific conductance	*1,000 micromhos per centimeter at 25°C*
Total dissolved salts	*700 mg/L*
Sodium (Na)	*60% of total cations as milliequivalents per liter*

~~*Sulfates (SO_4)*~~	~~*10 mg/L, applicable to water used for production of wild rice during periods when the rice may be susceptible to damage by high sulfate levels.*~~
Radioactive materials	*Not to exceed the lowest concentrations permitted to be discharged to an uncontrolled environment as prescribed by the appropriate authority having control over their use.*

Justification. Subpart 2 is amended to remove the existing numeric standard for sulfate that applies to Class 4A waters used for production of wild rice. The introductory language of subpart 2 discusses the necessary qualities of waters for irrigation of crops. A discussion of the use for irrigation is not appropriate for the standards that apply to non-cultivated wild rice waters. In addition, and as discussed in the need for the proposed rules, (Part 2 of this Statement), the implementation of this standard was extremely problematic. First, some individuals have interpreted the location of the numeric standard in the subpart governing irrigation waters and the use of the phrase "production of wild rice" to suggest that it was only applicable to waters used to irrigate cultivated wild rice. However, the 1973 rulemaking record clearly indicated the intent that the standard applied to natural stands of wild rice as well as cultivated wild rice. Second, as discussed in Part 6.C. the phrase "applicable to water used for production of wild rice during periods when the rice may be susceptible to damage by high sulfate levels" presented a number of problems. The phrase "water used for production of wild rice" was not further defined. The phrase "during periods when the rice may be susceptible to damage by high sulfate levels" did not clearly establish when the standard applied because the use of "may" is indefinite and vague. With the proposed addition of subpart 5, which resolves these issues of clarity, it is reasonable to delete this now obsolete and problematic sulfate standard from subpart 2.

14. **Proposed change.** <u>*Subp. 5, item A.* ***Class 4D waters: Wild rice waters.***</u>

    A. <u>*The standards in items B and C apply to wild rice waters identified in part 7050.0471 to protect the use of the grain of wild rice as a food source for wildlife and humans. The numeric sulfate standard for wild rice is designed to maintain sulfide concentrations in pore water at 0.120 mg/L or less. The commissioner must maintain all numeric wild rice sulfate standards on a public Website.*</u>

Justification. All rule language related to the wild rice sulfate standard is now reasonably grouped in subpart 5. Item A begins by pointing to items B and C, which address the equation and the establishment of an alternate standard. Item A then states the existing wild rice beneficial use. The beneficial use is slightly rephrased from its original form in Minn. R. 7050.0224, subpart 1 to eliminate reference to "harvest." In order for the grain to be used as a food source for humans, it must be harvested; there is no need to specify that step of its use in the rule. The MPCA believes the current phrasing is more grammatically correct and succinct but does not change the existing beneficial use.

The second sentence provides the context that the ultimate goal of the wild rice sulfate standard is to protect wild rice from harmful levels of porewater sulfide – namely to keep porewater sulfide concentrations at or below 120 µg/L. The MPCA is essentially setting a porewater sulfide standard with the equation as a “translator” that allows the standard to be implemented in the MPCA’s regulatory framework that focuses on levels of a pollutant (sulfate) in ambient surface water and in facility discharges.

The final sentence resolves the question of how the regulated community and the public will know what the specific numeric standard is for any identified wild rice water. The process of sampling and calculating the applicable sulfate standard will be an ongoing process the MPCA expects to take many years to complete. The MPCA is committed to making the numeric sulfate standards available and use of a public website is a reasonable mechanism for providing this information. The MPCA intends to make the list of wild rice waters available to the public on the MPCA’s website and expects that as a sulfate standard is calculated for a given water, that information will be added to the website listing.

15. **Proposed change.** *Subp. 5, item B, subitem 1*

B. The annual average concentration of sulfate in a wild rice water must not exceed the concentration established as the calculated wild rice sulfate standard under subitem (1) or alternate wild rice sulfate standard under subitem (2) more than one year out of every ten years.

(1) The calculated sulfate standard, expressed as milligrams of sulfate ion per liter (mg SO_4^{2-}/L), is determined by the following equation:

$$Calculated\ Sulfate\ Standard = 0.0000121 \times \frac{Iron^{1.923}}{organic\ carbon^{1.197}}$$

Where:

a.) organic carbon is the amount of organic matter in dry sediment. The concentration is expressed as percent carbon, as determined using the method for organic carbon analysis in Sampling and Analytical Methods for Wild Rice Waters, which is incorporated by reference in item E;

b.) iron is the amount of extractable iron in dry sediment. The concentration is expressed as micrograms iron per gram dry sediment, as determined using the method for extractable iron in Sampling and Analytical Methods for Wild Rice Waters;

c.) Sediment samples are collected using the procedures established in Sampling and Analytical Methods for Wild Rice Waters; and

d.) The calculated sulfate standard is the lowest sulfate value resulting from the application of the equation to each pair of organic carbon and iron values collected and analyzed in accordance with units (a) to (c).

Justification. Item B begins by stating that, in order to meet the standard, the annual average concentration of sulfate in the ambient water must remain below the concentration established either by the equation, which the MPCA expects will be the most common situation, or by an alternate standard. In either case, the standard cannot be exceeded more than once every ten years. Item B establishes the magnitude of the standard (sulfate concentration as established by the equation or alternate standard), the duration (annual average), and the frequency (one in ten). The reasonableness of these choices is described in the general reasonableness Part 6 .E. 6.

A discussion of the reasonableness of the equation is also provided in Part 6.E. The formatting used for the formula is consistent with how other equations are presented in Minnesota rules.

Item B also incorporates by reference a document relating to how sediment and sediment porewater should be collected and analyzed to be used in the equation or in determining the alternate standard and how the chemical analysis for carbon and iron should be conducted. A justification of the reasonableness of the sampling and analysis document incorporated by reference is provided in Parts 6. E. 7 and 6. E. 11.

16. **Proposed change.** *Subp. 5, item B, subitem 2. The commissioner may establish an alternate sulfate standard for a water body when the ambient sulfate concentration is above the calculated sulfate standard and data demonstrates that sulfide concentrations in pore water are 0.120 mg/L or less. Data must be gathered using the procedures specified in Sampling and Analytical Methods for Wild Rice Waters, which is incorporated by reference in item E. The alternate sulfate standard established must be either the annual average sulfate concentration in the ambient water or a level of sulfate the commissioner has determined will maintain the pore water sulfide concentrations at or below 0.120 mg/L.*

    Justification. A discussion of the reasonableness of the alternative standard and the sampling and analysis document incorporated by reference is provided in Parts 6. E. 10 and 6. E. 11.

17. **Proposed change.** *Subp. 5, item C.* ***Site-specific sulfate standard.*** *The commissioner may establish a site-specific sulfate standard using the process in part 7050.0220, subpart 7, or 7052.0270 when the commissioner determines that the beneficial use is not harmed. This decision must be based on reliable and representative data characterizing the health and viability of the wild rice in the wild rice water.*

    Justification. The rules currently provide conditions for the MPCA to establish a site-specific standard. In subpart 5, item C, the MPCA reasonably cites to those existing requirements. The MPCA expects that there will be circumstances where neither the calculated sulfate standard nor the alternate standard will be appropriate to protect the beneficial use. It is reasonable to point to the health of wild rice, since that is the beneficial use. In those cases, the existing process for establishing a site-specific standard will be applicable. This is further discussed in Part 6. E. 10.

18. **Proposed change**. *Subp. 5, item D. Discharges of sulfate in sewage, industrial waste, or other wastes affecting Class 4D waters must be controlled so that the numeric sulfate standard for wild rice is maintained at stream flows that are equal to or greater than the* $365Q_{10}$.

    Justification. Minn. R. 7050.0210, subp 7, requires that "Point and nonpoint sources of water pollution shall be controlled so that the water quality standards will be maintained at all stream flows that are equal to or greater than the $7Q_{10}$ for the critical month or months, unless another flow condition is specifically stated as applicable in this chapter." As described in Part 6. G. , the $365Q_{10}$ is a more appropriate flow to use for the wild rice sulfate standard. Therefore, it is reasonable in this part to specifically state the applicable flow condition and to ensure that there is clarity that the $7Q_{10}$ is not the flow condition that should apply.

19. **Proposed change.** *Subp. 5, item E, Sampling and Analytical Methods for Wild Rice Waters, Minnesota Pollution Control Agency, (2017), is incorporated by reference. The document is not subject to frequent change and is available on the agency's website at www.pca.state.mn.us/regulations/minnesota-rulemaking and through the Minitex interlibrary loan system.*

    Justification. The MPCA is proposing to compile four different sampling and analytical procedures into a single document and incorporate that document by reference. Because this document is not being incorporated by reference "as amended", all future changes to this document must be made through the rulemaking process.

    The first part the incorporated document describes the process for collecting sediment samples for analysis for TOC and TEFe. MPCA staff developed this process based on the procedure used to conduct sediment sampling during the research phase of this rulemaking. The proposed sediment collection procedure represents a reasonable balance between the number of samples needed to accurately reflect the composition of the sediment in a wild rice water and the need to recognize the expenses associated with sampling and analysis.

    The second and third parts of the incorporated document establish the analytical procedures for conducting the analysis to determine TOC and TEFe for purposes of calculating the sulfate standard. These two parts establish the procedures necessary to produce valid results that are consistent with the results that were the basis for developing the revised sulfate standard.

    The fourth part of the incorporated document establishes the sampling methods and analytical procedures that are required for establishing an alternate sulfate standard. As discussed in section 16, the rules provide an option of developing an alternate standard based on the concentration of sulfide in sediment porewater. MPCA staff developed this procedure to produce valid results that are consistent with the results that were the basis for developing the revised sulfate standard.

    A more complete discussion of the sampling and analysis procedures included in the document incorporated by reference is provided in Parts 6. E. 7, 6. E. 8 and 6. E. 11.

20. **Proposed change.** *Subp. 6. **Class 4D [WR]; selected wild-rice waters.** In recognition of the ecological importance of the wild rice resource, and in conjunction with Minnesota Indian tribes, selected Class 4D wild rice waters have been specifically identified [WR] and listed in part 7050.0470, subpart 1. The quality of these waters and the aquatic habitat necessary to support propagating and maintaining wild rice must not be materially impaired or degraded.*

    Justification. Subpart 6 consists of the language in existing Minn. R. 7050.0224, subpart 1. As discussed in section 12 above, this language is moved to a separate subpart specifically applicable to the waters currently listed in Minn. R. 7050.0470 as wild rice [WR] waters. Addressing the narrative standard applicable to [WR] wild rice waters is reasonable to add clarity.

The Revisor of Statutes has slightly modified the existing language in Minn. R. 7050.0224, subpart 1 to change the phrase “this resource” to identify the resource more clearly. The Revisor has also suggested adding a reference to Class 4D to apply to the [WR] waters. Neither of these clarifying changes alter the meaning of the sentences moved from existing subpart 1 to new subpart 6.

7050.0470 Classifications for Surface Waters in Major Drainage Basins

21. **Proposed change.** *7050.0470, Subps. 1 to 9 (similar changes proposed to each subpart.)*

    Example- Lake Superior basin. *The water use classifications for the listed waters in the Lake Superior basin are identified in items A to D. See parts 7050.0425 ~~and~~, 7050.0430, and 7050.0471 for the classifications of waters not listed.*

    Justification. Each subpart identifying the use classifications that apply in each major drainage basin (subparts 1 to 9) is reasonably amended to reflect the addition of a new rule part in this rulemaking. The addition of Minn. R. 7050.0471 expands the range of rule parts where use classifications are provided.

22. **Proposed Change.** *7050.0470, subp. 2.* ***Rainy River-Lake of the Woods basin.*** *The water use classifications for the listed waters in Rainy River- Lake of the Woods basin are as identified in items A to D. see parts 7050.0425 ~~and~~, 7050.0430, and 7050.0471 for the classifications of waters not listed.*

    Justification. In addition to the changes made to the range of rules cited (see explanation in section 21), subpart 2 is amended to change the name of the Lake of the Woods basin to include the name that is more commonly used among water management professionals- Rainy River. The boundaries of the basin are not being changed in this rulemaking. The name “Lake of the Woods” may still be used in some technical documents and will be retained as part of the basin name to provide continuity with previous documents.

7050.0471 Class 4D Surface Waters in Major Drainage Basins

23. **Proposed change.** *7050.0471, subp. 1.* ***Scope****. Class 4D wild rice waters are identified in subparts 3 to 9. Identified waters are described by a water identification number.*

    Justification. In this rulemaking, the MPCA is proposing to identify approximately 1,300 waters as wild rice waters. This new rule part is organized similarly to the lists of waters in Minn. R. 7050.0470. Each major water basin is identified in a subpart, and each watershed within that basin is a separate item in that subpart. A more complete discussion of the reasonableness of the identified wild rice waters is provided in Part 6. D.

24. **Proposed change.** *Subp. 2.* ***Triennial review****. As part of each triennial review of water-quality standards conducted under Code of Federal Regulations, title 40, section 131.20 the commissioner must solicit evidence that supports listing additional wild rice waters. The evidence must demonstrate that the wild rice beneficial use exists or has existed on or after November 28, 1975 in the water body, such as by showing a history of human harvest or use of the grain as food for wildlife*

or by showing that a cumulative total of at least 2 acres of wild rice are present. Acceptable types of evidence include:

- *A. Written or oral histories that meet the criteria of validity, reliability, and consistency;*
- *B. Written records, such as harvest records;*
- *C. Photographs, aerial surveys, or field surveys; or*
- *D. Other quantitative or qualitative information that provides a reasonable basis to conclude that the wild rice beneficial use exists.*

Justification. Subpart 2 identifies the process the MPCA will use and the information the commissioner will consider when adding newly identified wild rice waters to the list of wild rice waters in part 7050.0471. A discussion of the reasonableness of this subpart is provided in Part 6. D. 5.

25. **Proposed change.** *Subp. 3. **Lake Superior basin.** The Lake Superior basin includes all or portions of Aitkin, Carlton, Cook, Itasca, Lake, Pine, and St. Louis Counties) The waters in each of the major watersheds in the Lake Superior basin that are identified as class 4D are listed in items A to E. Waters designated with[WR] were identified as wild rice waters in 1998 under part 7050.0470, subpart 1.*

    (*The lists of class 4D waters are not reproduced in this Statement.)*

    Justification. The watersheds identified in this subpart and the subparts below only include those where a wild rice water is being proposed as a wild rice water in this rulemaking. The reasonableness of the proposed wild rice waters is discussed in Part 6. D. For the convenience of the user, the MPCA is including in each subpart, a list of the counties in each basin. The list of counties within each basin was composed by reference to Geographic Information System data.

26. **Proposed change.** *Subp. 4. **Rainy River -Lake of the Woods Basin**. The Rainy River-Lake of the Woods basin includes all or portions of Beltrami, Cook, Itasca, Koochiching, Lake, Lake of the Woods, St. Louis, and Roseau Counties. The waters identified in each of the major watersheds in the Rainy River-Lake of the Woods basin that are identified as class 4D are listed in items A to G.*

    (*The lists of class 4D waters are not reproduced in this Statement.)*

    Justification. See the discussion in section 25 above.

    As discussed for the changes to Minn. R. pt. 7050.0470, (section 22) this basin is being called "Rainy River-Lake of the Woods" to include the name (Rainy River) that is now more commonly used by water management professionals as well as the name (Lake of the Woods) that formerly identified this basin in Minn. R.pt. 7050.0470.

27. **Proposed change.** *Subp. 5. **Red River of the North basin**. The Red River of the North basin includes all or portions of Becker, Beltrami, Big Stone, Clay, Clearwater, Grant, Itasca, Kittson, Koochiching, Lake of the Woods, Mahnomen, Marshall, Norman, Otter Tail, Pennington, Polk, Red Lake, Roseau, Stevens, Traverse, and Wilkin Counties. The waters in each of the major watersheds in the Red River of the North basin that are identified as class 4D are listed in items A to F.*

    (*The lists of class 4D waters are not reproduced in this Statement.)*

Justification. See the discussion in section 25 above.

28. **Proposed change.** _Subp. 6. **Upper Mississippi River basin** The Upper Mississippi River basin includes the headwaters to the confluence with the St. Croix River and all or portions of Aitkin, Anoka, Becker, Beltrami, Benton, Carlton, Carver, Cass, Chisago, Clearwater, Crow Wing, Dakota, Douglas, Hennepin, Hubbard, Isanti, Itasca, Kanabec, Kandiyohi, McLeod, Meeker, Mille Lacs, Morrison, Otter Tail, Pope, Ramsey, Renville, Saint Louis, Sherburne, Sibley, Stearns, Todd, Wadena, Washington, and Wright counties. The waters in each of the major watersheds in the Upper Mississippi River Basin that are identified as class 4D are listed in items A to O._

    (*The lists of class 4D waters are not reproduced in this Statement.)*

    Justification. See the discussion in section 25 above.

29. **Proposed change.** _Subp. 7. **Minnesota River basin**. The Minnesota River basin includes all or portions of Big Stone, Blue Earth, Brown, Carver, Chippewa, Cottonwood, Dakota, Douglas, Hennepin, Faribault, Freeborn, Grant, Jackson, Kandiyohi, Lac Aui Parle, Le Sueur, Lincoln, Lyon, Martin, McLeod, Murray, Nicollet, Otter Tail, Pipestone, Pope, Ramsey, Redwood, Renville, Rice Scott, Sibley, Stearns, Steele, Stevens, Swift, Traverse, Waseca, and Watonwan, Yellow Medicine counties. The waters identified in each of the major watersheds in the Minnesota River basin that are identified as class 4D are listed in items A to D._

    (*The lists of class 4D waters are not reproduced in this Statement.)*

    Justification. See the discussion in section 25 above.

30. **Proposed change.** _Subp. 8. **St. Croix River basin**. The St. Croix River basin includes all or portions of Aitkin, Anoka, Carlton, Chisago, Isanti, Kanabec, Mille Lacs, Pine, Ramsey, and Washington counties) The waters in each of the major watersheds in the St. Croix River basin that are identified as class 4D are listed in items A to D._

    (*The lists of class 4D waters are not reproduced in this Statement.)*

    Justification. See the discussion in section 25 above.

31. **Proposed change.** _Subp. 9. **Lower Mississippi River basin**. The Lower Mississippi River basin includes all or portions of Blue Earth, Dakota, Dodge, Faribault, Fillmore, Freeborn Goodhue, Houston, LeSueur, Mower, Olmsted, Rice, Scott, Steele, Wabasha, Waseca, Washington, and Winona counties. The waters in each of the major watersheds in the Lower Mississippi River basin that are identified as class 4D are listed in items A to F._

    (*The lists of class 4D waters are not reproduced in this Statement.)*

    Justification. See the discussion in section 25 above.

7053.0135 General Definitions

32. **Proposed change.** _Subp. 2a. **Annual average ten-year low flow.** "Annual average ten-year low flow" or "365Q10" has the meaning given in part 7050.0130, subpart 2a._

Justification. This term is also defined in Minn. R. 7050.0130 and a discussion of its reasonableness is provided in section 1 above.

33. **Proposed change.** *7053.0205, Subp. 7.* ***Minimum Stream Flow.***

    A. *Except as provided in items B, ~~and~~ C, and E, discharges of sewage, industrial waste, or other wastes must be controlled so that the water quality standards are maintained at all stream flows that are equal to or greater than the* $7Q_{10}$ *for the critical month or months.*

    B. *Discharges of ammonia in sewage, industrial waste, or other wastes must be controlled so that the ammonia water quality standard is maintained at all stream flows that are equal to or exceeded by the* $30Q_{10}$ *for the critical month or months.*

    C. *Discharges of total phosphorus in sewage, industrial waste, or other wastes must be controlled so that the eutrophication water quality standard is maintained for the long-term summer concentration of total phosphorus, when averaged over all flows, except where a specific flow is identified in chapter 7050. When setting the effluent limit for total phosphorus, the commissioner shall consider the discharger's efforts to control phosphorus as well as reductions from other sources, including nonpoint and runoff from permitted municipal storm water discharges.*

    D. *Allowance must not be made in the design of treatment works for low stream flow augmentation unless the flow augmentation of minimum flow is dependable and controlled under applicable laws or regulations.*

    E. *Discharges of sulfate in sewage, industrial waste, or other wastes must be controlled so that the sulfate water-quality standard for wild rice is maintained as specified in part 7050.0224, subpart 5. When determining reasonable potential and calculating effluent limits, the flow rate for receiving water is the* $365Q_{10}$ *flow.*

    Justification. The general reasonableness of the annual average time and of the $365Q_{10}$ flow are discussed in Parts 6. E. 6 and 6.G, respectively. Minn. R. 7053.0205 establishes the minimum stream flow for implementing water quality standards, so it is reasonable to add the appropriate stream flow for the wild rice sulfate standard in this part.

7053.0406 Requirements for Facilities Discharging to Wild Rice Waters

34. **Proposed change.** *Subp. 1.* ***No effluent limit required based on site-specific conditions.*** *If the commissioner determines that, based on the location of the discharge within the wild rice water or site-specific hydraulic or substrate conditions, the effluent will not affect the class 4D wild rice beneficial use in the wild rice water, the commissioner must not establish a water- quality-based effluent limitation for the class 4 sulfate in that discharge.*

    Justification. Minn. R. ch. 7053 includes the requirements for effluent limits. Existing rule parts, such as Minn. R. 7053.0255, include information for implementation of specific water quality standards such as phosphorus. It is reasonable, therefore, to establish a section providing specific implementation items for the wild rice sulfate standard.

The MPCA also provides a discussion of the reasonableness of the proposed provision addressing site-specific conditions in Part 6. E. 10.

35. **Proposed change.** *Subp. 2.* **Variances.** *A permit applicant may apply for a variance from the wild rice sulfate standard and associated water- quality-based effluent limit (WQBEL), as specified in parts 7000.7000, 7050.0190, 7052.0280, and 7053.0195, as applicable.*

    A. *The commissioner must base the determination of widespread economic and social effect on the procedures established in Interim Economic Guidance for Water Quality Standards, EPA-823-B-95-002 (March 1995 and as subsequently amended), which is incorporated by reference, not subject to frequent change and available at https://www.epa.gov/wqs-tech/economic-guidance-water-quality-standards.*

    B. *Publicly owned wastewater treatment plants are exempt from the variance fee requirement of part 7002.0253.*

    Justification. The MPCA provides a discussion of the reasonableness of the proposed variance requirements in Part 6.I.

8. Public Participation and Stakeholder Involvement

Minn. Stat. § 14.131 (Minnesota's Administrative Procedures Act) requires that an Agency include in its SONAR a description of its efforts to provide additional notification to persons or classes of persons who may be affected by the proposed rule, or explain why these efforts were not made. Minn. Stat. ch. 14 also establishes specific requirements for agencies to provide notice of rulemaking. In this Statement, the MPCA is documenting how it has met that requirement.

The MPCA developed the proposed revisions over a multi-year process involving many different points of public engagement. The discussions that follow include information on the numerous pre-proposal discussions and communications that occurred and on the notices specifically required by the Administrative Procedures Act.

A. Pre-proposal outreach and notice

The proposed revisions have been in development for many years and the MPCA has made extensive efforts to inform and engage specific stakeholders and the general public. The MPCA used a number of mechanisms to encourage public participation and provide access to information.

Webpages

In April 2011, the MPCA created a webpage to provide background about the existing wild rice sulfate standard and its plans to evaluate that standard. The MPCA has used this webpage and several related webpages to share information about the wild rice sulfate standard study protocol development, the study results, the Wild Rice Advisory Committee, the scientific independent peer review, the process of developing the rule revisions, and the many opportunities for stakeholder feedback and comments on these items. The MPCA has provided information about the webpage at meetings, presentations, phone conversations and other communications from 2011 to the present.

As of the date of this Statement, information about the wild rice sulfate standard has been consolidated onto two webpages that can be found on the following links.

https://www.pca.state.mn.us/water/protecting-wild-rice-waters

https://www.pca.state.mn.us/water/wild-rice-sulfate-standard-study

The first webpage (Protecting wild rice waters) provides information about the wild rice sulfate standard, the Wild Rice Advisory Committee and rulemaking information and schedules. On this webpage, the MPCA has posted the draft TSD, a draft of the rule language and preliminary regulatory analysis, and written feedback received from stakeholders. Additional rulemaking notices and information will be posted on this webpage as they are available, including required rulemaking notices. The second webpage (Wild Rice Sulfate Standard Study) provides detailed information about the wild rice sulfate standard study that was completed in December 2013, including the subsequent analyses and peer review.

GovDelivery

GovDelivery is a self-subscription service the MPCA uses to electronically (email) notify interested or affected persons of various updates and public notices issued on a wide range of topics, including rulemakings. Since 2011, the MPCA has used the GovDelivery system to share information about the wild rice sulfate standard. The MPCA has promoted and encouraged stakeholders to subscribe to receive notices, including:

- Sending a GovDelivery notice to 1,845 people who had registered to receive notice of all new MPCA rulemakings inviting them to register to receive future notices specifically regarding a sulfate standard for wild rice.
- Providing the invitation to register for future notices on the wild rice sulfate standard webpage.
- Sending a GovDelivery notice to people who had registered their interest in receiving notices about environmental justice to encourage that they also register for notices about the wild rice sulfate standard.
- Providing information at wild rice public meetings about how to register to receive notices regarding the wild rice sulfate standard.

Wild Rice Advisory Committee

The legislation passed in 2011 directed the MPCA to establish an advisory committee to provide input to the commissioner on various topics related to the wild rice scientific study and follow up, including:

- A protocol for scientific research to assess the impacts of sulfates and other substances on wild rice;
- Research results; and
- Agency rulemaking related to the wild rice sulfate standard.

The Wild Rice Advisory committee includes representatives of tribal governments, municipal and industrial wastewater treatment facilities, wild rice harvesters, wild rice research experts and citizen organizations. The Wild Rice Advisory Committee began meeting in October 2011 and has met or conducted conference calls several times a year since then to provide feedback and advice. Additional information about the committee is on the sulfate standard webpage under the Advisory Committee tab. https://www.pca.state.mn.us/water/protecting-wild-rice-waters

Tribal communication and consultation

Because of the sovereign status of tribes in Minnesota and the great cultural importance of wild rice to the Ojibwe and Dakota people, the MPCA has made special effort to communicate with Minnesota tribes about the wild rice sulfate standard.

The MPCA began talking with tribal environmental staff in 2010 to get their input on the effort to clarify the beneficial use for the wild rice sulfate standard. These discussions continued while the Wild Rice Standards Study was underway and as the data were analyzed. Communications included Wild Rice

Advisory Committee meetings, conversations at tribal technical meetings, general outreach, and formal consultation.

Tribal representatives from the Fond du Lac Band and the 1854 Treaty Authority participated as members of the Wild Rice Advisory Committee, and several tribal representatives attended the Wild Rice Advisory Committee meetings and provided input.

Following the release of the Draft Proposal, the MPCA held a discussion with tribal environmental staff on March 26, 2015, and several follow-up telecommunications in May, June and August of 2015 and March of 2016 to respond to questions and hear concerns about the MPCA's proposal. Tribal representatives provided comments during the RFC and on the Draft TSD. MPCA staff attended a pow wow sponsored by the Fond du Lac Tribe in January 2017, to provide information and encourage registering to receive future notice about the proposed revisions to the sulfate standard.

In addition, MPCA and tribal leaders held four government-to-government consultations to discuss the sulfate standard and the protection of wild rice. (Compiled meeting notes and comments –Exhibit 38) Tribes provided additional comments to the MPCA in March 2017.

Discussions with MDNR

The MPCA began consulting with MDNR staff and leadership on the wild rice standards evaluation effort, including the beneficial use, in 2011. This included participation of two MDNR staff on the Wild Rice Advisory Committee, group meetings to discuss data sources and provide feedback on possible approaches for further clarifying the beneficial use, and numerous one-on-one discussions among technical staff of the two agencies.

The MPCA met twice in January 2016 with MDNR management and staff to discuss the proposed criteria for identification of wild rice waters and a draft procedure for making field determinations of wild rice waters. The meetings included representatives from the fisheries and wildlife division, the ecological and water resources division, and the representatives of the MDNR on the Wild Rice Advisory Committee. The MPCA also met with MDNR wildlife biologists in May 2016 to discuss and get input on waterfowl foraging and feeding behaviors in Minnesota and the energy requirements of ducks to help put the beneficial use into context regarding use by waterfowl as a food source. The MDNR assisted the MPCA's review of potential wild rice waters by providing data and information from MDNR databases and field survey results, and assistance with questions about data sources.

Meetings

The MPCA held numerous meetings over the course of developing the proposed revisions to engage interested parties and obtain feedback on specific topics. Attachment 3 identifies and briefly summarizes the MPCA meetings where the proposed revisions were discussed. In addition to the meetings identified in Attachment 3, MPCA staff participated in many phone, email and in-person conversations to inform stakeholders and answer questions about this rulemaking.

Public opportunities to review the pre-proposal Draft and Technical Support Documents

In addition to the many meetings and presentations where the issues relating to the protection of wild rice from sulfate were discussed, and the notices required by the state rulemaking process, the MPCA provided two major opportunities for public review and comment during the process of developing the proposed revisions.

In March 2015, the MPCA released a draft proposal for public review. The March 2015 MPCA Draft Proposal included:

- A proposed draft approach to the wild rice water quality standard;
- A draft list of waters where the standard would apply; and
- Draft criteria for adding waters to the list over time as new or additional information becomes available.

The MPCA sent notice of the availability of the draft proposal to the MPCA's GovDelivery mailing list of people who had registered their interest in this topic, posted the draft proposal on the wild rice rulemaking webpage, and shared the draft proposal with the Wild Rice Advisory Committee and tribes. The MPCA also sought to inform a wider group of stakeholders via a news conference.

In July 2016, the MPCA released a draft TSD that provided technical background for the main topic areas of the proposed rule. The MPCA posted this document for review on the MPCA's rulemaking webpage and sent notice of its availability via GovDeliveryThe MPCA posted the feedback received regarding the draft TSD on the rulemaking webpage for public review.

In December 2016, the MPCA posted draft rule language on the rulemaking website for public review.

Open Houses

In February 2013, the MPCA held an open house at the mid-point of the wild rice study to report on the findings of the studies. In addition, before proposing rules, the MPCA hosted a series of three open house meetings to provide an informal opportunity for the public to review the proposal, ask questions, and become familiar with the hearing and comment process. To facilitate attendance by the interested public, the MPCA held these open houses during evening hours in St. Paul, Duluth, and Mountain Iron.

B. Notice Required by the Administrative Procedures Act. (Minn. Stat. ch. 14)

Providing notice

For all notices required by the Administrative Procedures Act , the MPCA uses a self-subscription service (GovDelivery), that allows interested and affected parties to self-register to receive rule related notices though email. When the MPCA initiates a rulemaking, it establishes a specific GovDelivery topic and encourages interested parties to register to receive future notifications regarding that rulemaking. Individuals may register to receive notice on a specific topic or may register to receive notice on a broad topic area (e.g. all water quality rulemakings). The MPCA widely encouraged registering for GovDelivery notice of this rulemaking, with the result that at the time of finalizing this Statement, 2,384 email addresses are registered to receive GovDelivery notification.

Although in almost all cases, interested and affected parties opt for electronic notification through GovDelivery, the MPCA also provides the option of receiving notice through the U.S. Mail. For this rulemaking, no one has requested U.S. Mail service notification.

Early rulemaking notice required by the Administrative Procedures Act

On October 26, 2015, the MPCA published the RFC in the *State Register.* This notice requested comments on planned rule amendments to the water quality rules regarding a sulfate standard to protect wild rice and identification of wild rice waters. The MPCA posted this notice on the MPCA's Public Notice webpage and the wild rice rulemaking webpage at https://www.pca.state.mn.us/water/sulfate-standard-protect-wild rice. The MPCA sent a GovDelivery notice to the 2,784 persons who had at that time registered their interest in the wild rice rules. Additional notice of this opportunity for comment was also provided in the *Minnesota Counties* newsletter and to the MPCA's list of tribal contacts. On November 16, 2015, the MPCA sent an additional notice to 848 persons on the MPCA's environmental justice topic list to notify them of the opportunity to submit comments during the Request for Comment period and to encourage them to register to receive future notifications regarding the wild rice rulemaking.

The MPCA posted the comments received on the rulemaking website and on January 5, 2016, following the close of the Request for Comment period, the MPCA provided GovDelivery notice to persons who had registered their interest to inform them of the status of the rules and provide information about where to review comments.

Notice plan when rules are proposed

The Administrative Procedures Act and other state statutes establish certain minimum requirements for providing notice. This section describe how the MPCA plans to meet these minimum requirements.

Required notice

1. *Minn. Stat. § 14.14, subd. 1a.* On the date the Notice is published in the *State Register*, the MPCA intends to send a GovDelivery notice to all parties who have registered with the MPCA for the purpose of receiving notice of rule proceedings. The notice will provide a brief description of the rulemaking and comment period and a hyperlink to where the rulemaking documents (the Notice, SONAR and attachments, proposed rule revisions and the documents incorporated by reference) can be viewed. Any parties who have requested non-electronic notice will receive copies of the Notice and the proposed revisions in hard copy via U.S. Mail.
2. *Minn. Stat. § 14.116.* The MPCA intends to send a cover letter with a link to electronic copies of the Notice, SONAR, and the proposed revisions to the chairs and ranking minority party members of the legislative policy and budget committees with jurisdiction over the subject matter of the proposal, as required by *Minn. Stat*. § 14.116. This statute also requires special notice if the mailing of the notice is within two years of the effective date of the law granting the agency authority to adopt the proposed rules. This requirement does not apply for this rulemaking because no bill was authored within the past two years granting rulemaking authority.

3. *Minn. Stat. §14.111.* If the rule affects agricultural land, *Minn. Stat.* § 14.111 requires an agency to provide a copy of the proposed rule changes to the Commissioner of Agriculture no later than 30 days before publication of the proposed rule in the *State Register.*

Although the MPCA does not expect this proposal to have any direct impact on agricultural land or farming operations, the MPCA intends to provide pre-publication notice to the Commissioner of Agriculture and the Minnesota Department of Agriculture staff who are rulemaking liaisons.

4. *Minn. Stat. § 115.44, subd. 7. Minn. Stat. § 115.44, subd. 7* requires that when a revision affects a municipality through which an affected water flows, the municipality must be notified at the time the rule is proposed. Because the proposed revisions will affect a large number of waters and potentially affect a large number of municipalities, the MPCA intends to send notice to the governing body of every municipality in Minnesota. The MPCA will provide electronic notice to a current mailing list of municipalities obtained from the League of Minnesota Cities.

Pursuant to the above-listed statutes, the MPCA believes it will meet the statutory obligations to provide adequate notice of this rulemaking to persons interested in or regulated by these rules.

Additional Notice

Because of the degree of public interest in the proposed revisions, the MPCA intends to conduct more outreach and public notice than the minimum required by the state Administrative Procedures Act. When the MPCA publishes the proposed revisions for public comment, the MPCA intends to conduct the following additional activities to ensure that all interested people and affected communities will be notified and have a chance to meaningfully engage in the comment process.

- Posting the Notice of Hearing, SONAR, SONAR attachments, the proposed revisions, documents incorporated by reference, and summary information on the MPCA webpage established for this rule. Information about how to comment and the times and locations of hearings will be provided.
- Publishing the Notice of Hearing on the MPCA's Public Notice webpage https://www.pca.state.mn.us/public-notices through the comment and post-comment period.
- Issuing a press release to provide information about the proposed revisions and how to comment.
- Providing an extended comment period to allow additional time for the review of the proposed revisions. The MPCA intends to provide more than the minimum 30-day comment period prior to the hearings and to request that the administrative law judge provide the maximum allowed post-hearing comment period.
- Holding public hearings in multiple areas of the state and providing daytime and evening opportunities to attend and comment. At a minimum, the MPCA will hold hearings in St. Paul and in two northern Minnesota communities. Additional access to those hearings will be provided by videoconference links to multiple outstate locations.

- Providing additional outreach to Native American communities and to mining areas to reach people. The MPCA has sought advice from members of its Environmental Justice Advisory Group about how to reach potentially affected and interested people and communities, and based on that input will provide additional notice to identified communities and news sources. Potential additional notice may include:
    - Notice to nonprofit organizations representing Native American communities such as Indigenous Environmental Network, Bemidji American-Indian Student Council, Headwaters Fund, tribal radio stations; and
    - Notice to organizations representing mining communities, such as Iron Ore Alliance, Iron Range Chambers of Commerce.
    - Municipalities that operate wastewater treatment facilities and the organizations that represent them, such as the Coalition of Greater Minnesota Cities, Minnesota Rural Water Association, League of Minnesota Cities.

9. Environmental Justice

This discussion of how the MPCA considered environmental justice in the context of this proposed rulemaking is an important element of the MPCA's rulemaking approach, although it is not a requirement of Minnesota's Administrative Procedure Act. Considering environmental justice means, in part, that the MPCA strives to 1) consider how proposed rules may affect low-income populations and communities that have a high proportion of people of color and 2) involve members of those communities in the rulemaking process.

Three key facets of wild rice and sulfate make it especially important to incorporate environmental justice considerations in the analysis of this rulemaking:

- The spiritual and cultural important of wild rice to Native American communities, particularly Ojibwe and Dakota communities;
- The availability of wild rice as a subsistence food, harvested particularly by Native Americans; and
- The costs of sulfate treatment and the potential impact on low-income communities.

In early 2017, the MPCA held a series of open houses to familiarize the public with the issues and the MPCA's expected proposal. The MPCA held two of those open houses in northern Minnesota (Duluth and Mountain Iron) where there is a particular concern about the effect on tribal and low-income communities. At these meetings, the MPCA provided information about the proposed amendments and encouraged registering for GovDelivery to receive notices of the opportunity to comment.

A. Background of MPCA's environmental justice policy.

The MPCA's Environmental Justice Framework 2015 – 2018, (Exhibit 39) describes the MPCA's history with environmental justice:

> *"Following action on the national level, the MPCA began formally working on environmental justice in the mid-1990s. Presidential Executive Order 12898, issued in 1994, directed each federal agency to make "achieving environmental justice part of its mission by identifying and addressing disproportionately high and adverse human health or environmental effects of its programs, policies and activities on minority and low-income populations." The Presidential Executive Order built on Title VI of the Civil Rights Act of 1964. Title VI prohibits discrimination on the basis of race, color, or national origin. As a recipient of federal funding, the MPCA is required to comply with Title VI of the Civil Rights Act."*

The MPCA developed a policy and strategy for environmental justice similar to that of the U.S. Environmental Protection Agency. The MPCA's environmental justice policy (Exhibit 40) states:

> *"The Minnesota Pollution Control Agency will, within its authority, strive for the fair treatment and meaningful involvement of all people regardless of race, color, national origin, or income with respect to the development, implementation, and enforcement of environmental laws, regulations, and policies.*

Fair treatment *means that no group of people should bear a disproportionate share of the negative environmental consequences resulting from industrial, governmental, and commercial operations or policies.*

Meaningful involvement means that:

- *People have an opportunity to participate in decisions about activities that may affect their environment and/or health.*
- *The public's contribution can influence the regulatory agency's decision.*
- *Their concerns will be considered in the decision making process.*
- *The decision-makers seek out and facilitate the involvement of those potentially affected.*

The above concept is embraced as the understanding of environmental justice by the MPCA."

In 2013, the MPCA renewed its commitment to environmental justice and added an environmental justice goal and objectives in the MPCA's strategic plan (https://www.pca.state.mn.us/about-mpca/mpca-strategic-plan).

Pollution does not have a disproportionate negative impact on any group of people.

Objectives:

- *Develop and implement program strategies to identify and address environmental justice concerns.*
- *Identify and enhance opportunities for all Minnesotans to provide meaningful input into MPCA environmental decision-making.*

The MPCA has considered both aspects of the environmental justice policy: fair treatment and meaningful involvement. The MPCA has considered how the impacts of the proposed rule revisions are distributed across Minnesota and has worked to engage all Minnesotans in this effort regarding the protection of the wild rice beneficial use.

B. Equity analysis

The MPCA strives to consider how proposed rules may affect low-income populations and communities that have a high proportion of people of color. In addition, the MPCA is aware that the protection of wild rice is of extraordinary importance to Native American communities, both from an economic and cultural/spiritual perspective.

The MPCA's environmental justice goal is to look at whether implementing proposed rules will create a disproportionate impact or worsen any existing areas of disproportionate impact (disproportionate impacts occur when environmental burdens and resulting human health effects are unequally distributed among the population). The MPCA may also consider whether a rulemaking has a chance to reduce an existing disproportionate impact. The MPCA also considers the distribution of the economic costs or consequences of a proposed rule, and whether those costs are disproportionately borne by low-income populations and communities of color. Examining a proposed rule from the perspective of fair treatment is difficult, and requires first examining whether there is an existing disproportionate impact.

An aspect of wild rice that affects the review of potential disproportionate impact is its singular importance to the Ojibwe and Dakota people. No other natural or environmental resource in Minnesota is so central to the heritage of a group of people; and the generally marginalized status of native culture makes this even more critical. Wild rice is certainly of economic importance to native harvesters and valued as a source of food, but it is also a very important spiritual component of native culture. As an example, as stated in *Wild Rice and the Ojibway People* (Vennum, 1988), "*Wild rice, called manoomin in the Ojibway language, once played a central role in tribal life. It was endowed with spiritual attributes, and its discovery was recounted in legends. It was used ceremonially as well as for food, and its harvest promoted social interaction in late summer each year. Consequently, many Ojibway view the commercial exploitation of this resource by non-Indians as an ultimate desecration.*" (pg.1)

When the MPCA published a Request for Comments, it received comments that highlighted the specific cultural importance of wild rice to the Native American communities.

- *"For native people in our region it is considered necessary to their traditional diet but also next to sacred."*
- *"We need to do everything we can to protect wild rice. It's not just a 'food.' It is also a sacred commodity."*
- *"Indigenous elders instruct us to honor the spirit of water or manoomin the food that grows on water disappears. Without clean water all lifeways sicken and die."*
- *"The MPCA proposal…robs wild rice of its intrinsic value…."*

This rulemaking attempts to acknowledge the cultural importance of wild rice while recognizing that the rule focuses on a specific beneficial use (the grain) and pollutant (sulfate/sulfide), and not on all aspects of wild rice.[17]

In particular, the cultural and spiritual importance of rice could be seen as making any diminishment of rice an impact that disproportionately falls upon Native American communities. Several Minnesota tribes feel that such a disproportionate impact does exist. A letter to the MPCA from the leaders of the Minnesota Chippewa Tribe (sent March 15, 2017), states that "dischargers have borne *zero* costs to comply with the existing wild rice water quality standard, and Minnesota tribes (and any Minnesotan that harvests or eats Minnesota wild rice) have lost undocumented thousands of acres of productive wild rice waters." This clearly demonstrates a belief that a disproportionate impact exists, where Native communities are bearing the costs of the loss of wild rice. These costs may be in the loss of cultural resources, or, especially where there is an intersection of Native and low-income communities, in the loss of wild rice resources as a subsistence food.

The proposed amendments, which establish a sulfate standard and the clear identification of wild rice waters, are protective of the Class 4D wild rice beneficial use and provide more accurate protection than the current 10 mg/L sulfate standard. Therefore, the proposed standard will not have any negative

[17] The MPCA remains committed working with tribes, state agencies and others on strategies to protect wild rice, both within and outside of water quality standards rulemaking.

effect on the growth, harvesting, or sustainability of wild rice. It will not exacerbate any existing disproportionate impacts or environmental justice concerns. Both the existing and the proposed sulfate standard are admittedly narrow in scope relative to all the factors that may impact the wild rice beneficial use. The MPCA does not have the scientific information or staff resources to develop and propose additional Class 4D water quality standards at this time. However, the increased clarity proposed by the MPCA is intended to improve implementation of the sulfide standard and therefore, improve protection of wild rice waters.

Another perspective on disproportionate impact relates to the costs of sulfate treatment. Compared to the existing 10 mg/L standard, the MPCA expects the proposed revisions to result in increased costs for wastewater treatment for certain municipalities and industries and decreased costs for others. (A discussion of the economic effects of the proposed revisions is provided in Part 10 of this SONAR.) Although dischargers throughout the state may potentially be affected, a large number of the listed wild rice waters are in northern Minnesota, meaning that there will be a greater potential for economic impact in those areas.

Where dischargers need to make upgrades in order to meet the standard, there may be impacts. If the dischargers are located in a low-income area, the costs of compliance may place an additional burden on these communities. For example, municipal wastewater treatment facilities charge fees to all households connected to them. If additional treatment is needed to meet the standard, there is likely to be an increase in fees; in a lower income area, this additional payment may be more of an economic hardship. Industrial dischargers do not charge fees, but a requirement to install new treatment may impact their investment decisions. An industry may close or reduce production rather than invest in treatment mechanisms that will meet the standard, resulting in lost jobs. This impact may be especially significant in lower-income areas or areas where there are fewer employers. Variances are an important mechanism to mitigate these impacts, as they explicitly consider these kinds of adverse economic effects in determining whether or when a facility must meet a WQBEL.

There is likely to be concern that variances will allow for greater sulfate discharge in certain areas, which may be environmental justice areas. While this is possible, that concern exists for the existing 10 mg/L standard as well – so it is not changed by the proposed rule revisions. A more tailored standard is likely to result in fewer variance requests than expected with the implementation of the existing 10 mg/L standard.

Figure 7 shows certain demographics relative to the proposed revisions, in order to provide information as to whether the proposed revisions have the potential to affect areas that have populations that are predominantly low-income, people of color, or both; the map also shows tribal lands. As part of its environmental justice program, the MPCA has established screening criteria based on population characteristics, to determine if an area is one that may be experiencing disproportionate pollution impacts and with a higher concentration of people who may be the most vulnerable to that pollution. The MPCA used the screening criteria to help determine if a rule is likely to have an impact on areas that meet the screening criteria. The MPCA based its screening criteria on census tracts where the population is:

- 50% or more people of color; or

- 40% or more of the population has a household income less than 185% of the federal poverty level.

The MPCA reviewed the proposed list of wild rice waters and determined that approximately 135 dischargers (industrial and municipal) will discharge within 25 miles of an identified wild rice water.[18] The MPCA then determined whether any of these dischargers are located in or near census tracts that meet the screening criteria described above. Based on the review, the MPCA identified several municipal and industrial dischargers that may be affected by the proposed sulfate standard in census tracts that may meet the screening criteria.[19] The information in Figure 7 does not provide evidence of a potential disproportionate impact or lack of meaningful participation. . It only identifies that possibility and indicates where the MPCA should pay particular attention. The following qualifiers should be considered in viewing the information in Figure 7.

- The fact that a discharger is within 25 miles of a wild rice water does not mean that the proposed revisions will result in additional treatment costs for that WWTP or economic burden to the surrounding community. Determining costs, and especially costs to the surrounding community, will depend on the calculation of the sulfate standard, the determination of effluent limits and permit conditions, and a number of other variables that cannot be determined until the MPCA adopts and implements the proposed revisions. Part 10 of this Statement (Regulatory Analysis) provides a more complete discussion of economic impact and the variables associated with costs.
- The location of a potentially affected WWTP in a census tract identified as being low-income or predominantly people of color does not indicate an environmental justice issue. For example, the residents of a census tract identified as low income may be served by individual sewage treatment systems that will not be affected by changes in the municipal WWTP. Another example is if an identified WWTP is an industrial discharger and the costs to that industry may have no negative effect on the residents in the immediate area.

The analysis shows that in the areas that meet the criteria of having more than 40% of the residents with an income below 185% of the poverty level (blue-shaded), there are two potentially affected dischargers, one in northern Minnesota and one in the Twin Cities area. The number of potentially affected dischargers located in areas where there is a possibility that the median level meets the 40% poverty level (pink-shaded) is greater. In those areas, the proposed standards may affect 37 dischargers. In the tracts where more than 50% of the residents are people of color, 39 dischargers may be

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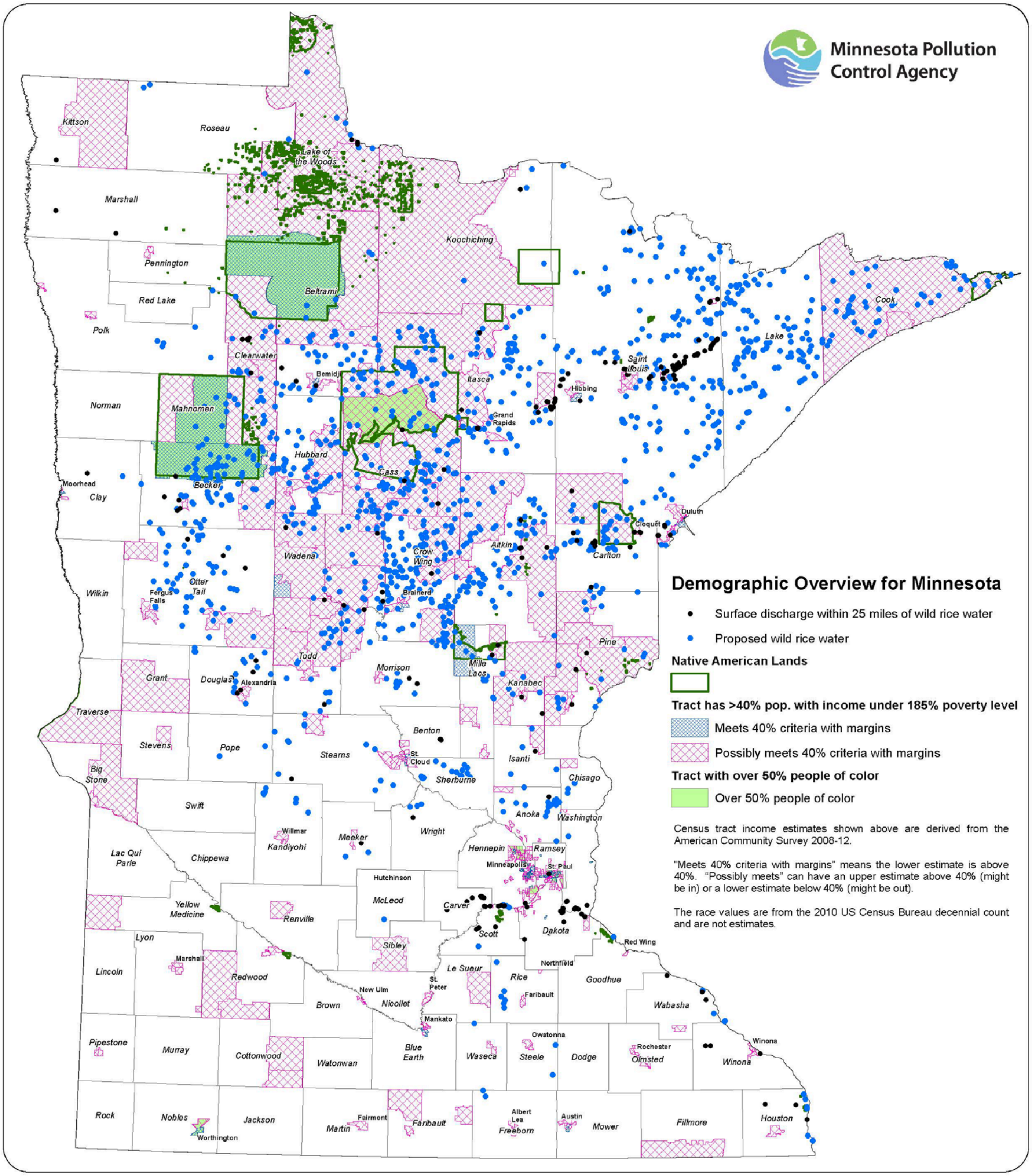
[18] A discussion of how the MPCA made this determination is provided in Attachment 4

[19] The margins of error on the census tract data sometimes mean that the MPCA cannot make a definitive determination of whether or not a given census tract meets the screening criteria. For instance, a census tract may be listed as one where 42% of the population has a household income less than 185% of the federal poverty level. Because income is estimated using surveys, there is a margin of error on the 42% estimate. If, for example, the margin of error is 4%, the true percentage of the population with a household income less than 185% of the federal poverty level could be between 38% (in which case the tract would not meet the screening criteria) or 46% (which does meet the screening criteria). This margin of error is why so many tracts are listed as possibly meeting the criteria.

potentially affected. Because high-poverty areas and areas populated by people of color often overlap, most of these potentially affected dischargers are the same.

Figure 7 Demographic review relative to the proposed revisions



C. Meaningful involvement

In order to meet the directive to strive for "meaningful involvement," the MPCA works to seek out and facilitate the involvement of those potentially affected by a proposed rule, particularly those populations that have historically not been as engaged in the public process.

According to the MPCA's Environmental Justice Policy, "*Meaningful involvement means that:*

- People have an opportunity to participate in decisions about activities that may affect their environment and/or health.
- The public's contribution can influence the regulatory agency's decision.
- Their concerns will be considered in the decision making process.
- The decision-makers seek out and facilitate the involvement of those potentially affected."

As noted in Part 8 (Public Participation), the MPCA has conducted extensive outreach work during the development of the proposed revisions. This outreach resulted in substantial feedback to the MPCA; some of the feedback resulted in changes to the proposed rule. Although the MPCA did not agree with all the input received, all of it was carefully considered.

The MPCA conducted much of this outreach effort and stakeholder work on a broad basis without specific focus on environmental justice. The MPCA continues to work to develop effective tools and methods to reach out to new stakeholders and communities – particularly low-income populations, Native Americans, non-English speakers, and communities of color. For this rulemaking, the MPCA specifically sought to engage Native American communities because of the value of wild rice to those communities. The MPCA did not conduct outreach activities specifically focused on low-income populations, non-English speakers, or communities of color because of the uncertainty regarding which communities will be affected by the proposed revisions. As discussed above, the MPCA will not know what communities will be affected or to what extent the effect will be felt by communities of color, non-English speaking, or low-income communities until the sulfate standard is calculated and implemented. In the discussion of the MPCA's additional notice plan for when the rules are proposed (Part 8.B), the MPCA discusses its intent to provide special notice and encourage meaningful involvement to all communities potentially affected by environmental justice concerns.

The MPCA routinely engages Minnesota's tribal communities in all rulemaking that affects water quality. For this rulemaking, the MPCA conducted extensive pre-rulemaking outreach to tribal staff and leadership to obtain their input and encourage them to register to receive ongoing communication about the rule development and opportunities to comment. The MPCA regularly included tribal representatives in discussions of the issues, starting when the MPCA was still in the research phase of rulemaking, through the development of the TSD and the rules as proposed. The MPCA's efforts to encourage meaningful involvement by tribal government included:

1. Formal Consultations.

Since the MPCA began working on the wild rice sulfate standard in 2011, four tribal consultations between the MPCA and Tribes have been held. The MPCA formally invites Tribal chairs to participate in a consultation through a letter from the MPCA Commissioner's office, from either Assistant Commissioner and Tribal Liaison David Thornton or MPCA Commissioner John Stine. Tribes review the MPCA's notes following the consultations.

Consultations

March 7, 2011

Location: MPCA Duluth Regional Office
Topic: Definition of Wild rice waters and Wild Rice Sulfate Toxicity Proposals

March 12, 2012

Location: Fond du Lac Resource Management Office
Topic: Water used for Production of Wild Rice

August 26, 2015

Location: Fond du Lac Reservation and EPA lab in Duluth
Topic: Protecting Wild Rice from Excess Sulfate

January 31, 2017

Location: EPA Lab in Duluth
Topic: MPCA's proposed revisions.

2. Tribal representation on the MPCA's Wild Rice Advisory Committee.

The MPCA formed a Wild Rice Advisory Committee in fall 2011, which included representation from tribes. Nancy Schuldt, water projects coordinator from the Fond du Lac Tribe, and Darren Vogt from the 1854 Treaty Authority have served as members of the Wild Rice Advisory Committee since 2011. The committee was set up to provide input to the commissioner on the protocol for scientific research, research results and any rulemaking on wild rice.

3. Meetings and technical calls with tribal environmental department staff following release of MPCA proposal March 26, 2015.

Following an initial discussion of the MPCA proposal with tribal environmental staff on March 26, 2015, the MPCA held several calls to take questions and hear concerns about the MPCA's proposal. As a result of these communications, MPCA re-analyzed data from the studies including the survey data related to wild rice presence to sulfide in the sediment, the field survey data that related sulfate to sulfide as well as the basic assumptions relating sulfate to wild rice.

March 26, 2015 — Initial discussion of MPCA proposal with environmental staff from tribes, Grand Casino Hinckley.

May 27, 2015 — Tribal technical conference call.

June 29, 2015 — Tribal technical call.

August 12, 2015 — Tribal technical call.

March 2, 2016 — Tribal technical call to discuss MPCA wild rice water determination procedure.

July 19, 2016 — Tribal technical call to discuss the pending release of the draft TSD.

August 12, 2016 — Tribal technical call to discuss the draft TSD .

4. Ongoing communication via email and phone.

In addition to the meetings and communications mentioned above, MPCA staff and leaders have held numerous phone conversations with tribal staff and email communications with tribal contacts during the evaluation of the wild rice sulfate standard.

The MPCA recognizes that the affected and interested Native Americans are not always associated with tribal government and may live inside or outside recognized tribal boundaries. The MPCA has sought advice from members of our Environmental Justice Advisory Group on how to provide notice from these parties so that they can participate in the formal rulemaking process.

The MPCA provides a GovDelivery topics list for environmental justice and registrants to that Environmental Justice list include non-affiliated Native Americans and groups who represent them. The MPCA sent a GovDelivery notice on November 19, 2015 to 848 people on the MPCA's environmental justice GovDelivery list to notify them of the wild rice rulemaking and to encourage them to register to receive future notices through the GovDelivery list that is specifically for the wild rice rulemaking.

10. Statutorily Required Regulatory Analysis

Several Minnesota statutes require agencies to address certain topics in the Statement of Need and Reasonableness. The discussion in this Part addresses each of the requirements of Minnesota statutes and law as they specifically relate to the proposed revisions. Together, several of these statutory requirements comprise a regulatory analysis of the economic effect of the proposed revisions.

Comparison of the existing and proposed revised standard

The proposed revisions are needed to provide a more accurate level of protection and more effective implementation than the current wild rice sulfate standard. Simply stated, the MPCA considers that the proposed revisions will be a more effective and efficient means of protecting wild rice waters from the effects of sulfate.

Sulfate, through its transformation to sulfide, has an impact on wild rice growth and health. However, sulfate is not the only factor that does so; water clarity, water level, and many other factors affect wild rice presence and health. The MPCA's wild rice sulfate standard generally – and these rule revisions specifically – only have an impact on wild rice where it grows in water bodies that are impacted by sulfate discharges.

With this limitation in mind, the proposed revisions should encourage the re-establishment of wild rice to waters impacted by sulfate where the 10 mg/L standard was under-protective. Where the 10 mg/L standard was over-protective, the rule revision will reduce the cost of treatment for dischargers.

However, since numeric standards have not yet been calculated, the MPCA cannot today quantify how many wild rice waters need a standard more stringent than the existing 10 mg/L, and how many can tolerate a less stringent sulfate standard and still protect the beneficial use.

Because the number of dischargers who must meet a different limit (either more or less stringent) is not known, it is difficult to quantify the change in environmental costs or benefits based on this rule revision. Although the MPCA expects that a more accurate and effective standard would be reflected in increased wild rice yields and generally improved environmental quality in specific areas, it is similarly difficult to quantify the economics of those benefits. In Section E below (Discussion of the probable costs of not adopting the proposed revisions), the MPCA discusses the value of wild rice and the expected benefits to people who value wild rice resulting from the proposed revisions. However, this analysis does not quantify the potential positive economic effects of the proposed revisions that may result from additional protection from wild rice losses, increased property values, or environmental benefits.

There are two parts to the proposed revisions. As described above, the revisions replace the 10 mg/L sulfate standard with an equation-based standard or alternate, which results in allowable sulfate levels tailored to water body conditions that affect how efficiently sulfate is converted to sulfide. The second major revision is the replacement of the existing vague reference to "water used for the production of wild rice" with a specific list of water bodies where the beneficial use is an existing use (or has been). One benefit is having a stable regulatory environment so that dischargers know whether or not they are subject to the sulfate standard protecting wild rice. As noted above, how many dischargers will be required to install additional treatment is unknown until the actual sulfate standard is calculated, reasonable potential is determined, and options such as source reduction and variances are considered. This fact limits the MPCA's analysis.

Statutory Mandates of 14.131

The MPCA's regulatory analysis is arranged to address the following statutory mandates of Minn. Stat. § 14.131.

A. Classes of persons who probably will be affected by the proposed rules

B. Probable costs to the MPCA and to any other agency and any anticipated effect on state revenues

C. Assessment of alternative methods for achieving the purpose of the proposed rules, including those that may be less costly or less intrusive.

D. Probable costs of complying with the proposed rules

E. Probable costs of not adopting the proposed rules

F. Assessment of the differences between the proposed rules and corresponding federal requirements and rules in states bordering Minnesota and states within EPA Region V

G. Assessment of cumulative effect

H. Performance based standards

Overview – Comparing the proposed revisions to existing rules

The goal of the regulatory analysis is to describe the impacts of the proposed rule revisions – in terms of what will change and the costs and benefits of those changes. In order to describe the changes, it is important to understand both existing rules and the proposed changes.

As described throughout this Statement, Minnesota currently has a rule designed to protect the wild rice beneficial use from the adverse impacts of sulfate. In order to protect that use, a standard of 10 mg/L sulfate applies to water used for production of wild rice during periods when the rice may be susceptible to damage by high sulfate levels. This existing rule is the baseline. This regulatory analysis compares the changes expected from the proposed revisions to the baseline of the existing rule.

There are two parts to the proposed revisions. First, the revisions replace the 10 mg/L sulfate standard with an equation-based standard, which results in the allowable sulfate levels varying by water body. Second, the proposed revisions also provide clarity by specifically identifying the water bodies where the beneficial use has been demonstrated and therefore, where the standard applies. In general, it is much easier for this analysis to describe the impacts of the proposed revision where the proposal affects the allowable amount of sulfate in the water. It is much more difficult to describe the changes that result from clarifying where the beneficial use exists. For that aspect of this analysis, the MPCA must compare the effects of the proposed lists of wild rice waters with the current system of case-by-case identification of waters where the standard applies. This regulatory analysis will compare the impacts of both parts of the proposed revisions to the effect of the MPCA implementing the existing standard.

A. Classes of persons who probably will be affected by the proposed rule revisions

The MPCA is required to provide "*A description of the classes of persons who probably will be affected by the proposed rule, including classes that will bear the costs of the proposed rule and classes that will benefit from the proposed rule.* Minn. Stat. § 14.131 (1)"

This regulatory analysis focuses on two major classes. The first is regulated (permitted) facilities that discharge wastewater to a water body subject to the water quality standard. When the revised standard is adopted, the MPCA must determine if the discharges from these facilities are likely to cause or contribute to the standard being exceeded. If so, the facilities will receive effluent limits in their permit to control discharge of the pollutant and may need to install equipment to reduce pollution. The proposed revisions may impose costs on this class. The MPCA would likely include a schedule of compliance in any permit requiring installation of new treatment systems as the result of the new standard being applied.

The second affected class is the people that want to enjoy the beneficial use that the water quality standards protect – whether fishing, swimming, boating or harvesting wild rice. If the proposed standard results in cleaner water and more opportunities to enjoy the use, then those people are a class that will benefit. This benefit will be dependent on implementation of the standard, so may not be seen for a number of years, as data to implement the standard is gathered and new limits are imposed and treatment systems designed, funded, and implemented.

In the discussion that follows, the MPCA will provide a general discussion of the classes that are likely to be affected by the proposed revisions.

Classes of persons who will bear costs

Wastewater treatment plant dischargers.

Water quality standards set the conditions that are necessary to ensure that beneficial uses (fishing, swimming, agriculture, etc.) are maintained. A key mechanism in meeting water quality standards is the imposition of effluent limits – limits to the amount of pollution that a permitted facility can discharge to a specific surface water. In Minnesota, these limits are applied through NPDES/SDS permits, which are reviewed and re-issued every five years. Any facility that discharges to a water where standards apply is likely to be affected by a change in water quality standards.

After adopting a water quality standard, the MPCA goes through the implementation (i.e. permitting) process, which is where the standard affects individual facilities. In the case of this wild rice sulfate standard, this implementation process will begin with data collection. As noted in Part 6.G, the data required will be sediment data to calculate the sulfate standard (or porewater sulfide data to establish an alternate standard), surface water sulfate data, and effluent sulfate data. The MPCA plans to collect the sediment data over time, largely in conjunction with its regular ten-year cycle of intensive watershed monitoring, focusing first on wild rice waters that are most likely to be impacted by high levels of sulfate. The exception would be that where a new or expanded discharge is proposed, the proposer may be required to collect the sediment data following the procedures proposed to be incorporated into the rule.

The first impact to facilities is likely to be the need to gather sulfate effluent data. Some facilities may already be collecting this data. Those that are not will likely have a requirement to monitor their effluent for sulfate added for their first five-year permit reissued after the rule is adopted.

The next impact to facilities will come through an effluent limit review. The effluent limit review involves analysis of a number of site-specific variables to determine whether a permit limit must be applied to any given facility to ensure that the facility does not cause or contribute to an exceedance of the standard. These variables include the specifics of the facility and the receiving water (including the level of the pollutant). The effluent limit review identifies whether a discharger has the potential to cause or contribute to an exceedance of the water quality standard. (see Part 10.G.1 for more information about effluent limits). In order to complete the effluent limit review, there must be a numeric sulfate standard specified for at least one wild rice water impacted by the facility's discharge. For facilities that already have information on sulfate in their effluent, the effluent limit review is more likely to happen in their first five-year permit reissued after the rule is adopted; for facilities that have to add effluent monitoring, the effluent limit review will likely happen in the second five-year permit term or later after the rule is adopted.

If a discharger has the reasonable potential to cause or contribute to an exceedance of the standard, the MPCA develops a water-quality-based effluent limit (WQBEL) applicable to the WWTP. In addition to the standard, the factors in developing a WQBEL include:

- The distance between the discharge and the affected water;
- The volume and concentration of the relevant pollutant in the effluent;
- The percent pollutant contribution to an affected water from an upstream discharge;
- The flow of the receiving water; and
- The effect of additional WWTPs upstream of the affected water.

Ultimately, the WQBEL and any treatment needed to meet the WQBEL are the key drivers of the costs of complying with a water quality standard.

Therefore, permitted facilities that discharge pollution are the classes of persons potentially affected by the proposed revisions to the wild rice sulfate standard. Any facility that discharges sulfate either directly to a wild rice water or upstream of a wild rice water may potentially be affected by the proposed revisions. The main types of facilities with sulfate-containing discharges are municipal and industrial WWTPs.[20]

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[20] *A few of the identified dischargers are not wastewater treatment plants but are water treatment plants. A water treatment plant is usually a municipally operated facility that, because it is only treating clean water to remove certain substances, has a*

The distance from the discharge point to the wild rice water will be a significant parameter in setting the WQBEL, and is the parameter most conducive to the level of general analysis that can reasonably be included here. Although it is only an approximation and by no means definitive of the potentially impacted permittees, identifying the WWTPs within a specified distance of a wild rice water is a reasonable way to characterize the universe of affected dischargers.

In Attachment 4 the MPCA describes an analysis conducted based on 2015 NPDES/SDS permit information.[21] In that analysis of both municipal and industrial dischargers, the MPCA found that an estimated 745 discharge stations are upstream of at least one proposed wild rice water (note: because several WWTPs have multiple stations discharging to different waters, the actual number of potentially affected WWTPs is less than 745). The distance from discharge stations to the nearest proposed wild rice water ranges from less than one mile to 413 river miles. It is important to note that the number of potentially affected facilities is larger than the number of facilities that the MPCA actually expects to be affected. Several factors will affect a facility's potential to impact a wild rice water and those factors cannot be determined in advance of establishing the numeric sulfate standard and evaluating the specific circumstances associated with each discharge and each wild rice water.

However, for purposes of examining the effect on wastewater dischargers, the MPCA made some assumptions in its analysis of the potentially affected dischargers. After reviewing the list of potentially affected dischargers, the MPCA determined that there were logical points where the assumption of effect was evident. The first natural break point in the data is at 60 miles - approximately half (43% or 319) of the discharge stations are within 60 miles of a proposed wild rice water. The next natural break point is at 25 miles, which includes approximately 18% of the 745 discharge points. Half of these 135 are municipal dischargers and half are industrial dischargers. For purposes of this regulatory analysis, these facilities within 25 miles of a wild rice water were considered to be the most likely to be affected to the extent that they will need an effluent limit review, and may bear costs depending on the result of that review and the treatment that would be needed to meet a limit. Attachment 5 identifies the potentially affected dischargers. It is important to note that this list of potentially affected dischargers is very preliminary and subject to change depending on a number of factors. However, Attachment 5 provides an approximation of the dischargers that the proposed revisions may affect.[22]

The fact that a WWTP is within a certain distance of a wild rice water does not provide any information regarding the specific effect (or costs) of the proposed revisions on these dischargers. It also does not provide information about when costs may be incurred. The timing of imposing a sulfate effluent limit on an existing facility will depend on the availability of data, including the sulfate levels of the facility's

much less complex discharge than a wastewater treatment plant. However, for purposes of this discussion, the terms "discharger" and wastewater treatment plants" will apply to both types of facilities.

[21] *The estimates provided in this discussion are based on the MPCA's 2015 permit data and potential wild- rice waters that the MPCA had identified as of November 1, 2016. Changes that occurred since that time may affect the estimates provided here.*

[22] *Wastewater treatment plants discharging farther than 25 miles from a wild rice water may also be subject to an effluent limit review; 25 miles is not a definitive predictor for impact, merely a useful pointer to the facilities most likely to be impacted.*

effluent and the analyses needed to calculate the numeric sulfate standard in the downstream wild rice water(s).

As mentioned previously, many factors will influence the actual effect and related costs of the proposed revisions. Compared to the existing standard, the proposed revisions might result in costs (if more treatment is needed than would be needed to meet the 10 mg/L standard) or in cost savings (if less or no treatment is needed compared to what would be necessary to meet the 10 mg/L standard).

Users of wastewater treatment facilities and industrial customers.
If, as a result of the process just described, a discharger needs to install new treatment equipment or technologies to comply with any proposed water quality standard revision, the affected discharger is likely to pass along the costs of such treatment. Municipal wastewater treatment facilities are likely to pass the costs of new treatment on to their system users, including residential, commercial, and industrial customers. Although many factors – including wastewater funding structure, the volume and composition of discharges, the design, size and age of the WWTP – determine wastewater treatment user fees, it is reasonable to assume that users of any treatment system will incur costs where new and additional treatment is required.

Industrial wastewater treatment facilities that must install new treatment equipment are also likely to pass on those costs. The class of individuals and businesses affected by these costs is extremely broad and diverse, and includes potential indirect impacts. If an industrial discharger is required to spend money to treat their wastewater, it will likely pass those costs on to the purchasers of their product where the market will support the increased costs. Where the market will not support the increased cost, the cost will need to be absorbed and may reduce profits. Either passing on or absorbing that cost might make the industry less competitive in the marketplace, leading to negative effects on shareholders or employees. A company might choose to stop operations rather than invest in the treatment technology needed to meet a revised standard.

Taconite/iron-ore mines and related facilities discharge sulfate. Employment is a particularly key issue around taconite mining and the economy of Minnesota's Iron Range. The market for iron ore, like that of many global commodities, has been extremely cyclical. A large number of factors affect the price of iron and, therefore, the profitability of the taconite mines. At times, temporary closures have caused large layoffs at the facilities. These factors affect the economy of the towns surrounding the taconite mines and processing plants. It would be very difficult to discern the economic impact of this one environmental regulation among all the other global factors affecting the iron mines and the steel industries. Nevertheless, there is the potential for costs incurred by any business to affect shareholders, employees, purchasers of the product, and local communities. These indirect consequences and their multiplier effects may be as minor as a small increase in the price of the product, or may be as extensive as the consequences to an entire community when a company ceases operations.

As noted previously, adopting the standard is only the first step in what will be a multi-year process of implementing it through the MPCA's water assessment cycle and permit review. Obtaining sediment data, calculating the standard, establishing effluent limits, reissuing permits, and all the activities associated with permit reissuance will require many years.

Second, the CWA and Minnesota rules include provisions that allow variances to be granted from a water quality standard or WQBEL where the compliance with the standard or limit would be technologically infeasible or the costs make it economically infeasible. State and federal requirements also provide a phase-in period to achieve compliance with a standard where design, construction or operational changes need to occur to meet the standard. This provision, called a schedule of compliance, may also factor in the time needed to secure the financing needed to make the necessary changes to the wastewater treatment facility. If a variance can be justified due to substantial and widespread social and economic impacts of meeting a standard or limit, this may mitigate costs or push them into the future. Section D of this discussion (Probable Costs of Complying) provides a more complete discussion of the expected costs of compliance and the options, such as variances, that may mitigate those costs.

Classes of persons who will benefit

In the broadest sense, the people who benefit from any proposed water quality standard rule are those who have an interest in or who rely on the quality of Minnesota's waters and the biological communities those waters support. This extensive and significant class includes any person who uses Minnesota waters for any of the following purposes: drinking water; recreation such as swimming, fishing, and boating; commerce; scientific, educational, or cultural purposes; and general aesthetic enjoyment. It may also include those who simply value knowing that there is clean water, or that certain kinds of aquatic life exist.

Minnesota's sulfate standard exists to protect the use of wild rice grains as a food for wildlife and humans. The standard may provide specific benefits to any person who harvests wild rice and uses it as food or who harvests wildlife that use wild rice as food. Wild rice has an important cultural and spiritual value for Ojibwe and Dakota Tribes. The value placed on wild rice for this reason is inestimable and cannot be overstated.

The preservation of the state's water quality is a benefit to not only those who actively use Minnesota's surface waters, but also those who place a value on the existence of clean water and aquatic life (including wild rice) even where they do not actively use it. In addition, the preservation of water quality is important to future generations.

The following classes benefit from a standard that is protective of wild rice waters.

- **Those for whom wild rice represents a cultural or spiritual value.** Many Native Americans, especially members of the Ojibwe and Dakota Tribes, consider wild rice to be a very important aspect of their culture and religion. Wild rice is sacred to some Native Americans. Tribal rights to harvest wild rice are enshrined in treaties. Harvesting, preparing, sharing, and selling wild rice is an important cultural, spiritual, and social activity to Native American Minnesotans.
- **Those who harvest wild rice for personal use or sale and persons who operate businesses that benefit from harvesting.** Wild rice is Minnesota's state grain. Many individuals harvest wild rice,

either for personal consumption or for sale.[23] Transactions and activities associated with the wild rice harvest benefit individuals and local economies. Some tribal members have shared stories about how money from ricing paid for each year's school supplies. Many people place a high value on wild rice as food, especially for its availability, flavor, and health benefits. For persons who have limited incomes or a cultural connection, wild rice can be an important subsistence food.

- **Those who hunt or who operate businesses that depend on hunting or wildlife based tourism.** Wild rice is an important food source for wildlife, especially migratory waterfowl. People who hunt waterfowl or who are engaged in bird watching or other wildlife-related activities will benefit from effective protection of wild rice as a food source for wildlife, as will those who economically benefit from tourism and hunting activities.
- **Those who derive a value from ecosystem services.** Ecosystem services are all the goods and services produced by ecosystems that people value, regardless of whether those goods are marketed. Wild rice occupies a significant place in the ecology of Minnesota lakes, rivers and wetlands, and provides various ecosystem services that include marketable value, sustenance, recreational value, cultural and spiritual value, and more. Protecting wild rice as a food source for wildlife and humans also helps protect the ecosystem services wild rice waters provide. These ecosystem services are important not only to individuals but to the state economy as a whole.

Some of these benefiting groups overlap and the magnitude of the value to each of these groups and to individuals within each group will vary considerably. However, clearly there is a diverse suite of benefits provided by wild rice waters in Minnesota and thus a diverse set of beneficiaries. Implementing a standard that will aid in the protection of wild rice waters will thus add to the wellbeing of many Minnesotans.

Within this context of very broad classes that includes all parties, present and future, who benefit from protected wild rice waters, there are distinct groups who will see specific benefit from the proposed revision to the wild rice sulfate standard. These are:

1) People who will benefit from revisions to the magnitude of the water quality standard (from 10 mg/L to the more accurate equation-based or alternate standard); and
2) People who will benefit from clarity around how and where the standard is applied, including a clearer identification of wild rice waters.

People who will benefit from a water quality standard that is more accurate.

The existing 10 mg/L standard is generally protective of the wild rice beneficial use. However, the proposed revisions provide a more accurate standard. As described elsewhere in this Statement and in the TSD, it is sulfide created in the sediment porewater that adversely impacts wild rice. While sulfate in

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[23] *In 2006, 1,625 permits to harvest were issued in Minnesota and approximately 700,000 lbs. of wild rice were harvested (Exhibit 22 MDNR, 2008)*

the surface water contributes to the levels of sulfide, iron and carbon in the sediment of a particular water body also impact sulfide levels. Therefore, a single sulfate value does not ensure that sulfide in the sediment porewater remains below harmful levels. The proposed equation-based approach is more accurate, reflecting the natural dynamics of the system, and therefore more able to ensure that sulfide stays at levels that the wild rice can tolerate.

The value of this increased accuracy is seen in the fact that an equation-based approach results in fewer times where the standard is inappropriate for the environmental conditions. That is, the standard calculated from the equation results in both: 1) fewer times when an ambient sulfate concentration exceeds the standard, but porewater sulfide is actually below the protective concentration; and 2) fewer times when the ambient sulfate concentration is less than the standard, but the porewater sulfide is actually above the protective concentration.

In a water body where ambient sulfate levels need to be less than 10 mg/L to ensure that sulfide remains at a protective level (below 120 µg/L), the equation based standard is more protective of the wild rice than the current standard. In these cases, the proposed revisions will result in better protection of wild rice and provide a benefit to those who use and value wild rice.

In a water body where ambient sulfate levels can be higher than 10 mg/L while ensuring that sulfide remains at a protective level, the equation-based standard fully protects the rice while potentially reducing treatment costs. Some municipal or industrial dischargers (particularly new or expanding dischargers) may be able to operate a lower level of sulfate treatment, thereby deriving a direct benefit from the proposed revisions by not paying for a level of wastewater treatment that is over-protective of wild rice, or needing to apply for and justify a variance request. Because the equation-based standard continues to be protective, this benefit is not offset by a cost to wild rice.

The rule also proposes an alternate standard that can be used in cases where the equation is not appropriate. The alternate standard allows sulfate levels to be higher than calculated by the equation if the sulfide is at a protective level. As with the above scenario, this alternate standard fully protects the rice (by ensuring that sulfide does not get too high) while reducing potential treatment costs. Treatment costs are not limited to monetary cost. Treatment also involves costs in terms of energy use and the generation of treatment by-products.

People who will benefit from clarity of how and where the standard applies

Many dischargers may derive benefits from the adoption of the proposed revisions in the form of the benefit of regulatory certainty, prompt permit renewal, and protection from litigation.[24]

The current regulatory status for dischargers of sulfate is complicated. In particular, the application of the 10 mg/L sulfate standard to "water used for production of wild rice" has been difficult. The existing standard does not:

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[24] In this context, "regulatory certainty" refers to the general ability of permittees to know and anticipate environmental regulations and reasonably plan for compliance, not the specific MPCA effort related to nutrient removal at a wastewater treatment plant.

- Provide a duration or averaging time for the standard, which has resulted in uncertainty as to whether the standard must be met at all times or over some average period; or
- Clearly explain the criteria for determining if a water is used for production of wild rice, requiring regulatory decisions to be made on a case-by-case basis.

To some extent, this complexity and lack of clarity (particularly around waters used for production of wild rice) has prevented the prompt issuance of new or renewed NPDES/SDS permits.

By providing more details about the standard and specifically identifying wild rice waters in rule, the proposed revisions provide clarity about how and where the standard applies. This allows dischargers to have more certainty as to whether their effluent may impact a wild rice water and whether they will need to take actions because of the standard – from monitoring their effluent to undergoing an effluent limit review to installing treatment.

Therefore, adopting the proposed revisions will establish a clearer standard and increase regulatory certainty, a benefit to industrial and municipal dischargers. This certainty will speed the permitting process and reduce MPCA permitting backlogs, reduce the risk of litigation, and allow existing facilities to implement improvements and innovations that are currently stalled. The improved efficiency of having a clearer, implementable standard will also benefit industries and taxpayers by allowing permitted dischargers to more effectively obtain and update their permits.

Greater clarity about how and where the wild rice sulfate standard applies will also allow the development of a clear process of assessing wild rice waters to determine attainment of the standard. This is important both for assessment and identifying impaired waters and for developing point source permit limits to ensure compliance with the standard. In this way, a clearer, more effective standard will also benefit those concerned about the effective protection of wild rice waters, and the identification and restoration of wild rice waters affected by elevated sulfate levels.

B. Probable costs to the MPCA and to any other agency and any anticipated effect on state revenues

The MPCA is required to provide an analysis of "The probable costs to the agency and to any other agency of the implementation and enforcement of the proposed rule and any anticipated effect on state revenues. Minn. Stat. § 14.131 (2)"

What will be the costs to the MPCA?

The MPCA implements water quality standards primarily through permitting and assessment. The MPCA will continue its activities relating to permit applications, variance requests, assessments, impaired water identification, and compliance and enforcement – just using the revised standard instead of the previous standard.

When the proposed rules are adopted, some of this ongoing work will change in ways that will affect the MPCA's costs. The MPCA will incur costs in the following areas:

1) Updating the list of wild rice waters (data gathering and rulemaking);

2) Conducting sediment and surface water sampling and analysis;

3) Permit applications;

4) Variances; and

5) Possible litigation.

What is the expected cost to update the list of wild rice waters?

There are two aspects to the cost of updating the list of wild rice waters. The first is the cost of obtaining the information necessary to identify a wild rice water. In this rulemaking, the MPCA is proposing to identify approximately 1,300 waters as wild rice waters. Although the MPCA expects that this rulemaking will identify most of the wild rice waters in Minnesota, it will likely be necessary to amend the rule to add newly identified wild rice waters in the future. Future identification of wild rice waters will be the result of new information. The MPCA will use the existing triennial standards review process to seek information from outside sources and to share that information or information obtained through the MPCA's routine water assessment activities. The MPCA does not expect that adding a review of wild rice waters to the triennial review or verifying the information provided from outside sources will require significant staff effort beyond normal operations. MPCA staff will evaluate wild rice presence as part of the MPCA's existing water assessment program. The MPCA does not expect to incur additional costs to obtain wild rice information.

The second area of MPCA cost will be the cost of rulemaking to update the list of wild rice waters. The MPCA will need to conduct rulemaking to make any changes to the list of wild rice waters in Minn. R. 7050.0471. Because the MPCA routinely conducts rulemaking to revise the waters identified by specific use class, the cost of future rulemaking cannot be solely attributed to the adoption of the proposed wild rice revisions. However, the proposed revisions may increase the general need to conduct rulemaking to keep the rules up-to-date. The cost of rulemaking varies depending on the level of controversy associated with the rule. The MPCA expects that within the first three years after the adoption of the proposed revisions, there will be a need for one additional rulemaking to amend the list of wild rice waters and that the rulemaking will involve an adjudicated hearing process. The MPCA estimates it costs $129,000 to adopt a rule through the hearing process. Although it is difficult to predict the controversy around future rules, future amendments may not be controversial and may either be adopted without the need for a hearing, making them less costly, or may be combined with other rulemaking projects at no additional cost.

What is the expected cost to calculate the applicable sulfate standard?

In order to calculate the numeric sulfate standard, the MPCA or a permittee must characterize the sediment of a wild rice water for TEFe and TOC. Several commenters have expressed concern that the MPCA will be unable to implement the proposed revised standard because of the effort need to collect sediment and the cost of the analysis necessary to calculate the numeric sulfate standard for each of Minnesota's wild rice waters.

Analyses of the sediment of wild rice waters will be conducted as part of the permitting process for new or expanding sources and the MPCA's regular 10-year cycle of monitoring (the intensive watershed monitoring program). The MPCA's efforts to characterize wild rice waters and calculate the sulfate standard will initially focus on wild rice waters associated with existing permitted dischargers.[25] Of the 1300 proposed wild rice waters, between 1,050 and 1,100 waters are not currently impacted by a discharge. Therefore, the MPCA will begin by prioritizing 200 to 250 waters. During the existing process of preparation for each year's lake and stream monitoring, the MPCA will review how many wild rice waters are in the watershed, and the resources to collect and sample sediment. Waters to be sampled, if there are more than resources allow, will be prioritized based on factors such as the distance from dischargers, type of discharger, and timeline for permit reissuance.

The MPCA has developed required methods for sampling and analyzing sediment to calculate a numeric sulfate standard. The sediment collection methods describe the process for collecting the 25 required sediment samples composited into five samples to be analyzed, within a wild rice water. These procedures and the requirements of the analytical methods for carbon and iron are described in the document *Sampling and Analytical Methods for Wild Rice Waters*, which is being incorporated by reference in this rulemaking. The cost of sediment collection, particularly the time and effort needed to collect the samples, will likely vary according to the size and complexity of the wild rice water. However, the MPCA estimates that the total cost of conducting the sampling and analysis of a wild rice water to be approximately $1,200 per wild rice water. The MPCA bases this estimate on laboratory services conducted in 2016 for sediment samples collected by the MPCA. Cost of analysis of five samples for TOC and TEFe was approximately $100 for each of five composite samples, totaling $500 per site; the remaining amount is an estimate of labor costs.

The costs for porewater sampling and analysis to establish an alternate sulfate standard will be in a similar range. The MPCA estimates that costs for travel and field personnel for porewater sampling will also be approximately $700 per wild rice water and that the analysis of 10 porewater samples will cost approximately $350.

The costs for establishing a site-specific standard will be highly variable. In addition to the cost of sediment sampling, and possibly porewater sampling, there will be other costs unique to the situation. It is likely that more extensive sampling and analysis will be needed and additional costs will be incurred to determine the factors affecting the wild rice beneficial use in that water body.

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[25] *For new or expanded discharges, the permittee will be responsible for the cost of characterizing sediment total extractable iron and sediment total organic carbon.*

Table 11 Costs associated with calculating a sulfate standard

Type of Standard	Sampling Cost per wild rice water (estimated staff travel and sampling time)	Cost of Analysis	Total
Equation-based (sediment sampling)	$700	$500/analysis of 5 samples for TOC and TEFe	$1,200
Alternate (porewater sampling)	$700 (porewater sampling)	$350 /analysis of 10 samples)	$2,250 (Initial $1,200 in sediment sampling/analysis plus an additional $1,050 for porewater sampling/analysis)
Site-specific	Undetermined- will include costs associated with sediment sampling, porewater sampling and other site-specific determinations	-	costs as needed to characterize the wild rice water

What is the expected cost to review permit applications for discharges to a wild rice water?

Regardless of whether the MPCA adopts the proposed revisions, the MPCA must continue to conduct reviews of permit applications to discharge to wild rice waters and will incur staff costs for those reviews. The MPCA expects that the complexity of the proposed wild rice sulfate standard will increase the amount of MPCA staff time needed to review some permit applications. However, the MPCA also expects that the proposed revisions will decrease the MPCA's permit review costs to some extent by eliminating the current ambiguity associated with the characterization of the receiving waters to determine if the wild rice sulfate standard applies. Determining whether a water is a "water used for production of wild rice" has been a significant obstacle to efficiently applying the existing sulfate standard, requiring time from multiple staff to make a determination. The MPCA does not anticipate the proposed revisions will significantly increase or decrease the MPCA's current administrative costs to review permit applications.

What is the expected cost to process and administer requests for variances from the proposed revised standard?

With any water quality standard, the MPCA may incur costs related to water quality variances. A water quality variance is a temporary change in a state's water quality standard or effluent limit, allowing a particular discharger temporarily to deviate from meeting a water quality-based effluent limit. The

MPCA incurs staff costs for the review of variance requests and the activities associated with administering variances (e.g., EPA review and approval, mandated re-examination of the variance).

The MPCA expects that the adoption of a revised standard will prompt requests for a variance from the standard, although it is difficult to predict how many, when they will be received, and the degree of complexity of those requests. Although the process of implementing the adopted sulfate standard will take several years, the MPCA expects that because the proposed rules more clearly identify wild rice waters, the number of variance requests will accelerate over the next several years and will require the MPCA to apply additional resources to its variance review process. However, as discussed above, regardless of whether the MPCA adopts the proposed revisions, there will be costs to the MPCA to review and administer variances. Implementing the current standard also involves costs that will be mitigated by the adoption of the proposed rules. The MPCA already expends resources to conduct site-by-site determinations of whether waters are used for the production of wild rice and complete effluent limits reviews. The MPCA does not expect that the costs associated with increased variance reviews will exceed the costs associated with the complicated and time consuming process required to implement the current rules.

The proposed revision to Minn. R. 7053.0406 describes how both public and private dischargers may apply for a variance based on substantial and widespread economic and social impact. The proposal also provides an exemption to municipalities from the fees charged to apply for such a variance. The MPCA would normally charge a fee to any discharger for a variance review. In this case, specifically for municipalities seeking variances from the wild rice sulfate standard and associated effluent limits, the MPCA is proposing to waive the fee. This will result in a loss of revenue for the MPCA, although the MPCA does not expect it to have a significant effect on its resources for the reasons provided in Part 6.G.5.

What may be the cost of litigation after adopting the proposed revisions?

Regardless of whether the MPCA adopts the propose revisions or maintains the existing standard, the MPCA expects that litigation may result in significant costs to the MPCA for staff support and legal services. If the proposed revisions are not adopted, the MPCA expects there could be permit-by-permit challenges to whether a facility discharges to a water used for production of wild rice. Although there may be legal challenges to permits issued under the revised standard, the MPCA expects that the increased accuracy of the standard and clarity about where it applies will result in a net decrease in litigation. Because of the high degree of uncertainty about future legal challenges and the variability in the possible challenges to the proposed revisions, the MPCA does not believe it can accurately estimate those potential costs.

What will be the costs to any other state agency?

Other state agencies incur costs to comply with water quality standards if they have permitted projects or operations that need to comply with a standard. This may include operation of a facility with a discharge that must meet the revised standard or discharge to an affected municipal WWTP that incurs increased costs and recovers those costs from their customers. It may also include projects, such as road construction, that need construction stormwater permits or 401 certifications that require compliance with water quality standards.

The Minnesota Department of Transportation (MnDOT) operates highway rest areas and the MDNR operates campgrounds and fish hatcheries, all of which generate wastewater. Although the wastewater treatment systems associated with these activities are often subsurface sewage treatment systems that do not discharge, the MPCA has determined that eight MnDOT or MDNR facilities operate a WWTP that discharges to a proposed wild rice water. Determining the costs to the state agencies that operate those facilities will depend on whether:

- The discharge would need to be treated to meet an effluent limit developed based on the wild rice sulfate standard; or
- The system would need to be redesigned to either have no discharge or to discharge to a water other than a wild rice water.

The cost to a state agency in these situations will vary based on the treatment facility and receiving water characteristics and may be incurred regardless of the adoption of the proposed rules. The MPCA cannot make a reasonable estimate of possible costs without considering the site-specific factors.

It is also possible that MnDOT will conduct road construction in an area of high sulfate rock, which could result in an increase in stormwater runoff of sulfate to any nearby wild rice waters. If any additional permit conditions are required to protect those wild rice waters from elevated sulfate in runoff, MnDOT could incur project costs. Again, the variability of potential project specifics makes it impossible for the MPCA to make a reasonable estimate of possible costs.

What will be the effect on state revenue?

Water quality standards and changes to them may affect state revenue in several ways. The effects may counterbalance each other — being both positive and negative — and they are difficult to predict or quantify.

Effective water quality standards support clean water, sustainable wildlife, and many other social and economic benefits. These valuable benefits can have a positive effect on state revenue. For instance, improved water quality and wildlife habitat may increase tourism revenue as people travel to enjoy clean water and see wildlife.

The proposed revisions are more accurately protective of wild rice. In particular, the proposed equation-based standard will protect some areas where a 10 mg/L sulfate standard is not sufficiently stringent to be protective. Being more protective will increase the value provided by wild rice, which may include state revenues. This may include tourism revenue as people travel to harvest rice or participate in wildlife-based activities. It may also include sales taxes on the increased amount of marketed wild rice. Therefore, if the proposed revisions are not adopted, these will be forgone benefits to state revenue.

Adoption of the proposed rule may adversely impact industrial growth or expansion. The proposed rules will identify the location of wild rice waters and clarify where the standard applies. That degree of clarity could potentially discourage new industry from locating in areas with wild rice waters. The addition of treatment costs to meet a standard more stringent that the current standard could also prevent business investment, if an industry does not want to locate in an area where they need to shoulder some costs of sulfate treatment. If those industries choose not to locate within Minnesota, this could reduce income and subsequent state revenue from taxes. However, it is also possible that the calculated sulfate standard will require less treatment than would be required to meet the existing 10 mg/L sulfate standard. In the cases where there is not additional required treatment, the effect of the proposed revisions may be reflected in additional investment in the facility and a beneficial effect on state and local revenue.

Conversely, where the standard is more stringent than the existing standard or where the standard explicitly applies in an area, the need to design new treatment systems and to install and operate those systems could result in new income and new equipment purchases. This would increase income and sales taxes. Overall, the revised standard will have some effect on state revenues, and may potentially affect the distribution of state revenues, but it is difficult to say with certainty whether that effect will be positive or negative.

Many stakeholder discussions and comments have expressed concerns that the revised sulfate standard may have a negative economic effect on some municipalities and especially on the mining industry. Sulfate is a difficult pollutant to treat for, and any need for treatment of sulfate is likely to result in high costs. There are concerns that such high wastewater treatment costs, whether for municipal or industrial purposes, would have a negative effect on local economies in general, and could affect the state's economy. These concerns about the implications of a sulfate standard exist regardless of whether the existing 10 mg/L sulfate standard is revised. Whether the proposed revisions will alleviate or exacerbate these concerns must be determined as the standard is applied to specific water bodies and to specific dischargers under specific conditions. The CWA variance provisions, which are echoed in Minnesota's water quality standards rules and explicitly included in the revised sulfate standard, are intended to provide relief for situations where implementing a standard would cause substantial and widespread social and economic impacts.

C. Assessment of alternative methods for achieving the purpose of the proposed rules, including those that may be less costly or less intrusive

The MPCA is required to provide *"A determination of whether there are less costly methods or less intrusive methods for achieving the purpose of the proposed rule.* [Minn. Stat. § 14.131] *(3)"* and *"A description of any alternative methods for achieving the purpose of the proposed rule that were seriously considered by the agency and the reasons why they were rejected in favor of the proposed rule.* [Minn. Stat. § 14.131] (4)"

The MPCA is addressing these statutory requirements in a combined discussion because of their similarities.

The purpose of the proposed rules. Both of these statutory questions require a determination of how alternatives will *achieve the purpose of the rule.* It is therefore important to establish the purpose of the proposed revisions in order to discuss how that purpose relates to costs and then determine whether less costly alternatives could achieve that purpose. The need for, or "purpose" of, the proposed revisions is discussed in detail in Part 2 of this Statement. The purpose of water quality standards in general is to describe the goals and acceptable conditions in Minnesota's water resources. Water quality standards serve to protect waters so that they can maintain their beneficial use, whether that use is as drinking water, aquatic life, irrigation, or other purposes. The specific purpose of the proposed revisions is to identify wild rice waters and protect the wild rice beneficial use in those waters from the negative effect of elevated sulfide through controlling sulfate. The proposed revisions do this by establishing the means for determining a protective sulfate value.

However, the range of what is meant by "protect" could extend from standards so stringent that they require water quality be restored to pre-settlement conditions, to standards so lenient that they only protect wild rice from being entirely extirpated in Minnesota. The determination of whether there are less costly or less intrusive methods depends on what level of protection is the goal. Making the determination of what constitutes "protection" required the MPCA to make a number of policy decisions.

The MPCA based the proposed revisions on two fundamental decisions. The first decision determined what portion of the wild rice population the standard would protect. Would the standard protect 100% or 1% of wild rice or some level in-between? The second decision determined what constituted a wild rice water. How much wild rice must be present in a river, lake, or stream, or how must that wild rice have been used, before the water body is considered a wild rice water protected by the standard? The discussion of the general reasonableness of the proposed revisions provides extensive detail about how the MPCA made each of these decisions and the MPCA's justification for each of those decisions. To summarize those discussions, the purpose of the proposed revisions is to:

1. Establish the protective level of sulfide and the equation for relating that value to a protective level of sulfate in a wild rice water;

2. Identify waters that have an existing use as a wild rice water; and

3. Clarify how and where the standard applies.

Less costly or alternative ways to meet the purpose. For every alternative that provides a benefit to some interest, there is a negative effect on some other interest. A less protective sulfate standard may result in lower treatment costs for some dischargers, but by being less protective of wild rice, will be less beneficial or costlier for the groups who value wild rice. Similarly, there are alternatives to how the MPCA established what constitutes a wild rice water. An alternative that broadly defines all Minnesota waters as wild rice waters may be considered a benefit by some but will be deemed overly conservative by others. An alternative that applies to fewer waters may seem to leave many waters that could potentially be a source of wild rice grain to wildlife and humans with insufficient protection. Although there may be less costly or alternative ways to achieve a general goal of protecting wild rice, the MPCA believes the proposed revisions reasonably and effectively balance costs and benefits.

Analysis of alternatives considered. The entire process of developing the proposed revisions involved decisions regarding alternatives and a series of adjustments and refinement of ideas. Throughout the process, the MPCA considered a number of specific alternatives. The following discussion identifies the alternatives considered, but only provides a brief overview of the reasons the MPCA chose the alternative it is proposing. The MPCA's justification of the general reasonableness of the proposed revisions provides a more complete discussion of why the MPCA selected the proposed alternatives. In some cases, that discussion of reasonableness overlaps or supplements the more general discussion of alternatives provided in this Part.

A clear potential alternative is that of not changing Minnesota's existing sulfate standard applicable to water used for production of wild rice. In the discussion of the need for the proposed revisions, the MPCA has described the issues associated with the existing standard. The alternative of not revising the existing standard ignores the available scientific understanding of sulfate's effect and perpetuates the issues and complications of implementing the existing standard. In addition, the Legislature in 2011 specifically directed the MPCA to initiate a process to amend the existing rules related to wild rice. Therefore, the MPCA did not seriously consider this alternative.

- Alternatives considered regarding the sulfate standard. During the process of developing the proposed revisions, the MPCA received a great deal of comment and advice from stakeholders and interested parties and the MPCA considered a number of possible alternatives. The MPCA considered all the suggestions and reviewed the cited research as it developed the proposed standard. A number of commenters cited a particular research paper (the "Fort" or "Fort Environmental Laboratory" study) as evidence supporting a lesser impact of sulfate on wild rice and therefore suggested a higher sulfate standard. A discussion of the research and analysis of alternative studies and how they were interpreted as a basis for a suggested standard is provided in Chapter 1 of the TSD. A brief summary of the alternatives the MPCA considered pursuing is provided below.
    - Alternative of a narrative standard. Commenters recommended the adoption of narrative sulfate standard, or a broader narrative standard, for managing wild rice waters and implementation of the narrative standard through management plans administered by the MDNR. Although many factors influence the health of wild rice, this alternative does not reflect the current scientific understanding of the effect of sulfate and sulfide on wild rice. The MPCA also does not feel that a narrative standard can be effectively implemented through permitting or assessment. A narrative standard would not represent a significant improvement over the current standard with regard to when and where wild rice requires protection, and would create regulatory uncertainty. Additionally, a narrative standard will not meet EPA expectations that a standard be either numeric or, if narrative, that numeric translators be established to allow development of specific effluent limits.
    - Alternative of a different protective value. The MPCA received analysis from Ramboll Environ and associated comments supporting a much higher protective sulfide value than is being proposed by the MPCA, and related changes to the equation. The MPCA's review of that analysis, and its reasons for continuing to propose the sulfide value included in this rulemaking, is provided in Chapter 1 of the TSD.
    - Alternative of a fixed standard. Commenters suggested that the MPCA either retain the existing 10 mg/L sulfate standard or adopt a different numeric standard that is not an equation. The MPCA based the current sulfate standard of 10 mg/L on the best information available at the time of promulgation in 1973. It is not reasonable to ignore

current scientific information correlating wild rice viability with sulfide resulting from the interaction of sulfate with other compounds in the sediment. An equation-based standard is a more reasonable alternative than a fixed standard because it is most accurate and reflective of new scientific information. The equation-based standard, addresses the environmental variability that explains why wild rice can be observed growing in high-sulfate water. The most accurate fixed standard is still much less accurate than the proposed equation-based standard.

Analysis of the MPCA-sponsored field data offers information as to the rates of false positives and false negatives relative to the achieving the goal of keeping wild rice porewater at a protective sulfide concentration. The minimum misclassification rate for fixed standards is 32%, which occurs in the MPCA data at sulfate concentrations of 5, 10, and 26 mg/L. A standard of 5 mg/L would be over-protective in that most (74%) of the misclassifications would be false positives, requiring control where none is needed to protect wild rice. Conversely, 26 mg/L would be under-protective because most (88%) of the misclassifications would be false negatives, allowing sulfate concentrations that produce porewater sulfide above the protective level. If the goal were simply balancing rates of false positives and false negatives while minimizing the overall error rate, 10 mg/L would be the preferred fixed standard, because the rates are about equal in the MPCA data set.

- <u>Alternative of an equation other than the proposed equation</u>. The MPCA proposes to adopt an equation based on the analysis of data collected in an extensive field study. MPCA staff evaluated three different statistical tools to relate surface water sulfate to porewater sulfide: (a) structural equation modeling (SEM), (b) MLR, and (c) MBLR. As described in the TSD, (a) and (b) produced similar results but suffered from re-transformation bias, which resulted in over-prediction of sulfide at low concentrations and under-prediction at high concentrations. The MPCA used MBLR to develop the proposed equation-based standard, since it does not suffer from re-transformation bias and its accuracy (misclassification rate of 16 to 19%) is appreciably better than that of SEM (26%). The MBLR is therefore the best option for an equation-based standard.

- Alternative of adopting an interim standard to apply to wild rice waters where no equation-based sulfate value has been calculated. The MPCA considered adopting an interim standard that would apply to wild rice waters until an equation-based sulfate value was determined. Commenters identified a concern that it would take the MPCA many years to calculate a standard for the 1,300 wild rice waters identified in this rulemaking. The MPCA considered the alternatives of either:
  - Specifying that there could be no net increase in sulfate discharges until a numeric standard is established;
  - Applying the current 10 mg/L sulfate standard to all identified wild rice waters.

While the concern about the time needed to characterize 1,300 newly identified wild rice waters is valid, the MPCA intends to determine the sulfate standard according to the highest priority needs. Although many wild rice waters are proposed in this rulemaking, the highest priority for establishing a sulfate standard will be those wild rice waters that receive or may receive a discharge from a permitted facility. Relatively few (250 to 350) of the identified wild rice waters receive a discharge, and although these represent a significant number of waters, the MPCA has developed an implementation plan to address the sampling needed to calculate a numeric sulfate standard for those waters. The implementation plan is based primarily on the MPCA's intensive watershed monitoring schedule, so sediment would be collected during these routine monitoring visits. The MPCA may prioritize wild rice waters for data collection earlier based on needs for priority permit renewals. In addition, in some watersheds there may be more wild rice waters than MPCA's monitoring crews have the resources to sample. In those cases, wild rice waters will be prioritized for sediment collection based on factors such as the number of upstream dischargers, the characteristics of their discharge, and the distance to the closest discharger.

In addition, the MPCA considered the idea of requiring "no net increase" in sulfate discharges to wild rice waters until a numeric standard is determined. Ultimately, this proved to be difficult to create in rule and unnecessary. Since new or expanding sources will need to collect the data to calculate the numeric sulfate standard in order to complete permitting, there will not be new discharges without a standard being calculated.

- Alternatives considered regarding the identification of wild rice waters. The MPCA considered a number of alternatives in its efforts to establish the criteria for identifying wild rice waters.
  - Alternative to limit the identification of a wild rice water to only the area where rice beds are located. Commenters were concerned that identifying an entire river stretch or large water body as a wild rice water would not be reasonable if wild rice was only located in a small portion of the water body.

    The MPCA agrees with the concern about how to identify wild rice waters where wild rice may not be widely present, but does not agree that it is reasonable to identify wild rice waters based solely on the location of wild rice beds. A discussion of the alternatives the MPCA considered in addressing this issue is provided in Parts 3 (Scope) and 6 (General Reasonableness) of this Statement. Proposed part 7053.0406, subpart 1 addresses those situations where a discharge cannot impact the wild rice beneficial use because of where wild rice is or could be located.
  - Alternative to identify waters with either a greater or smaller amount of wild rice as wild rice waters. The MPCA received comments that its process of identifying wild rice waters was based on consideration of either too little or too much wild rice. Commenters stated that if a water body contained even a small amount of wild rice, it should be identified as a wild rice water. Other commenters questioned the waters the MPCA identified, stating that the beneficial use could only be demonstrated at higher density than was found in those waters. The MPCA considers that the process it has used to identify wild rice waters reasonably characterizes them in regard to both the

beneficial use of a Class 4D water (use of the grain as a food source by wildlife and humans), and the statutory mandate to consider the acreage and density of wild rice.

- o Alternatives for the future identification of wild rice waters. It is important to be clear that wild rice waters can only be added to Minn. R. 7050.0471 through rulemaking. However, in developing the proposed revisions, the MPCA considered a number of alternatives for defining and describing how the MPCA could address the future identification of additional wild rice waters.

  The proposed revisions require the commissioner to include consideration of information about wild rice waters in the regular triennial standards review process, which includes a public notice and comment period. The rule indicates that the commissioner will be looking for information that demonstrates that the wild rice beneficial use exists or has existing since November 28, 1975, and describes how and what types of evidence would be acceptable to make such a demonstration. Ultimately, the evidence must be sufficient to support a SONAR for a rule revision. The MPCA considered several alternatives to this process for future identification of wild rice waters, most of which required meeting some specific criteria in order for a water body to be considered a wild rice water. These included:

  - A density based on a number of stems per water body (8,000 stems/river mile or 800 stems/lake).
  - A criteria of a certain density of stems within a certain area of wild rice. A preliminary proposal was a density of eight stems per square meter over at least a quarter acre or four stems per square meter over a half acre.
  - A specific stem density without an acreage limitation (any size bed of wild rice at a density of a certain number of stems in any square meter).
  - A single stem in a water body.
  - Criteria based on observation of wild rice over several growing seasons.

  Although the MPCA considered many alternatives, it ultimately decided that a specific threshold for determining a wild rice water was too limiting, and that it would be better to evaluate adding waters based on their own unique factors as they relate to the beneficial use – as it did in identifying the 1300 wild rice waters being proposed. Since each addition to the list of wild rice waters needs to go through rulemaking, the specific factors that demonstrate the beneficial use to establish the water as a wild rice water will be considered in the SONAR and can be evaluated in that rulemaking.

- Alternatives considered regarding the application of the equation-based sulfate standard.
  - Alternative of applying the standard with averaging periods other than annual. The proposed revisions apply the sulfate standard as an annual, arithmetic average. Commenters identified a concern that allowing an annual average would not be protective of wild rice during critical growth periods and that an alternative, such as a maximum or monthly average would be more protective. The MPCA considered alternatives to an annual average. Wild rice is affected by the level of sulfide in porewater, which is a function of the level of sulfate in surface water. The MPCA's research (field and mesocosm data) supports the conclusion that porewater sulfide does not respond to short-term changes in surface water sulfate, but, rather, is a function of the long-term (at least one year) average concentration of sulfate.
  - Alternative of applying the equation-based standard as a maximum, either on a monthly or annual basis, or from April to September. The MPCA considered alternatives to applying the equation-based standard as an annual average. The proposed equation is based on a model that uses average sulfate concentrations, not maximum sulfate concentrations. Therefore, applying the standard as a maximum would shift the actual porewater sulfide concentrations to lower levels than predicted, and be more protective than necessary as presented by the MPCA in this Statement. Since the MPCA presented evidence that the porewater sulfide concentrations predicted by the equation are adequately protective, application of the standard as maximums would be unnecessarily protective, and therefore unnecessarily costly.

In addition, although the duration and frequency of a standard must be set to protect the beneficial use, it is important to be no more stringent than needed, as longer averaging times and some allowable exceedances will generally allow dischargers more operational flexibility.

  - Alternatives for sediment sampling and analytical results in the equation. The proposed rule establishes how many sediment samples must be taken and analyzed for iron and carbon and how the resulting values are used in the equation. In making these determinations, the MPCA considered:
    - How many sediment samples were needed to characterize a wild rice water;
    - Whether to composite samples; and
    - How to apply the resulting data.

    The sediment-sampling document proposed to be incorporated by reference strikes a balance between obtaining detailed information and the cost of obtaining that information. The MPCA proposes that the sediment of a wild rice water can be adequately characterized by a composite of five sediment cores from each of five different areas within the water body.

    Upon application of the equation, this information will produce five different calculated protective sulfate concentrations. The MPCA proposes to designate the lowest of the five calculated sulfate concentrations as the sulfate standard for that wild rice water. Some commenters suggested taking the average value of the five sulfate concentrations, rather than the lowest; other options included calculating the 10th or 20th percentile concentration from the data. The MPCA considered each of these alternatives and concluded that taking the lower value would be the best approach. An average a) would not be protective of the entire wild rice population and b) is vulnerable to biasing high if the analysis yields one unusually high value that then gets incorporated into calculation of the average. Using the lowest value is also easier to implement than calculating a percentile value. Therefore selecting the lowest value from the set of calculated sulfate concentrations is a reasonable method to produce a protective sulfate concentration for a wild rice water.

- Alternatives considered to the Class 4D beneficial use classification.

  Commenters suggested that the revised sulfate standard should not be a Class 4 standard.

  As discussed in Part 6.C, regarding the reasonableness of clarifying the Class 4 beneficial use class, the use of the grain of wild rice as a food for wild life and humans is already clearly established as a Class 4 beneficial use and it is neither reasonable nor desirable to change that beneficial use protection. The MPCA considered establishing a new and separate use classification only applicable to the wild rice beneficial use. The MPCA considered whether a new and separate wild rice use class (e.g. new Class 8) would be more convenient and accessible for people who were only interested in the standards applicable to wild rice and the waters identified as wild rice waters. However, the difficulty of re-establishing the same Class 4 wild rice beneficial use as a new Class 8 beneficial use outweighs the potential convenience and clarity of establishing the standard in a new use classification.

D. Probable costs of complying with the proposed rules

The MPCA is required to provide "The probable costs of complying with the proposed rule, including the portion of the total costs that will be borne by identifiable categories of affected parties, such as separate classes of governmental units, businesses, or individuals. Minn. Stat. § 14.131 (5)"

The following discussion addresses the probable costs of complying with the proposed revisions, beyond those associated with implementing current rule requirements, such as general permitting requirements, borne by entities other than the MPCA. The MPCA has limited information about the probable costs of complying with the proposed revisions, primarily because many variables affecting costs cannot be determined until the standard is revised and implemented at a specific location.

This part of the Statement provides a general overview of the expected costs of complying with the proposed rules. It is important to note that providing additional detail regarding cost estimates would not change the proposed rule revisions. Water quality standards are based on environmental science and the CWA and case law prevents consideration of cost from being a factor in establishing the magnitude of a standard. In order to be approved at the federal level, economic effects cannot be a factor in establishing or revising the standard.

However, the state Administrative Procedures Act require that the economic effect of a rule must be identified and discussed in the Statement of Need and Reasonableness, and the MPCA acknowledges the value of cost estimates to inform the implementation of the standard via permits. Given that implementing the revised standard will extend for a period of several years, there will be ample opportunity to make use of cost information, such as the pending study funded by the Legislative-Citizen Commission on Minnesota Resources.

Sulfate Chemistry and Wastewater Treatment

Most municipal WWTPs are not designed to remove sulfate from their wastewater. In order to remove sulfate, a discharger will need to upgrade or change their treatment processes. The MPCA is in the process of conducting a study to analyze alternatives for improved treatment of sulfate at municipal WWTPs and the costs of such sulfate treatment. In October 2016, the MPCA published a Request for Proposal seeking a contractor to conduct an engineering feasibility and cost analysis of technologies that might remove sulfate in a municipal WWTPs. The Legislative-Citizen Commission on Minnesota Resources funds this project, which must be complete and submitted to the MPCA by May 31, 2018. The MPCA expects the study to provide useful information for implementation efforts to augment the limited information currently available about the costs of sulfate treatment needed to comply with the existing or revised standard. However, even that study will not be sufficient to provide exact, facility-specific cost estimates.

This discussion aims to lay out the costs – or at least the variables that will impacts the costs – in as much detail as possible at this time. The discussion of treatment technologies and their associated costs is relevant to both industrial and municipal dischargers because a similar range of treatment technology and possible costs exists for both types of facilities.

If a facility needs to treat its wastewater discharge to comply with the revised water quality standard, the design, construction/installation, and operation of the treatment system would be a major cost. The chemistry of sulfate affects how wastewater can be treated to remove sulfate. The following brief overview of sulfate chemistry helps to understand the options for sulfate treatment.

Sulfur

Sulfur is a naturally occurring element and can have many oxidation states ranging from highly oxidized to highly reduced (Table 12). Sulfur is also an essential nutrient found in all living organisms (Brosnan and Brosnan, 2006).

Table 12. Sulfur oxidation states and their most common ions.

Sulfur Oxidation State	Representative Formulas	Name
+6	SO_4^{-2}	sulfate
+4	SO_3^{-2}	sulfite
+2	SO_2^{-2}	sulfone, sulfine
0	S_8	elemental sulfur
-1	S_2^{-1}	disulfide
-2	H_2S, HS^{-1}, S^{-2}	hydrogen sulfide, bisulfide, sulfide

Sulfate

Sulfate is the most oxidized state of the element sulfur. In an aerobic wastewater system where the water is oxidized, sulfate will be the most common form of sulfur. Sulfate is a doubly negatively charged ion and is commonly balanced by the major positively charged cations in water (Na, Ca, Mg, K). Sulfate has relatively high solubility with these four major ions and will not precipitate in conditions of typical wastewater chemistry. Gypsum ($CaSO_4$) has the lowest solubility of the major ions and sulfate solubility with gypsum ranges from 1200 mg/L to 2000 mg/L depending on the ionic strength, temperature, and major cation composition of the water (Tanji, 1969). Sulfate has low solubility with some cations (barium, strontium) (Collins and Davis, 1971), but these cations are not typically found dissolved in Minnesota waters in concentrations near their solubility product with sulfate. Ettringite is a calcium aluminum sulfate mineral that has a low solubility and is used as a sulfate precipitant in engineered systems, but it requires specific pH, calcium, and aluminum conditions to precipitate (Myneni et al., 1998) that do not typically exist in Minnesota waters.

Sulfide

Sulfide is the most reduced oxidation state of sulfur. Sulfide ions, when present in water, exist typically as hydrogen sulfide gas (H_2S) or other sulfide species, such as bisulfide (HS^{-1}), depending on solution pH. Hydrogen sulfide gas is the best-known form of sulfide; it is a toxic gas that can be released from water into the air when the pH of the water is less than seven. In addition to being toxic, hydrogen sulfide gas is corrosive at low concentrations.

Sulfide chemistry is governed by the overall oxidation potential of the solution. An understanding of oxidation chemistry and electron acceptors is essential for biological sulfate treatment design. Certain microorganisms can convert sulfate to sulfide under anaerobic conditions; they respire, or "breathe", sulfate the same way humans breathe oxygen, except that they exhale hydrogen sulfide instead of carbon dioxide. The function of the oxygen or sulfate in respiration is to accept electrons after energy has been stripped from them. However, sulfate is not as efficient an electron acceptor compared to oxygen or nitrate because sulfate does not have as much free energy available (Table 13) (Metcalf and Eddy, 5th edition). A community of microorganisms will only use sulfate as an electron acceptor if electron acceptors with more available energy are not present. This is why the low-oxygen environments where wild rice grow also result in sulfide production. As the free energy of the electron acceptor increases, the microbial preference for using that electron acceptor decreases; this is known as the electron acceptor ladder theory. Functionally, this leads to systems where sulfate will not be microbiologically converted to sulfide until all dissolved oxygen and nitrate have been consumed. When oxygen and nitrate are not present, the overall oxidation potential of the solution is low. For this reason, sulfate reduction to sulfide is considered an anaerobic microbiological process.

Table 13. Gibbs free energy of common microbiological electron acceptors.

Electron Acceptor	Gibbs Free Energy of Half Reaction (kJ per electron equivalent)
Nitrite NO_2^-	-93.23
Oxygen O_2	-78.14
Nitrate NO_3^-	-71.67
Sulfite SO_3^{-2}	13.60
Sulfate SO_4^{-2}	21.27

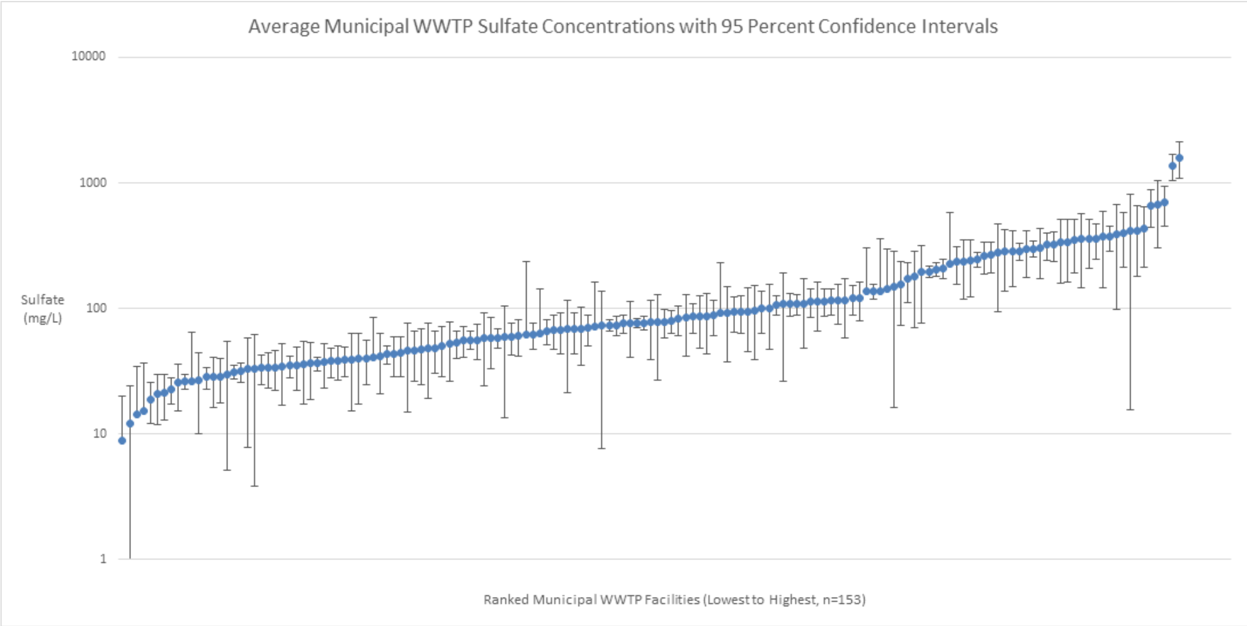
Sulfide can be oxidized to a higher oxidation state both biologically and chemically. Sulfide is oxidized chemically to sulfate in the presence of oxygen in the timescale of hours in activated sludge systems (sulfide half-life of 1 hour, Wilmot et al., 1988). Biological oxidation of sulfide is slower in activated sludge systems (sulfide half-life 11.7 hours, Wilmot et al., 1988); however, the rate of biological oxidation is much more variable and the typical final sulfur state is elemental sulfur, rather than sulfate (Nielsen et al., 2006).

Sulfide has a low solubility with most metals (Fe, Cd, Cu, Pb, Ni, Zn, Ag) and will readily form insoluble precipitates with them (EPA AVS ESB Doc, 2005). These sulfide-metal precipitates will dissolve back into water in the presence of oxygen (Nielsen et al., 2005).

Municipal Wastewater Sulfate Concentrations

Minnesota municipal WWTPs have a wide range of effluent sulfate concentrations. Currently 153 municipal facilities monitor for sulfate in their effluent and the range of average effluent sulfate concentration ranges from a minimum of 9 mg/L to a maximum of 1,600 mg/L. Figure 8 shows the average effluent sulfate concentration of the 153 municipal WWTPs ranked from lowest to highest; the error bars represent 95 percent confidence intervals surrounding the average.

Figure 8. Average municipal WWTP Sulfate concentrations



No municipal dischargers are required to monitor sulfate that comes into the treatment plant in their influent. It is reasonable to assume that, because most WWTPs are not specifically engineered to treat sulfur, and because aerobic biological wastewater processes do not remove sulfur, influent sulfur is conserved through municipal WWTPs.

The most likely sources of sulfate to wastewater are significant industrial users, naturally occurring sulfate in the source water, and residential and commercial activities that add sulfate to the source water. Human waste naturally contains sulfur compounds proportional to the amount of protein in the diet (Magee et. al., 2000). The likely sulfur load from each source for a municipal discharge would be treatment plant-specific and would require testing to verify exact sulfur loading and sulfur speciation.

Industrial Wastewater sources, volumes and sulfate concentrations

The MPCA permits nearly 520 industrial wastewater dischargers under its NPDES/SDS permitting program. The MPCA permits a variety of types of industrial wastewater discharge, including discharges from non-contact cooling water systems, ethanol producers, manufacturing facilities, food processors, paper mills, and power plants. Industrial wastewater dischargers also include sand/gravel/stone mining, peat mining, and taconite mining.

Non-Mining Industrial Wastewater

NPDES permitted discharges from non-mining industrial facilities include ethanol producers, food processors, power plants, cooling water, and manufacturing facilities. Approximately 40 non-mining industrial facilities are currently required to monitor for sulfate in their discharges. Additional facilities may also discharge some amount of sulfate but their NPDES/SDS permits do not currently require monitoring for sulfate.

Sources of sulfate in non-mining industrial facilities include reject water from reverse osmosis (RO) treatment systems, filter backwash water, process wastewater, and source water contributions. Examination of the effluent monitoring data from a subset of the non-mining industrial facilities that are required to monitor for sulfate (Table 14) shows that from 2014 to 2016, average effluent sulfate concentrations ranged from 74 mg/L to 2,446 mg/L.

Table 14. MPCA Discharge Monitoring Data-Sulfate in non-mining discharges

Non-Mining Discharges						
Facility	Type of Discharge	2014-2016 Average Flow Range (mgd)	2014-2016 Average Flow (mgd)	2014-2016 Average Sulfate Concentration Range (mg/L)	2014-2016 Average Sulfate Concentration (mg/L)	Facility Status
Facility A	Cooling tower blowdown	0.001 - 4.5	0.315	10 - 212	74	Active
Facility B	Reverse osmosis reject	0.085 - 0.166	0.141	4 - 282	156	Active
Facility C	Process wastewater & Non-contact cooling water	0.024 - 0.830	0.79	43 - 638	165	Active
Facility D	Process wastewater	1.119 - 1.346	1.29	241 - 356	299	Active
Facility E	Process wastewater	0.090 - 0.120	0.109	285 - 864	536	Active
Facility F	Utility wastewater	0.098 - 0.180	0.135	188 - 2387	624	Active
Facility G	Coal Pile Runoff	0.290 - 0.720	0.54	339 - 4710	801	Active
Facility H	Reverse osmosis reject	0.0063 - 0.160	0.03	686 - 2230	1271	Active
Facility I	Reverse osmosis Reject/Filter backwash	0.119 - 0.220	0.17	770 - 2970	2323	Active
Facility J	Wastewater treatment plant discharge	0.020 - 0.040	0.03	2070 - 2390	2446	Active

Mining Wastewater

There are three major types of mining in Minnesota - sand/gravel/stone, peat, and taconite mining. At this time, Minnesota does not have any active non-ferrous metallic mines operating in the state, though there is interest in developing such mines. The PolyMet Northmet Project is a proposed non-ferrous metallic mine; information about the expected costs for wastewater treatment to 10 mg/L sulfate, taken from the permit to mine application, is provided in Exhibit 41. Non-ferrous mines may be affected by the proposed revisions because of their potential proximity to wild rice waters and focus on ore that contains sulfide-bearing minerals.

Sand /Gravel/ Stone Mining:
Mining operations for sand, gravel, and other types of stone are found throughout the state. These products are commonly mined along river valleys. Wastewater generated at sand/gravel/stone mining operations is most commonly from mine pit dewatering or aggregate washing. Stormwater runoff is also discharged when it does not infiltrate within site boundaries. The MPCA regulates wastewater discharged from sand/gravel/stone mining operations under NPDES/SDS permits. The typical pollutants from sand/ gravel/stone mining discharges are total suspended solids and pH. Because these types of mining operations are not expected to contribute significant amounts of sulfate to the environment, the MPCA does not require monitoring for sulfate at sand/gravel/stone mining operations and will likely not prioritize these sources for future monitoring.

Peat Mining:
Peat mines are generally located in the northeastern and north central parts of Minnesota. There are several peat mines currently permitted by the MPCA under the NPDES/SDS permitting program. Wastewater is generated at peat mines when a bog area is drained to dry out the peat for harvesting. The drainage from the bog area is collected via a series of ditches and routed through a settling pond system for treatment prior to discharge.

Typical pollutants regulated in peat mine discharges are total suspended solids and pH. The MPCA's limited data indicates that peat mine discharges traditionally have not contained elevated concentrations of sulfate (i.e. sulfate concentrations are less than 10 mg/L); therefore, the MPCA has not required monitoring for sulfate for discharges from peat mining facilities. The need for future monitoring may depend on the numeric standard set for any potentially affected wild rice water.

Taconite Mining:
Minnesota is the largest producer of iron ore and taconite in the United States. Taconite is a low-grade iron ore that is mined, processed, and shipped to steel mills. Minnesota currently has eight permitted taconite mining operations in Minnesota (six active, one closed, and one under construction); all are located in northeastern Minnesota on the Mesabi Iron Range.

In taconite mining operations, several stages of crushing and grinding are required to reduce the crude ore to a fine powder. Following primary and secondary crushing, the ore is sent to ball or rod mills for further size reduction. During the crushing and grinding stages, water is added to facilitate the grinding, reduce the dust and make the ground ore easier to move within the facility. After crushing, processes such as gravity concentration, magnetic separation, and floatation are used to increase the total percentage of iron. Finally, in the last stage of ore processing, the iron ore concentrate is bound together into marble-sized pellets and fired in large kilns. During the different processing stages, the waste material, termed *fine* and *coarse* tailings, and associated slurry water are removed and pumped to a tailings basin for disposal (Berndt and Bavin, 2009).

Wastewater is generated at taconite mines through various processes such as mine pit dewatering/mine pit overflows, tailings basins (including seepage and/or controlled discharges), air pollution control equipment, and stockpile drainage. Sulfate is a parameter of concern in mining wastewater and comes from various sources, including the oxidation of sulfide minerals found in taconite ore and sulfur captured by air emission control equipment. Equipment such as wet scrubbers transfer sulfur compounds from the air emissions to the process wastewater system.

Rocks containing sulfur may be exposed at or near the earth's surface as a result of mining. When exposed to oxygen, sulfide minerals in tailings, waste rock, and mine pit walls can be oxidized to sulfate which can then be transported to surrounding watersheds in surface runoff, groundwater outflow, pit-overflow, and during pit dewatering (Bavin and Berndt, 2008). Chemical data analyzed by MDNR and documented in various MDNR studies indicates that the primary sources of sulfate at taconite facilities is from the oxidation of small amounts of iron sulfide minerals present in stockpiles, tailings, and mine pit walls (Berndt and Bavin, 2009).

Mine Pit Dewatering:

Mine pit dewatering is necessary to gain access to ore bodies to be mined. Mine pit dewatering involves collecting accumulated groundwater and runoff in sumps within the mine pit and then pumping the water to the surface for use as process water in the plant or for discharge via permitted mine pit dewatering outfalls. In most cases, there is little or no treatment of mine pit dewatering wastewater other than the settling of particulates that occurs within the sumps.

Mining dewatering operations discharge large volumes of water. Although mine pit dewatering discharges are typically permitted at large maximum flow rates, actual discharge volumes are often substantially below permitted rates, and can be zero over extended timeframes if the pit is inactive. Volumes of discharges from mine pit dewatering vary between facilities, but typical flow rates (from 2014-2015) were in the 1 - 6 million gallons per day (MGD) range. Collecting such large volumes for treatment may be impracticable, as flows from these discharges need to be equalized or reduced in some way to make treatment feasible. This is difficult due to the nature of mining – finding a suitable location is problematic as the locations of mine pits are always advancing downward and outward. In addition, the nature of the constituents involved and the degree of treatment that may be required for some, such as sulfate, may necessitate advanced forms of treatment (such as membrane technologies) further complicating the technical feasibility.

The quality of mine pit dewatering water depends on the amount of settling that occurs before discharge and the composition of the rock being mined. Average concentrations of sulfate found in mine pit dewatering discharges from permitted facilities ranged from 51 mg/L to 1,190 mg/L in 2014-2015. The volumes of mine pit dewatering water discharged vary and depended on the depth at which ore is being mined (i.e., groundwater hydrology) and the amount of precipitation and runoff into the mine pit. The primary source of sulfate in the mine pit dewatering discharges is oxidation of sulfide minerals from waste rock stockpiles within the watershed of the mine pit and from the exposed rock of the mine pit walls (Berndt and Bavin, 2009).

Tailings Basins

Tailings basins are large engineered structures used for holding waste tailings and water from the crushing/concentrating operations at taconite mining plants. Tailings basin sizes in Minnesota range from a few hundred acres to approximately 9,000 acres. Tailings generated during the different ore processing stages are removed from the processing circuit and routed to the tailings basin via slurry. Slurry water derives from a variety of sources including: return water, makeup water, crude ore feed, fluxstone moisture, and indurator combustion (Bavin and Berndt, 2008). Tailings basins may also receive the collected scrubber water from air pollution control systems. After settling in the tailings basin, most of the water is pumped back to the processing facility for reuse.

Water leaves the tailings basin as surface seepage through the dikes of the basin, as deep seepage to groundwater, or through controlled point source discharges.

Water leaving tailings basins, whether controlled or via seepage, is regulated under NPDES/SDS permits. Volumes of water ultimately leaving the basins varies and depends on precipitation, the design of the basin, and the volume of water being reused in the processing plant. Average flows from tailings basin discharges from 2014-2015 ranged from 0.015 to 9.0 MGD.

Some mines have reduced the volume of seepage leaving the tailings basins by installing seepage collection systems to collect surface seepage. The seepage collection systems collect surface seepage from various points around the tailings basin and pump it back into the basin. The practicality and effectiveness of collecting and returning surface seepage to the basin can be limited by the design, construction, depth to bedrock, and perimeter length of the tailings basin dams through which the surface seepage occurs. Collecting and returning surface seepage may contribute to increased sulfate concentrations within the tailings basin ponds.

The practicality of collecting large volumes of seepage for treatment is questionable. Seepage points have a high degree of seasonal and operational variability and are often in remote locations. Flows from these discharges may need to be equalized or reduced to make treatment feasible. In some cases, flows could potentially be collected via the permitted controlled discharge points for treatment. However, issues of cost and access may limit treatment options.

Sulfate content in tailings basins varies depending on the mineralogy of the ore being mined, the oxidation and dissolution of the minerals comprising the waste tailings, the type of air pollution control equipment used in processing, sources of make-up water, and other factors. Water that is recirculated from the tailings basin for reuse in plant operations can increase concentrations of sulfate in tailings basin water. Sulfate concentrations may also be due to collection of scrubber water (described in the next paragraph) as well as oxidation of iron sulfide minerals contained in the tailings material (Berndt and Bavin, 2009). Over time, continued tailings oxidation and extensive reuse of basin water in the ore processing circuit can significantly increase the concentration of sulfate in the basin water.

Air Pollution Controls

Air pollution control equipment known as wet scrubbers are typically in place at taconite plants to help remove sulfur compounds and other pollutants from smoke stack exhaust that are generated from the burning of coal or other fuels at the plant. Sulfur dioxide removed by the wet scrubbers is oxidized to sulfate and removed from the scrubber system via blow down of a portion of the scrubber water to the tailings basin system. Sulfate concentrations in the tailings basin water can increase over time due to recycling of water from the tailings basin back to the processing plant and scrubbers. Increased scrubber efficiency can also result in an increased sulfate concentration in taconite process water (Engesser, 2006).

Waste Rock Stockpile Drainage

Waste rock stockpiles are large engineered piles of the overburden or waste rock material that is removed to access the taconite ore. These waste rock stockpiles can be located outside or adjacent to the mine pit or they can be located within the mine pit in areas that have already been mined out. Waste rock stockpiles may either be reclaimed (that is, contoured and revegetated) or left as-is depending on where they are located and when they were developed. Stockpile seepage is often routed to mine pits to be discharged in conjunction with mine pit dewatering water. Minnesota's reclamation rules for ferrous mining have historically focused reclamation efforts on the physical stability, revegetation and erosion control aspects of stockpile construction and reclamation. The rules have been less prescriptive on aspects related to stockpile drainage water quality, such as with respect to sulfate concentrations. (Stockpiles constructed prior to 1980 are not subject to these ferrous reclamation rules).

Sulfate can be generated within waste rock stockpiles by the oxidation of sulfide minerals contained in the waste material. A portion of the precipitation falling on the stockpile infiltrates through the waste material, picking up and transporting the generated sulfate as it moves through. In addition, some waste rock stockpiles, particularly those developed before modern reclamation laws, may be located in former wetland areas or other areas of ground water flow that can contribute to the leaching of the waste rock material. Stockpile drainage that is generated by water percolating through or underneath stockpiles can consequently have elevated concentrations of sulfate and other constituents. This stockpile drainage often flows to or is routed into permitted mine pit dewatering locations and is managed through permitted NPDES discharge points.

Capping of stockpiles to reduce the ability of water to come in contact with the rock has occurred at some closed sites. The potential to re-route surface waters to preclude contact with stockpiles has also been studied. Large volumes of capping material such as soil, clay, or membranes are needed to effectively cap stockpiles and can be expensive to install due to cost of membrane materials or costs associated with excavation and transport of soils/clays. In limited cases, small treatment systems have been installed at the toe of certain stockpiles at closed mine sites to address metals issues, but have had limited success for the treatment of sulfate. Passive treatment options such as wetlands or permeable reactive barriers are preferred at closed sites, but have not yet proven successful at effectively removing sulfate under full-scale conditions in Minnesota.

Stockpiles in active mining operations are managed better today than they were in the past, either by isolating waste rock with potential reactive sulfide mineral concentrations or by improved reclamation of the stockpile. Isolating the waste rock or conducting reclamation activities reduces the amount of water percolating through the waste rock thereby reducing the loading of sulfate and other constituents to mining discharges.

Mining Status

Taconite mines may be either actively operating, closed, or in idle status. Although no longer generating new waste rock material or tailings, closed mines may still be a source of sulfate-containing wastewater from the remaining stockpiles or tailings basins on site; these continue to be managed by the MPCA and

DNR through reclamation and NPDES/SDS permits. Although closed mines can have active permits with active discharges, the actual permitting and management of these can be complicated. Treatment and management options are often limited due to the closed status including factors such as remoteness/lack of electrical power, unavailability of large-scale mining equipment, long-term reclamation goals that may be in conflict with short-term needs, and the potential lack of financial resources.

A number of mining companies periodically shut-down or idle their operations so that day-to-day operations are minimal. A shut-down or idled mine will usually continue to have tailings basin discharges and may continue to have discharges of wastewater from active mine pit dewatering to maintain water levels. These discharges are still subject to NPDES/SDS permits.

Mining Wastewater Discharge Volumes and Concentrations of Sulfate

Volumes of wastewater generated at taconite mining operations vary greatly depending on the site. Data submitted on discharge monitoring reports were reviewed for average flow volumes and concentrations of sulfate in the discharge. Table 15 summarizes that review.

Table 15. Discharge Monitoring Report data from taconite mining.

Taconite Mines						
Facility	Type of Discharge (mine pit dewatering, tailings basin discharge, stockpile discharge)	2014-2016 Average Flow Range (MGD)	2014-2016 Average Flow (MGD)	2014-2016 Average Sulfate Concentration Range (mg/L)	2014-2016 Average Sulfate Concentration (mg/L)	Facility Status
Facility A	Mine Pit Dewatering	1.1 - 19.8	4.1	83 - 132	111	Idle
Facility B	Mine Pit Dewatering	5.3 - 6.0	5.5	111 - 134	121	Closed
Facility C	Mine Pit Dewatering	2.7 - 7.2	6.3	70 - 213	127	Active
Facility D	Mine Pit Dewatering	0.01 - 2.2	1.0	51 - 596	371	Active
Facility E	Mine Pit Dewatering	0.260 - 3.10	0.770	652 - 1190	1006	Closed
Facility F	Stockpile Seepage	0.07 - 0.370	0.170	823 - 1670	1229	Closed
Facility G	Tailings Basin Discharge	8.5 - 9.2	8.8	49 - 83	66	Active
Facility H	Tailings Basin Discharge	0.015 - 0.380	0.163	96 - 239	151	Closed

Sulfate concentrations range from 49 mg/L to 1,670 mg/L in the permitted mine pit dewatering, waste rock stockpile drainage, and tailings basin discharges. The volume of discharges varies depending on the type of discharge and range from 10,000 gallons per day to almost 20 MGD.

Assessment of Treatment Plant Design, Risk Tolerance and Uncertainty

In order to minimize full-scale treatment plant uncertainty and risk, engineers use bench and pilot testing. Bench and pilot testing are procedures that verify the conceptual theories of a how a treatment system might work and allow for full-scale design. The testing regimes used in bench or pilot testing can range from very simple to extremely complex. Bench and pilot tests are always designed to discover necessary information for full-scale treatment plant design.

When designing a conventional wastewater treatment system to remove standard wastewater parameters of concern, bench and pilot testing are frequently not needed. This is because there is a wide body of design information that engineers can easily find and use. When a technology is new, there is no body of knowledge to draw upon and testing of that new technology is required for full-scale design as a way to mitigate risk.

Bench testing is performed before pilot testing and employs very controlled and idealized experimental conditions to verify the relevant theoretical treatment processes. Pilot scale testing builds on the information discovered during bench testing to verify long-term resiliency of the treatment regime and ascertain unforeseen operational logistics. A pilot test is typically a miniature version of the full-scale treatment plant and is run for periods up to a year. The long-term operational data gathered during pilot testing is a necessity for full-scale design.

It is difficult to say exactly how much bench or pilot testing is required for any given project. This is because the testing regimes are specific to a given project and frequently iterative. For example, it is very common to stop a pilot test to go back and ascertain data that could only be discovered through additional bench testing, and then resume pilot testing.

As a general rule, if bench and pilot testing are required it would add well over a year to the full-scale plant design time and hundreds of thousands of dollars to the design costs.

Sulfate Wastewater Treatment

Treatment to remove sulfate from wastewater has historically been associated with the management of wastewater from mining and acid rock drainage, which may also contain elevated heavy metal concentrations. There is an abundance of literature that highlights the treatment unit operations and examines full-scale treatment systems used to remove sulfate and heavy metals from mine drainage around the world (Johnson and Hallberg, 2005; Bowell, 2004; INAP, 2003).

Sulfate is not a parameter that is conventionally targeted for removal in municipal wastewater treatment. The most complete reference on municipal wastewater treatment, (Metcalf and Eddy, 5th edition) describes no treatment processes specifically intended to remove sulfate from a discharge. Metcalf and Eddy consider sulfur treatment in the context of managing the formation of toxic and corrosive sulfides during anaerobic digestion and in wastewater collection systems. Accumulation of hydrogen sulfide gas, which has a strong rotten-egg odor, can also create a public nuisance for those living or working nearby. As a general rule, municipal wastewater engineers design municipal treatment systems to minimize and control the formation of hydrogen sulfide gas, not to treat sulfate.

The design of a treatment system to remove sulfate is based on the chemistry of sulfate. Broadly, the methods to remove sulfate from a discharge can be categorized as biological, chemical, or physical. A summary of these categories and their advantages and disadvantages related to wastewater treatment is provided below.

Biological Treatment

Sulfate is considered a conservative substance across aerated biological systems. Sulfate is not removed to any significant degree when oxygen is present. This means that activated sludge, oxidation ditches, trickling filters, and stabilization pond systems would not remove sulfate from a waste stream.

There are engineered biological sulfate treatment systems that exploit the chemistry of sulfide to remove sulfur. These systems work by first biologically converting sulfate to sulfide and then precipitating the sulfide by introducing a metal, typically iron. The solid metal-sulfide species is then physically removed from the treatment system, removing sulfur mass from the waste stream (Neculita and Zagury, 2007).

Conversion to sulfide, followed by metal-sulfide precipitation, is capable of removing sulfate to relatively low concentrations (< 200 mg/L sulfate; INAP 2003) but suffers from several significant drawbacks identified below:

- The conditions to biologically reduce sulfate to sulfide must be consistently maintained. Careful consideration of available energy sources, microbiological sensitivity to winter temperatures, biological waste byproducts, and bacterial population dynamics is required. Consistently operating a successful anaerobic treatment system is complex and beyond the resources of many small municipal wastewater systems.
- The biological reduction of sulfate to sulfide must be decoupled spatially from the precipitation of the metal sulfides (Johnson and Hallberg, 2005; INAP 2003). A separate unit operation would be required downstream of biological treatment to precipitate metal sulfides and remove them from the waste stream. There is no standard way to design this system and any design would need to carefully evaluate methods to ensure the metal-sulfides do not form back into hydrogen sulfide gas in order to protect operator health and ensure treatment goals.
- Biological systems could require significant land area for their unit operations and sludge storage. Biological conversion of sulfate to sulfide occurs relatively slowly, especially at low temperatures. The slow rate of biological sulfate conversion could necessitate relatively large volumes of biological reactors compared to other biological processes (Johnson and Hallberg, 2005).

Biological sulfate conversion to sulfide coupled with metal-sulfide precipitation is theoretically possible but would require significant, high-level engineering design and pilot testing to ensure consistent sulfate removal and to protect operator health from toxic sulfides. Biological treatment is not currently a viable sulfate treatment strategy for municipal wastewater plants because the technology has not been verified to work at full scale. Assigning a cost to biological treatment is not a worthwhile exercise because the treatment technology has not been verified to work at full scale.

Chemical Treatment

Sulfate precipitation with common cations suffers from a high aqueous solubility with the common cations found in water. Gypsum (calcium sulfate, $CaSO_4$) precipitation will only remove sulfate down to approximately 1,200 mg/L sulfate. In industrial mining applications, gypsum precipitation can be very useful in removing very high concentrations of sulfate down to this level. If the sulfate treatment goal is below 1,200 mg/L, gypsum precipitation alone is not an appropriate treatment method.

Barium and strontium salts can be used to remove sulfate to low concentrations but this treatment has several significant disadvantages. The first is cost; barium and strontium are expensive and not readily available on the industrial scale that would be required. Barium sulfate precipitates can be recycled and reused but this is an expensive technology and impractical for small-scale WWTPs. Additionally, barium and strontium are metals with known human and aquatic life toxicity.

Ettringite has also been used in engineered treatment systems to remove sulfate to low levels. Ettringite is a mineral that, when added to a wastewater, can produce high-quality low-sulfate waters but requires significant process control to maintain the correct pH, calcium, and aluminum concentrations. The ettringite sludge produced has been known to form a cement-like consistency that often fouls clarifiers used to settle the ettringite precipitate. Additionally, treatment steps would be required to re-adjust the chemistry of the water back to neutral to be suitable for discharge.

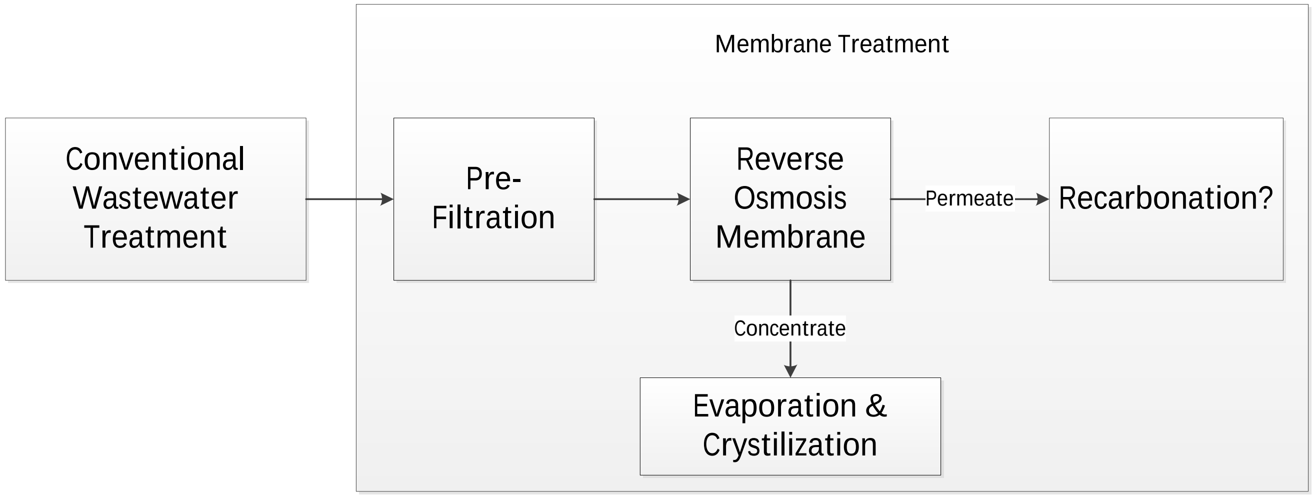
Sulfate can also be removed using ion exchange resins. These ion exchange resins can produce high-quality effluents that are low in sulfate but their drawback is cost and regeneration of the resin. Strong acids and bases are required to regenerate the resins and a municipality would have to find a way to dispose of the regenerant solution while complying with their permit limits. The proprietary sulfate ion exchange resins currently available are adapted for industrial applications and in municipal applications would require pre-filters to remove organic material that would foul the resin media.

Chemical treatment of sulfate is theoretically possible but comes with several significant drawbacks including cost, sludge disposal, and the need for significant high level engineering design and pilot testing to ensure consistent sulfate removal. Chemical treatment is not currently a viable sulfate treatment strategy for municipal wastewater plants because the technology has not been verified to work. Assigning a cost to chemical treatment is not a worthwhile exercise because the treatment technology has not been verified to work.

Physical Treatment

Physical treatment involves using membranes to remove sulfate from the effluent; the most commonly known membrane treatment process is RO. Membrane treatment would be a “polishing” set of unit operations that would need to be added at the end of the conventional wastewater treatment process. A schematic of a possible membrane sulfate treatment is provided in Figure 9.

Figure 9 Simplified conceptual treatment chain for sulfate treatment



Membrane treatment works by forcing the water through a porous membrane that excludes dissolved minerals (including sulfate) but allows water molecules to pass through. The water that passes through the membrane is called "permeate" and is low in dissolved minerals and sulfate. The water that does not pass through the membrane is called the concentrate and contains all of the dissolved minerals that did not pass through the membrane. In a typical RO membrane, 80% of the water that enters a membrane passes through as permeate and the remaining 20% ends up as concentrate.

Electrodialysis is another membrane treatment process that uses electrical potential to separate salts across a membrane. It is used in niche water treatment applications and is typically used to treat brackish waters. Electrodialysis is not an appropriate technology for municipal wastewater treatment because less complicated and more commercially available RO membranes can achieve similar treatment goals.

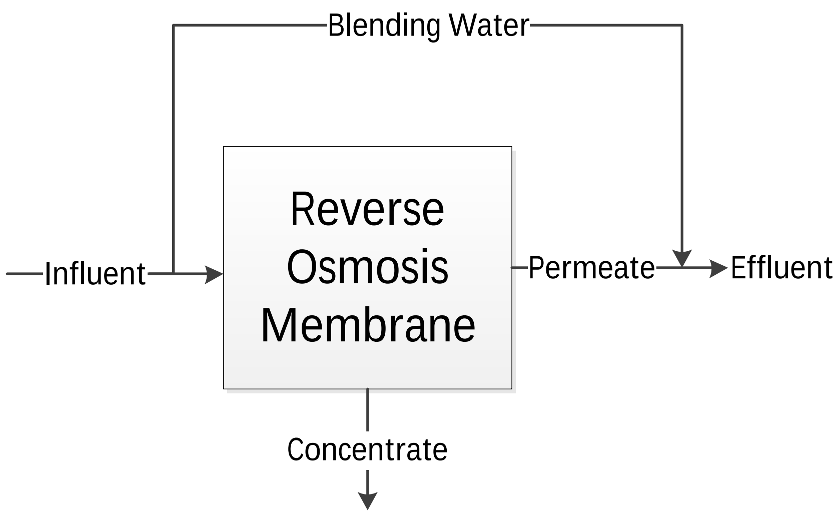
Water treatment membranes come in many grades. RO is one of the finest grades of membrane and has pore sizes that exclude greater than 99% of all dissolved minerals. The pores in RO membranes are so small that they foul readily, degrading the function and life of the membrane. In order for an RO membrane to function consistently, it must have a "pre-filter" upstream that removes large particles, colloids and dissolved solids as necessary in order to prevent excessive fouling.

The exact nature of the pre-filtration that would be required to protect the RO membrane would have to be determined on a case-by-case basis. A personal communication with a staff person in the membrane treatment department of General Electric (Dan Winkler, personal communication on July 28, 2015) indicates that membrane bioreactors have been successfully used in Texas as pre-filters before a RO system at wastewater plants. A nanofiltration membrane upstream of the RO membrane is another conceivable pre-filter. A complication associated with this process is that many WWTPs in Minnesota treat very hard water (> 180 mg/L as $CaCO_3$). In those cases, a pre-filter might also need to be designed to prevent hardness fouling of the RO membrane.

Concentrate management is another significant concern when designing an RO membrane system. The MPCA has found that discharging RO concentrate directly to a surface water cannot be permitted because the concentrate is too "salty" to pass whole effluent toxicity tests. Because of this discharge constraint, the only option for managing the brine is evaporation and crystallization. Evaporation and crystallization is the unit operation of boiling off water in the concentrate and leaving the dissolved salts behind to crystalize. The crystalized salt must be trucked to a landfill for disposal. Evaporation and crystallization is a costly and energy-intensive concentrate management strategy.

Permeate toxicity is another concern when designing a RO membrane system for discharge to a surface water. The permeate of a RO membrane is very pure water that is low in dissolved solids and pH. This permeate is corrosive to metal piping and is unlikely to pass a whole effluent toxicity test. In most RO designs for drinking water, permeate toxicity and corrosiveness are managed by treating a fraction of the design flow using RO and then mixing the permeate with blending water that has been short circuited, meaning it is diverted before going through the RO membrane (Figure 10). The mixed in blending water increases the dissolved mineral concentration of the permeate and buffers the effluent pH back to neutral so that the water can be safely discharged within permit limits. A drinking water RO plant will typically divert 20% or more of the flow.

Figure 10. Schematic of the concept of blending RO permeate with diverted influent water to produce an effluent that could be discharged to a surface water.



Diversion of blending water is an inexpensive and effective permeate management strategy when the effluent sulfate limits are relatively high. If effluent sulfate limits are low, then blending is no longer an effective strategy because the blending process would add excessive sulfate to the effluent. This concept is illustrated in Table 16. When influent sulfate concentrations are high and target water quality concentrations are low, a very high percent removal of sulfate is required. Under this circumstance, blending of the permeate is not possible because any blending would elevate sulfate concentrations above the target effluent limit.

In the circumstance where blending is not possible (>90% target sulfate removal), the entire permeate flow would have to be re-carbonated. Re-carbonation is the process of adding minerals, typically lime or calcium carbonate, to the permeate to buffer the pH to neutral and allow the permeate to pass a whole effluent toxicity test. There are no standard design protocols for re-carbonation unit operations. A design engineer would need to perform careful bench and pilot testing to develop operational protocols that would ensure permit limits are always met in a full-scale treatment plant.

Table 16. Percent removal of sulfate required based on a range of target sulfate effluent limits and influent sulfate concentrations.

	Influent SO_4 (mg/L)			
Target SO_4 Effluent Limit (mg/L)	25	100	300	500
1	97%	99%	99%	99%
10	69%	92%	97%	98%
25	22%	80%	94%	96 %
50		61%	87%	92%
100		22%	74%	84%
200			48%	69%
500				22%

Note: A blank indicates that no treatment would be required. The percent removal calculation considers effluent variability and assumes that in order to reliably meet the target limit, the treatment plant must average an effluent sulfate concentration below the limit.

Physical treatment using RO to remove sulfate is the most practicable sulfate treatment technology currently available. However, there are significant design uncertainties that make it difficult to estimate costs and reliability. A design engineer would need to perform extensive site-specific analysis and engineering testing in order to get the correct design parameters to design and cost a full-scale plant capable of removing sulfate and meeting all potential permit limits. The next section discusses a range of estimated treatment costs based on assumptions about the influent quality and a range of sulfate treatment goals.

Sulfate Treatment Conclusions

Physical treatment of sulfate using a RO polishing process is the most practicable treatment alternative for municipal dischargers. It is possible to link conceptual treatment unit operations together to meet sulfate treatment goals.

The overall conclusion of this analysis is that the linked physical treatment processes used to remove sulfate are non-standard and would require significant site-specific analysis and engineering testing. Bench or pilot testing of the relevant unit operations would be necessary to obtain design parameters and determine other implementation concerns. In general, if bench and pilot testing were required it would add well over a year to the full-scale plant design time and hundreds of thousands of dollars to the design costs.

The knowledge to design a full-scale municipal wastewater plant with sulfate treatment in Minnesota does not currently exist and would have to be developed before a full-scale treatment plant could be constructed. Having said this, the bench and pilot testing required for municipal sulfate treatment is not an insurmountable obstacle. For example, every wastewater treatment technology that is now considered “standard” was at one point, either bench or pilot tested before installation in a full-scale system. However, it takes time, money, effort, and scientific rigor to design bench and pilot tests to obtain design parameters necessary for full-scale treatment plant design.

Because of the range of potential treatment goals and influent water quality, there is no one-size-fits-all strategy for sulfate treatment.

Cost of treatment

Treatment for sulfate removal can be extremely expensive. As discussed above, there are few options for sulfate removal, with RO/membrane filtration being the most reliable method for effectively removing sulfate from wastewater discharges.

Estimating exact costs for RO treatment of sulfate is not possible without detailed design information. The treatment plant design constraints are still very open ended and the questions below would need to be answered.

- What kind of pre-filter should be used before the RO membrane?
- How would the potential range of water quality standards and influent sulfate concentrations be accounted for?
- Is it possible to use a nanofiltration membrane instead of RO to selectively remove sulfate but not the smaller monovalent ions?
- How should costs for re-carbonation be estimated, if re-carbonation is even needed at all?
- How should the evaporator/crystallizer sludge transport and disposal costs be estimated?
- Are there potential cost savings in terms of running the RO concentrate through another membrane to reduce concentrate disposal costs?
- How do capital and operations costs scale from large to small treatment systems?

There are significant uncertainties to answering any of the questions above. One certainty, though, is that the answers would require a combination of site-specific engineering analysis and bench and pilot testing.

Cost estimates of membrane treatment with evaporation and crystallization are discussed below. The source of the information is from Appendix C of the “Engineering Cost Analysis of Current and Recently Adopted, Proposed, and Anticipated Changes to Water Quality Standards and Rules for Municipal Stormwater and Wastewater Systems in Minnesota” report by Barr Engineering. (Exhibit 42) The Barr report goes into greater cost detail than this analysis; topics such as membrane cleaning schedules, building cost assumptions, and membrane permeate fluxes are addressed in the report.

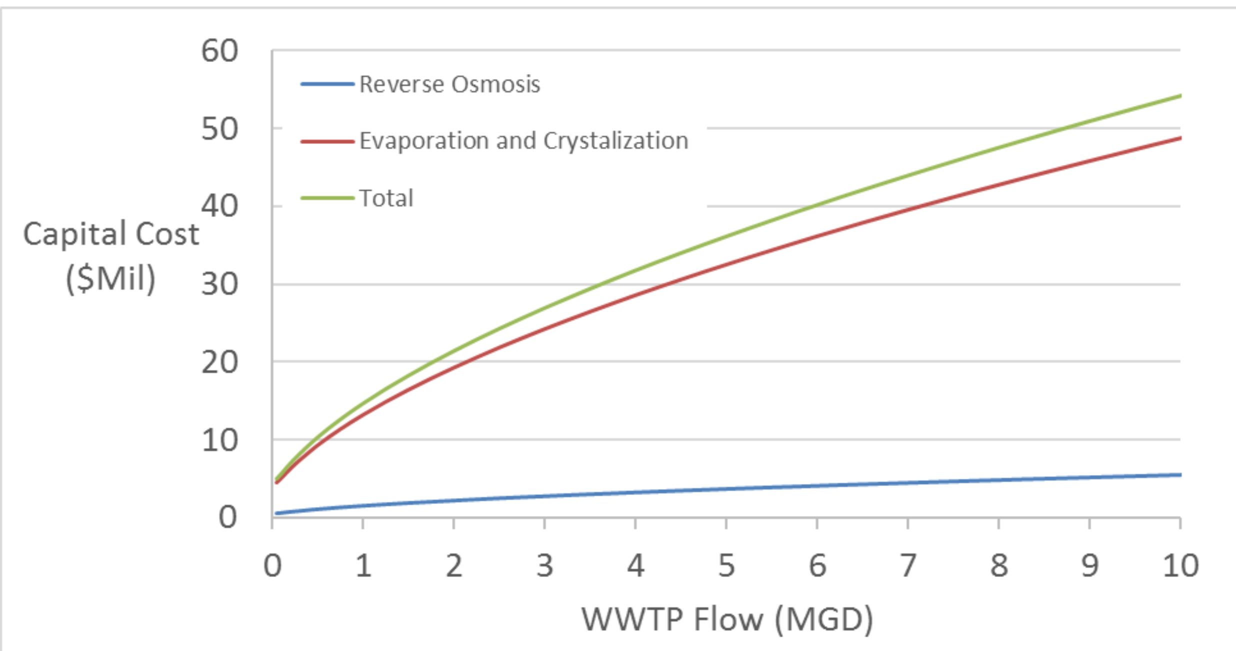
The MPCA submitted a proposal to the Legislative Citizen Commission on Minnesota Resources (LCCMR) to receive funds to hire a consultant to produce a report investigating the engineering feasibility and cost analysis for municipal wastewater treatment of sulfate. The contracting process selected a co-proposal from Bolton and Menk and Barr Engineering and they are in the process of completing the project. The final due date of the project is May 2018. The MPCA does not expect that the final results of this work to substantially change the proposed implementation of the new standard.

Capital costs

Treating municipal wastewater water using RO followed by evaporation and crystallization is likely to have high capital costs. The capital costs in this section represent sulfate-polishing costs above the cost of a conventional WWTP. The capital costs of additional conventional wastewater treatment, re-carbonation system, etc., are not included.

Figure 11 shows the general trend of the costs provided by Barr Engineering (Exhibits 42 and 43). The figure assumes RO membrane treatment followed by evaporation and crystallization of the RO concentrate. The costs assume that 100% of the wastewater flow will be treated and a membrane water rejection rate of 25%. The capital costs of the evaporator and crystallizer are the major driver of total cost.

Figure 11. Cost Trends



Operations and Maintenance Costs

Treating municipal wastewater water using RO followed by evaporation and crystallization is likely to have high operation and maintenance costs. The primary driver of operation and maintenance costs is concentrate management. Energy and disposal costs are the primary drivers of concentrate management operations and maintenance costs. RO is an energy intensive process but evaporation with crystallization is much more so. Table 17 shows the likely energy costs of continuous operation of a 1

MGD RO and evaporation with crystallization system at a market rate of $0.08 per kW-hr. For a RO with evaporation and crystallization system, upwards of 50% of the total operations and maintenance costs are energy costs.

Table 17. Operation and maintenance costs for RO polishing treatment train

		Power Usage per MGD	Annual Energy Cost per MGD of WWTP Flow
RO		145 kW	$101,000
Evaporation and Crystallization		9600 kW	$1,700,000

Disposal costs are another driver of costs. The crystalized salts must be disposed of at a landfill and the tipping and hauling fees will add cost. The disposal costs will depend on the quantity of dissolved solids in the water, the distance to the nearest landfill, and disposal costs. The Barr report analyzed tipping and hauling costs associated with evaporation and crystallization for several Minnesota cities and found that five to ten percent of operations and maintenance costs were associated with disposal fees. More detailed explanation of disposal costs can be found in the Barr report (Exhibit 42).

Membrane Treatment Secondary Costs and Externalities

Membrane treatment with evaporation and crystallization also has significant secondary costs such as high-energy requirements leading to high carbon emissions, advanced operator training requirements and an increased need for operator labor hours. The combination of these secondary considerations could prove prohibitively burdensome for affected communities.

An evaporator with crystallization has a high-energy demand. If the extra energy associated with evaporation and crystallization comes from the burning of fossil fuels, it would also worsen the carbon footprint of the facility and possibility require upgrading the power plant to a larger power capacity.

When evaporators and crystalizers are operated in conjunction with a RO plant, 4-8 additional labor hours per 8-hour shift are normally required. Brine concentrators require laboratory support similar to RO plants, where it is advantageous to have operators perform basic lab analysis. (Mickley, 2006) The highest classification of wastewater operator would be required for these technologies; Minnesota currently suffers from a lack of qualified wastewater operators. Attracting, retaining and funding qualified wastewater operators would be a significant hurdle for municipal wastewater plants.

Costs Specific to Taconite Mine Dischargers

Mining-influenced waters that contain sulfate often have much higher concentrations of dissolved solids and lower concentrations of residual organics when compared to treated municipal wastewater effluent. These differences affect sulfate removal using membrane separation or other potential sulfate removal technologies. The treatment of taconite mine wastewater will vary depending on the volume, concentration, level of treatment, and process used. A mining company provided an estimate of some of the costs associated with mining wastewater treatment (Table 18) as part of a variance request received in 2012 (Exhibit 44). The reported costs are based on achieving the existing wild rice sulfate standard of 10 mg/L.

Table 18 does not provide a full examination of the potential flow rates to be treated, the potentially achievable discharge limits or the extent to which pretreatment technologies may be required. Estimating the cost of these items is important when considering costs specific to taconite mine dischargers but it is impossible for the MPCA to estimate these items with a high degree of certainty. Every taconite mine in Minnesota is unique and thus has unique sulfate management challenges. It is very likely that the combination of waste management technologies would differ substantially from one taconite discharger to another. Table 18 provides valuable information that could be used to better understand the potential costs for sulfate treatment of mining- influenced waters, but additional information not currently available to the MPCA would be needed to estimate costs with a higher degree of certainty. The costs for RO with evaporation and crystallization from Exhibits 42-43, discussed in the municipal treatment section above, are also relevant to taconite dischargers.

Table 18. Effectiveness, Implementation, and Cost Information for Potential Treatment Technologies for Sulfate-2012 Data – Facility Variance Request

		Estimated Costs [6,7]		
Alternative	**Effectiveness in Meeting WQS**	**Capital Cost**	**Annual O & M Cost**	**Net Present Value[5]**
Source Isolation[2,3]	U	$10,400,000	$71,000	$10,900,000
Natural Attenuation[2]	X	$170,000	$105,000	$1,700,000
Enhanced Natural Attenuation[2]	U	$890,000	$480,000	$7,300,000
Permeable Reactive Barrier[2]	U	$35,800,000	$98,000	$37,200,000
Floating Wetland[2]	U	$12,400,000	$720,000	$23,300,000
Surface Flow Wetland/Lagoon[2,4]	U	$3,500,000	$120,000	$5,100,000
Ion Exchange (modified Sulf-IX)[2]	U	$16,300,000	$1,400,000	$26,200,000
Membrane Treatment (Nanofiltration)[1,8]	U	$9,700,000	$1,000,000	$23,900,000
Membrane Treatment (RO)[1,9]	L	$20,700,000	$2,800,000	$62,500,000

Key:
L = Likely to be effective in meeting water quality standard (WQS) at end of pipe
U = Ability to meet WQS uncertain/requires additional testing to demonstrate
X = Unable to meet WQS at end of pipe

Notes:

1. *Cost for this option includes treatment to Class 3 & 4 WQS. Does not specifically include treatment of sulfate to 10 mg/L.*
2. *Cost for this option includes treatment to Class 3 & 4 WQS. Does include treatment of sulfate to 10 mg/L, however, treatment of sulfate to 10 mg/L is unproven.*
3. *Capital cost provided is for an 85-acre geosynthetic clay liner-type cover. Actual cost depends on size and type of cover to be implemented (e.g. capital costs for a 85-acre soil cover are estimated at $3,400,000, while capital costs for a 190-acre geomembrane type cover may be $32,000,000.*
4. *Not intended to be operated as a stand-alone process. The wetland/lagoon would be coupled with the floating wetland for removal of sulfate. Cost presented is the added cost of this process.*
5. *20 years, 3.5%*

6. *These cost estimates are considered conceptual level costs or Class 5 estimates (according to the Association for the Advancement of Cost Engineering International), and should only be used for comparing the relative value of the technologies evaluated in this Plan. The typical associated level of accuracy of Class 5 cost estimates is ±25 to 100%.*
7. *Costs may vary from those presented in previously submitted Plans, due to additional information obtained during interim periods.*
8. *Nanofiltration may be capable of achieving compliance for Class 3 & 4 WQS, but not capable of reducing sulfate concentrations to 10 mg/L.*
9. *This cost estimate includes treatment of sulfate to 10 mg/L.*

Costs not associated with treatment

Cost of preparing a permit application

The proposed rule revisions will not expand the applicability of the permit requirements; entities that are not currently required to obtain a permit, or that are currently exempted from permit requirements, will not be affected by the proposed rules. The proposed rule revisions will clarify where the wild rice sulfate standard applies, however. The identification of wild rice waters in the rule will expand the number of permittees that are currently required to address sulfate in their discharge, which for those discharges will likely increase the cost of preparing a permit application and the fees associated with the review of the application.

When a municipality or industrial discharger applies to the MPCA for a permit, the permit application must include extensive information to characterize the design and operation of the facility and the wastewater treatment process. Developing the level of information needed for a permit application will require significant investment. Although many of these costs will be incurred in preparing any permit applicant and cannot be attributed solely to the proposed revisions, the complexity of treating sulfate to meet the revised standard or to apply for a variance will likely increase costs beyond what is currently required to prepare and submit a permit application.

Costs of developing the numeric standard

Some of the costs that can be determined at this time are the costs of taking samples to characterize the sediment to apply the equation and the costs of collecting porewater and analyzing it for sulfide to implement the alternate standard.

As noted above, in the section on costs to the MPCA, the rule contains required methods for sampling and analyzing sediment in order to calculate a numeric sulfate standard. The MPCA anticipates that applicants for a permit to operate a new or expanding source with a sulfate discharge that may impact one or more wild rice waters will need to do this sampling and analysis. The MPCA will complete the sampling and analysis for existing WWTP. The cost of sediment collection, particularly the time and effort needed to collect the samples, will likely vary according the size and complexity of the wild rice water. However, MPCA estimates the cost of conducting the sampling and analysis of a wild rice water to be approximately $1,200 per body of wild rice water.

The rule also includes a proposed alternate standard, which requires the collection of porewater and analyzing it for sulfide. Collection of porewater in a manner so that sulfide is not oxidized, and is comparable to MPCA data, requires adherence to a specific procedure, but the cost will be similar to the cost of sediment sampling and analysis. The MPCA estimates that the cost of sample collection will be approximately $700 per site and porewater analytical costs will be about $35 per sample (the method requires analysis of ten samples). The cost to conduct porewater sampling and analysis for a wild rice wateris estimated to be approximately $1,000. This cost is in addition to the cost for the initial sediment sampling.

Fees for a permit or variance application

Minn. R. 7002.0210 to 7002.0435 (Water Permit Fees) establish fees for water permit applications. The permit fee is based on a point system multiplied by a biennially adjusted factor. The rules assign points based on the complexity of the activity for which a permit is sought. For example, a request to modify an existing permit that does not require new construction would be assessed a fee equivalent of eight points ($2,480).[26] However, a major permit modification involving construction and an increase in the design flow of more than 50 MGD would be assessed a fee equivalent of 40 points ($12,400).

Where the proposed rule revisions result in a more stringent sulfate discharge limit and the WWTP must be upgraded to provide the necessary level of wastewater treatment, the MPCA expects there will be a corresponding increase in permit fees. Permit fees are based on the size of the facility and the complexity of the design of the treatment process.

The MPCA expects that many permittees will request a variance from the sulfate standards until the cost of treatment becomes economically feasible. Minn. R. 7002.0253, subpart 2, item D currently establishes the cost of a variance request at 35 points ($10,850), to account for the time MPCA must spend to review and approve or deny the variance requests. The proposed rule would waive the variance application fee for municipal dischargers because the MPCA will be developing variance application materials to make both the application and review process less labor intensive. See Part 6.I of this Statement for further discussion. Due to their more individualized nature and the greater review time needed, industrial users would still be charged a fee. Variances must also be sent to EPA for approval or denial.

Options to Mitigate Costs

Public Facilities Authority/State Revolving Fund for municipal wastewater treatment plants

Minnesota recognizes the importance of working with permittees to reach the goal of meeting the water quality standards and ensuring the protection of Minnesota's waters, particularly municipal-owned wastewater treatment facilities providing a public service. To that end, Minnesota has developed grant and low-interest loan programs for meeting municipal infrastructure needs. However, the wastewater treatment options available to municipalities that discharge to a wild rice water are so limited that the available financing programs may not be viable. Many of the funding programs provide money for secondary treatment of wastewater but there are currently no secondary treatment processes that remove sulfate from wastewater. RO is a proven technology for removing sulfate, but many factors, including the cost, operating complexity, and technological limitations, essentially exclude

[26] *Based on 2016 biennial fee computation.*

it from practical consideration for municipal wastewater treatment at this time. The only feasible design option for a municipality that discharges to a wild rice water may be to change the discharge point to a receiving water that is not a wild rice water. This type of design solution may be eligible for funding under certain of the MPCA's funding programs, although each program has specific conditions and limitations. The re-routing of a wastewater discharge might not qualify for a particular program or, if eligible, the amount of funding may not be sufficient to cover the expense of such a project. The public funding options available to mitigate municipal costs will vary depending on the proposed design solution and the program from which funding is sought.

The following state programs may be available to municipal dischargers to mitigate the cost of activities necessary to comply with the proposed sulfate standard.

- The Clean Water Revolving Fund (CWRF) is a federal-state matching program available to local units of government for both point source and nonpoint source construction projects. Low interest loans are awarded through this program depending on the state's Project Priority List score. (The process for developing the Project Priority list is described in Minn. R. 7077.0117-7077.0119.)
- Grant sources available for construction projects include the Wastewater Infrastructure Fund, which supplements the CWRF to provide gap financing for high project costs. The Small Cities Development Grant Program is available for cities with populations less than 50,000. It has a maximum award of $600,000 and addresses needs principally affecting low to moderate income households in a community. The Point Source Implementation Grant program is available to communities of all sizes. Currently, it has a grant maximum of 50% of project costs, up to a maximum of $3 million, although it is possible that those maximums could be increased in the future.

Additional information and details about the options available to municipalities is available at https://www.pca.state.mn.us/sites/default/files/wq-wwtp2-42.pdf

Variances

The MPCA expects that some negative economic effects can be mitigated on a facility-specific basis, at least temporarily, by a variance from the water quality standard, although a one-time fee is required as described above. State and federal regulations allow for consideration of economic impact in the granting of variances, and the MPCA expects that many dischargers will seek relief from the standard through the variance process.

Although economic considerations cannot be a factor in the establishment of a water quality standard, economic considerations are a very significant factor in how the MPCA implements a standard in a specific permit. The CWA, and state rules, allow the MPCA to consider economics in the granting of a variance from a standard or effluent limit. When considering options to mitigate costs, a variance is a viable option for dischargers, depending on their economic circumstances. The MPCA can also grant a variance where there is no technologically feasible treatment option.

E. Probable costs or consequences of not adopting the proposed rules

The MPCA is required to provide a discussion of "*the probable costs or consequences of not adopting the proposed rule, including those costs or consequences borne by identifiable categories of affected parties, such as separate classes of government units, businesses, or individuals*."
Minn. Stat. § 14.131 (6)

There is an existing standard to protect wild rice from the impacts of sulfate, providing some limitations to the costs or consequences of not adopting the proposed rules, assuming that the existing standard would remain in effect. The consequences of not adopting the proposed rule depend on:

- Issues related to implementing the existing standard;
- Whether the proposed revisions to establish an equation-based standard and alternate standard result in a more protective standard or limit based on the specific conditions; and
- The perspective of the affected person regarding the validity of either the proposed revisions to the standard or the existing standard.

<u>Issues relating to implementing the existing standard.</u>

The goals of the proposed revisions are to provide clarity in application of the sulfate standard to protect wild rice and to incorporate the latest scientific understanding. The need for the proposed revisions is discussed in Part 2 of this Statement. Briefly, there are two problems with the existing standard that would not be resolved if the proposed revisions are not adopted.

The first problem is the difficulty of determining how the standard applies and defining the waters to which the existing standard applies. As noted previously, the existing standard has no clear information about duration and frequency and implementing the current standard requires a detailed case-by-case analysis to determine whether the wild rice beneficial use exists or has existed in a specific water body.

Not adopting the proposed revisions will result in continued uncertainty and the attendant need for case-by-case interpretation. Permittees will need to conduct studies to inform a case-by-case evaluation of whether or not a water used for production of wild rice is present downstream of their discharge, and, if so, permittees and the MPCA will need to conduct an evaluation of whether a sulfate limit and sulfate treatment are needed to protect the wild rice. The consequence of not adopting the proposed revisions will be to perpetuate the confusion involved in applying the standard, which will in turn affect the MPCA's ability to issue permits effectively. That uncertainty will result in delays in the permit process and increased costs of permit design and review for both the MPCA and permit applicants. The costs associated with this uncertainty and need for further study will be eliminated or reduced if the proposed revisions are adopted.

The second problem is the existing numeric sulfate standard's lack of accuracy in protecting the wild rice beneficial use. The MPCA's current understanding of the site-specific dynamics of sulfate toxicity shows that the existing standard may be, depending on the circumstances, either over-protective or under-protective. An equation-based approach is more accurate, meaning that the standard is more likely provide the necessary protection for wild rice and less likely to require expensive treatment to reduce sulfate when that is not needed to protect rice. Retaining the existing standard will result in higher misclassification rates, while the equation-based approach is more likely to match the requirements to what is necessary to support the environmental goal of protecting wild rice. Not adopting the proposed rule will prevent more accurate (and therefore effective and cost-efficient) protection of wild rice and implementation of sulfate treatment.

Consequences based on the effect of the proposed revisions.

The consequences of not adopting the proposed revisions depend primarily on the result of the application of the proposed equation-based standard. Because any wild rice water identified in Minn. R. 7050.0471 would have been identified as being subject to the sulfate standardunder a case-by-case application of the existing standard, this discussion focuses on the change to the numeric standard. As described above, the existing 10 mg/L numeric standard is sometimes too protective and sometimes not protective enough. Ultimately, this means that the equation-based standard will result in an individual water body having a calculated sulfate standard that is either more than 10 or less than 10 mg/L. Because of this variability, not adopting the proposed revisions may have a positive consequence for certain classes of affected parties and a negative cost or consequences for others.

For example, when the proposed revisions are adopted, a discharger may be subject to additional permit conditions and increased costs if the equation results in a calculated numeric sulfate standard that is more stringent than the existing standard. Conversely, if the equation results in a calculated numeric sulfate standard that is less stringent than the existing standard, and the existing standard has not yet resulted in a permit limit met by that facility, the adoption of the equation-based approach will result in decreased costs.[27]

Consequences based on perception of the effectiveness of either the existing standard or the proposed revisions.

An additional complication in explaining the consequence of not adopting the proposed revisions is the divergence of opinion about the effect of maintaining the status quo (i.e. the current 10 mg/L sulfate standard applicable to "water used for production of wild rice during periods when the rice may be susceptible to damage from high sulfate levels"). There is a range of opinions among the public, tribes and the regulated community about the consequences of not adopting the proposed revisions and thereby maintaining the status quo of the existing standard. There are also concerns, as noted in the Part 9 of this Statement (Environmental Justice), about the populations that have borne costs or received benefits up to this point – with limited implementation of the existing standard and a sense by many that wild rice waters have been lost over the years.

Those opinions, and therefore each person's perception of the consequences of not adopting the proposed revisions, vary depending on a person's attitude toward the protectiveness of the existing

[27] *Because of CWA anti-backsliding provisions, limits cannot be removed once they are placed in a permit, even if the standard is subsequently revised, except under the conditions set forth in 33 U.S.C. § 1342(o). If a previously applicable permit limit has not become effective (as under a schedule of compliance) or it the treatment facilities did not achieve the previous effluent limitations, it may be possible to change the limit. However, most Minnesota sources do not yet have sulfate limits and therefore, the antibacksliding provisions will not apply.*

standard and the protectiveness of the proposed revision to an equation-based standard. The divergence of stakeholder views means that there will be a wide range of perceived costs and benefits to stakeholders. For those who prefer the existing 10 mg/L, believing it to be more protective of wild rice, there are positive benefits to not adopting the equation-based standard. For those who prefer the equation, there are negative consequences to not adopting the proposed equation-based standard.

Economic assessment of the benefit of a standard that is specifically protective of wild rice.

The cost of not adopting the proposed revisions is the loss of the benefits that would be realized by the adoption of the proposed revisions. In general terms, the benefit of implementing a standard comes from the preservation or improvement of the beneficial use that the standard is meant to protect – the benefits that accrue to society from having the ability to use a water body for activities such as fishing, swimming or boating, irrigation, drinking water, or other uses. There may also be societal benefits that relate not to the use of the water, but just to the knowledge that the water exists, is clean, and supports a population of aquatic life or other uses.

In this case, the proposed revisions do not establish a new beneficial use or new protections; instead, they refine the existing standard for the protection of wild rice from the impacts of sulfate. Because the existing standard provides some level of protection, it is difficult to quantify a specific level of benefits that might result from the proposed rules.

It must also be noted, as further explained below, that much of the analysis of benefits resulting from environmental improvements is necessarily qualitative. When a proposed rule requires implementation of pollution treatment technology, that cost is relatively easy to quantify – treatment technology is a marketed good that has a price tag. The public goods that accrue from environmental improvements do not have a price tag. Some benefits, such as human health benefits or the benefits of more tourism, can be quantified using various techniques. However, some experts question the efficacy of these techniques and the usefulness of deriving a dollar figure purported to measure how much the public values something they do not purchase – like the existence of clean water, wild rice, or thriving waterfowl. Further complicating the situation for this rulemaking is the centrality of wild rice to the cultural heritage of the Ojibwe and Dakota people; the value of wild rice in this context is inestimable.

This analysis attempts to delineate, if not fully quantify, the benefit of the proposed rule. Taking into account the complexities described above the benefits are not directly comparable to the costs. One should not be subtracted from the other to determine if this regulation is “worth it”. Instead, each should be reviewed.

The main benefit will be to water bodies with wild rice that are impacted by sulfate-containing discharges, specifically where the existing 10 mg/L sulfate standard is not sufficiently protective and the equation-based standard results in a more stringent sulfate level that is expected to keep sulfide below the harmful level and be more protective of the wild rice. Because of the difficultly in determining the specific benefits of the change from the existing standard to an equation-based standard, this analysis speaks generally to the benefits of wild rice protection.

According to EPA's *Guidelines for Preparing Economic Analyses* (2014), "The aim of an economic benefits analysis is to estimate the benefits, in monetary terms, of proposed policy changes in order to inform decision making."

The process of analyzing and quantifying the benefits for any environmental policy, rule or standard entails multiple steps:

1. Estimating the change in physical quantities of pollutants (in this case, sulfates) as a result of the rule (relative to the baseline of conditions before implementation of the rule);
2. Estimating the change in physical effects (in this case the impacts on wild rice habitat, productivity, etc.) as a result of the change(s) in pollutant amounts (again, relative to the baseline);
3. Determining the benefits that people value and care about that will likely be affected as a result of the change in physical effect;
4. Estimating the changes in the provision of these benefits (relative to the baseline); and
5. Estimating the value of these changes in benefits (ideally in monetary terms) to all affected individuals. The total benefit is the sum of all individual amounts for each type of benefit that is affected by the new rule and is the sum of benefit amounts for all individuals affected by the new rule.

In an ideal world, a regulatory agency could methodically undertake each of these steps to estimate the expected benefits of any environmental policy. This allows for a direct comparison to the estimated costs of implementing the change. However, time and budgets are always limited. Moreover, each of the above steps can be fraught with complexity and uncertainty, and in many cases, a lack of adequate data, methods, and models to produce confident estimates. In assessing the benefits of the proposed revision to the sulfate standard to protect wild rice, this is certainly the case for each of the steps above.

As a result, much of this benefits assessment will necessarily be qualitative with the intention of pointing out the likely benefits of the revisions and a ballpark estimation of the economic value of these benefits rather than precise quantifications of benefits and their economic values. It is also important to note that in the case of this proposed rulemaking, the analysis is further complicated by the existence of a standard that is proposed to be replaced, rather than being the proposed adoption of a new standard or policy.

Defining and Characterizing Benefits

Step 1: Estimating the change in quantities of sulfate

Because the proposed revision is an equation-based standard that results in a calculated numeric standard specific to each wild rice water, it is not feasible to determine a clear and comprehensive picture of the change in sulfate concentrations across all Minnesota wild rice waters as a result of the proposed revisions. In some water bodies, the calculated numeric sulfate standard will allow for higher sulfate concentrations relative to the current standard of 10 mg/L. In other water bodies, the standard will require sulfate levels below the current 10 mg/L standard and consequent reductions to get to that level. This is because other site-specific factors (sediment TEFe and TOC) that modulate the effects of sulfate on wild rice viability must be taken into account. Collecting the data and calculating the numeric sulfate standard will be a long-term process; the MPCA does not yet know how many water bodies will have sulfate standards either more or less restrictive than the current standard.

Step 2: Estimating the change in wild rice protection

The purpose of the wild rice sulfate standard is to protect the use of the wild rice grain as a food for wildlife and humans. Thus, the proposed revisions will protect wild rice productivity. As discussed for Step 1, collecting the data and calculating the numeric sulfate standard will be a long-term process and quantifying the change in wild rice protection is not possible based on the data and models available. The sediment TEFe and TOC have not yet been measured in most wild rice waters to allow calculation of the numeric standard and subsequent comparison to current sulfate levels in the water to determine the extent to which the wild rice beneficial use is currently supported. The nature of wild rice growth means that it is not simply present or absent in a water; wild rice may be present at high densities and over large areas or may be only sparse and scattered. The extent and density of wild rice stands varies in response to many factors, such as weather, habitat, water clarity, invasive species, etc. Because different waters and different conditions produce different quantities of wild rice, it is difficult to quantify at a specific time whether wild rice in a particular water is improving or declining.

Step 3: Determining the benefits that people care about and how they will be affected by this standard

This step entails translating the changes in beneficial use (as determined in Step 2) to changes in ecosystem services. Ecosystem services are essentially all the goods and services produced by ecosystems that people value, whether they are marketable commodities or services that are not bought or sold in any market (Daily, 1997). Thus, the ecosystem services provided by wild rice waters are equivalent to the benefits. There are several types of benefits provided by wild rice waters, which are both directly and indirectly related to the beneficial use of harvest and use of wild rice as a food source for wildlife and humans, including:

- **Provisioning benefits**. Wild rice is a food source with sustenance and economic benefits from its harvest.
- **Regulating benefits**. Wild rice habitat can help control erosion and provide some flood control and climate stabilization by storing carbon.
- **Supporting benefits**. Wild rice has ecological importance, with both migrating and resident wildlife using it as a food source. It provides a habitat and feeding grounds for a variety of waterfowl, migratory birds, fish, and mammals.
- **Cultural benefits**. Wild rice, the official state grain of Minnesota, is culturally and spiritually important to the state and to tribes. It provides both aesthetic benefits and opportunities for recreation and tourism in the areas where it grows, as well as spiritual value to many of the communities, particularly tribal communities. (Millennium Ecosystem Assessment, 2005)

The existence of a sulfate standard provides protection of the wild rice beneficial use. Relative to the current standard, the revised sulfate standard will result in protection of that beneficial use that is more accurate and effective. As stated above, the extent of effective protection is difficult to quantify. However, relative to the current standard, the revised standard will result in an equal number of affected wild rice waters and an improved level of protection of potential harvestable wild rice over time so that all the benefits of wild rice (and the value of those benefits) will increase.

Steps 4 and 5: Estimating the changes in the provision of these benefits and economic valuation of the changes

The added amount of each of these benefits that the revised standard will provide (relative to the current standard) is difficult to quantify.

Moreover, for several of these benefits, monetary valuation is challenging and fraught with uncertainty. For example, non-use values, such as the appreciation of nature, regional biodiversity and the cultural and spiritual values of communities that have traditionally harvested wild rice, are challenging to value in monetary terms. These challenges include uncertainty about several factors including knowledge gaps on species-ecosystem linkages, how exogenous factors such as climate change will affect these linkages, non-homogeneity of individual preferences/perceptions for cultural values, differing perceptions on present and future benefits and so on. These challenges are also associated with lively debates on whether these benefits should be valued at all.

Many stakeholders from the fields of conservation biology and anthropology may believe that values associated with nature or culture are 'infinite' or 'priceless' and trying to put a price on them is not meaningful and may undermine their real worth (McCauley, 2006, Snyder et al., 2003). Opponents to this view, mainly ecological economists, point out that not putting a price on such values effectively results in undervaluation or lack of valuation leading to overuse and degradation over time (Daily et al., 2000). While there is truth on both sides, it is likely that any monetary valuation, if possible, would probably be an under-estimate owing to knowledge gaps noted above, while serving as a benchmark for starting to value non-consumptive benefits. An interdisciplinary perspective and incorporation of related research findings from natural sciences and economics will better inform decision-making on preservation of natural and cultural resources and their non-use values (Polasky, 2008)

It is not feasible to conduct original valuation research to assess the monetary benefits of this specific proposal. This is a very common situation in many studies on the economic valuation of environmental resources. In such cases where budgetary and time constraints make performing original research infeasible, it is common to utilize "benefits transfer," or the application of values estimated in previous studies to new policy cases.

Therefore, this discussion does not attempt to place a total economic value on the benefits of the revised standard. Rather, it describes some of the benefits, who receives them, and how approximate values of some of these benefits in monetary terms have been estimated through benefits transfer or similar approaches. The MPCA does not intend this to be a complete and comprehensive tally of the economic benefits of this proposal, but rather a sketch of these values to give a rough sense of their magnitude.

Provisioning Benefits

According to the recently published "The Value of Nature's Benefits in the St. Louis River Watershed" (Fletcher and Christin, 2015) an estimated 4,000 to 5,000 people (both tribal and non-tribal) hand harvest wild rice annually with an average annual harvest of 430 pounds per individual (Exhibit 21

MDNR, 2008). Although cultivated wild rice is the majority of total production in Minnesota, hand harvested natural wild rice remains a vital component of tribal and local economies and is an important source of subsistence for tribal communities.

In 2007, the Leech Lake Band of Ojibwe, one of the primary wild rice harvesters in Minnesota, sold nearly 300,000 pounds of wild rice (Exhibit 21 MDNR, 2008). At $1.50 per pound, this harvest generated more than $400,000 of income for tribal members.

Some wild rice processors or finishers may also offer short-term seasonal employment for finishing wild rice.

Wild rice may be purchased from harvesters at a price of $1.50 per pound or similar, but is sold direct to general purchasers at higher prices. Prices for Nett Lake Wild Rice ranged from $6.75/lb for broken rice to $12.95/lb. for hand-picked regular parched rice to $19.95/lb. for hand-picked and hand-parched rice.[28] A call to the Leech Lake fisheries office indicated that wild rice sells for $8/lb.[29]

According to the MDNR, wild rice is a substantial food crop worth at least $2 million to the state's economy each year; and 5% of production is valued at approximately $100,000. Therefore, every 5% of wild rice production protected would maintain an estimated $100,000 benefit per year; in wild rice waters impacted by elevated sulfate levels, restoration to achieve the proposed revised standard would add an estimated $100,000 per year to state revenues for every 5% increase in wild rice production (Exhibit 21 MDNR, 2008).

Regulating Benefits

Neither the quantification nor economic valuation of non-market regulating benefits provided by the wild rice beneficial use can be estimated due to the lack of knowledge of changes in the extent of that beneficial use over time. However, it is important to realize that erosion control, flood mitigation, and climate stabilization are also likely benefits of protecting wild rice.

Supporting Benefits

A study on wild rice in Minnesota by the MDNR noted the ecological importance of wild rice in supporting a variety of wildlife including invertebrates, amphibians, both small and large fish species, waterfowl, migratory birds and mammals, which use wild rice seeds, waters, and the plants themselves for foraging, nesting, and reproduction. The MDNR 2008 report states, "It is one of the most important foods for waterfowl in North America. More than 17 species of wildlife listed in the MDNR's Comprehensive Wildlife Conservation Strategy as "species of greatest conservation need" use wild rice lakes as habitat for reproduction or foraging." The quantification and economic valuation of non-market supporting benefits provided by the wild rice beneficial use, including feeding grounds for several bird and fish species that people care about as well as general support for biodiversity, is also not feasible for this proposal. However, even if these benefits cannot be adequately quantified and valued in response to this proposal, it is important to acknowledge their existence.

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[28] *Prices for Nett Lake Wild Rice, retrieved from online store http://www.nettlakewildrice.com/home.php?cat=1 on April 7, 2017*

[29] *Called 218-335-7426 as indicated on https://www.llwildrice.com/; call made April 7, 2017.*

Cultural Benefits

These are some of the most significant (and often the most debated) benefits of the wild rice beneficial use in Minnesota. It is worth further subdividing this category into recreation and tourism on one side and the cultural and spiritual importance of wild rice on the other. Recreation and tourism are more tangible in that they contribute to both market-based benefits (for example: hunting, fishing, revenues to hotels, vacation rentals and recreation outfitters), and non-market benefits (for example: biodiversity conservation, wildlife watching, scenic beauty of wilderness, sense of place). There are various ways to estimate economic value of these benefits, but the majority are non-market valuation methods such as willingness-to-pay surveys and travel cost methods. Willingness-to-pay surveys, a subset of more general contingent valuation methods, ask a subset of beneficiaries (i.e., those that participate in the travel and recreation activities) to state how much they are willing to pay for that benefit. The results of this survey can then be extrapolated to estimate the value for the entire population of users. This method has been used extensively throughout the country. An example in Minnesota was an extensive report to value the benefits of the St. Louis River watershed in the northeastern part of the state (Fletcher and Christin, 2015). Travel cost methods have also been used extensively to value the benefits of travel and recreation provided by ecosystems. This method is based on the idea that the willingness to pay for recreation is reflected in the costs involved in traveling to their locations. The opportunity cost of travel time as well as the direct costs of travel (gasoline, airfare, etc.) are included in this estimation.

The cultural and spiritual importance of wild rice and wild rice habitat are clearly not marketable benefits and can be the hardest benefits provided by ecosystems to translate into monetary terms. In particular, the Dakota and Ojibwe people have cultural and spiritual ties to wild rice. Many stakeholders might say that the existence of wild rice has infinite value, which is to say that it is not possible to put a price tag on these aspects of nature. Nevertheless, the most direct approach that has been used to translate aesthetic, cultural and spiritual values into monetary terms have been willingness-to-pay surveys, including in the St. Louis River watershed. (Fletcher and Christin, 2015) However, willingness-to-pay surveys are certain to underestimate cultural and spiritual values because of constraints on stakeholders' ability to pay (that is, their income) and the lack of substitutes for spiritual resources.

F. Assessment of differences between the proposed rules and corresponding federal requirements and rules in states bordering Minnesota and states within EPA Region V.

Minn. Stat. § 14.131, together with Minn. Stat. § 116.07, subd. 2 (f), requires an assessment of differences between the proposed amendments and corresponding federal requirements, similar standards in states bordering Minnesota, and states within EPA Region 5.

14.131 (7) *an assessment of any differences between the proposed rule and existing federal regulations and a specific analysis of the need for and reasonableness of each difference;*

116.07, subd. 2 (f) *In any rulemaking proceeding under chapter 14 to adopt standards for air quality, solid waste, or hazardous waste under this chapter, or standards for water quality under chapter 115, the statement of need and reasonableness must include:*

(1) an assessment of any differences between the proposed rule and:

(i) existing federal standards adopted under the Clean Air Act, United States Code, title 42, section 7412(b)(2); the Clean Water Act, United States Code, title 33, sections 1312(a) and 1313(c)(4); and the Resource Conservation and Recovery Act, United States Code, title 42, section 6921(b)(1);

(ii) similar standards in states bordering Minnesota; and

(iii) similar standards in states within the Environmental Protection Agency Region 5; and

(2) a specific analysis of the need and reasonableness of each difference.

The water standards program, as established by the CWA, is based on the premise that States develop specific standards based on federal guidelines and criteria, and that the state standards will vary depending on state-specific conditions and needs. There is no federal counterpart to the equation-based sulfate standard or the process for identifying wild rice waters; therefore, an assessment of whether the proposed revisions are more or less stringent is not possible. The MPCA maintains that the proposed revisions are consistent with the intent of the CWA as well as reasonable interpretations of federal guidance, and meet the federal expectation that states develop state-specific water quality standards.

No other state has established a beneficial use class for wild rice or established a sulfate standard applicable to wild rice. Two Minnesota tribes have established water quality standards for wild rice.

The water quality standards for the Grand Portage Band of the Minnesota Chippewa Tribe are found at https://www.epa.gov/wqs-tech/water-quality-standards-regulations-grand-portage-band-minnesota-chippewa-tribe. (Exhibit 45) The Grand Portage standards:

- Define wild rice areas as "a stream, river, lake or impoundment, or portion thereof, presently has or historically had the potential to sustain the growth of wild rice (also knowns as *Zizania palustris* or manoomin)";
- Establish a numeric standard that "sulfates must not exceed 10 mg/L in wild rice habitats";
- Identify specific waters according to a cultural designated use of wild rice; and
- Establish a narrative standard that "waters capable of supporting wild rice will be of sufficient quantity and quality as to permit the propagation and maintenance of a healthy 'wild rice' ecosystem in addition to the associated aquatic life and their habitats."

The water quality standards for the Fond du Lac Tribe are found at https://www.epa.gov/wqs-tech/water-quality-standards-regulations-fond-du-lac-band-minnesota-chippewa-tribe (Exhibit 46). The Fond du Lac standards:

- Define wild rice areas as "a stream, reach, lake or impoundment, or portion thereof, presently, historically or that has the potential to sustain the growth of wild rice";
- Establish a numeric standard that "any lake or stream which supports wild rice growth shall not exceed instantaneous maximum sulfate levels of 10 mg/L";
- Identify specific waters according to a cultural designated use of wild rice; and

- Designate five of the most productive wild rice waters as "outstanding reservation resource waters", providing them Tier 3 antidegradation protection.

The state's current wild rice sulfate standard and the proposed revisions to the wild rice sulfate standard differ from the tribal standards as follows:

- The proposed revisions will retain and clarify the existing beneficial use to "the use of the grain of wild rice as a food source for wildlife and humans." The existing wild rice beneficial use is different from the tribal cultural use designation of wild rice waters.
- The existing state standards apply to "water used for production of wild rice" and the proposed revisions apply the standard to identified wild rice waters based on supporting the beneficial use. The tribal standards apply the standards to waters on the basis of "past, present, or future potential to sustain growth or be vegetated with wild rice" (Fond du Lac) or "presently, historically or with the potential to sustain the growth of wild rice" (Grand Portage), both broader designations.
- The existing state rules apply the sulfate standard "during periods when the rice may be susceptible damage by high sulfate levels" and the proposed revisions will apply the sulfate standard as an annual average that can be exceeded once in ten years. The Grand Portage tribal standards do not specify when the standard applies and the Fond du Lac tribal standards specify that the sulfate standard as an instantaneous maximum limit.
- The proposed revisions to the state sulfate standard establish the protective sulfate value through an equation rather than as a fixed 10 mg/L standard as established in both tribal standards.

G. Assessment of cumulative effect

Minn. Stat. § 14.131 (8) requires the MPCA to provide: *An assessment of the cumulative effect of the rule with other federal and state regulations related to the specific purpose of the rule.*

Minn. Stat. § 14.131 defines "cumulative effect" as *"the impact that results from incremental impact of the proposed rule in addition to the other rules, regardless of what state or federal agency has adopted the other rules. Cumulative effects can result from individually minor but collectively significant rules adopted over a period of time."*

The assessment of the cumulative effect must be based on a comparison of the proposed rules with other federal and state regulations "related to the specific purposes of the rule." It is important to consider the specific purpose of the rule before determining the cumulative effect. In section C of this part, the MPCA has provided a discussion of the alternatives considered that would achieve "the purpose of the proposed revisions." That discussion of the purpose of the rules is relevant to the question of the cumulative effect of the proposal.

The purpose of the water quality standards in general is to protect beneficial uses. As standards are modified, based on new scientific information, the associated wastewater treatment requirements are also affected. Water quality standards originally only required simple treatment to remove solids, then they required wastewater treatment to eliminate pathogens. Over the past several decades, facilities have been required to address other pollutants by installing certain treatment technology to meet technology-based effluent limits and now states are requiring facilities to meet water-quality based effluent limits (WQBELs).

In the context of the wild rice standard, it is important to remember that the existing 10 mg/L sulfate standard is in place and could require treatment. In some cases, the proposed revisions will require some facilities to conduct additional treatment to meet a numeric sulfate standard that is more stringent than the existing standard. In other cases, the proposed revisions will allow for lesser treatment, possibly reducing the impact of a sulfate standard.

However, because the sulfate standard has not been consistently implemented (and because of the legislation that prevents the MPCA from requiring permittees to spend money to meet the current standard until it has been revised), there is a perception among some that this rulemaking imposes a "new" standard. The MPCA is aware that many permittees are concerned about the ongoing refinement of water quality standards and feel a likely burden from the aggregate effect of standards and the costs of installing treatment to meet more stringent standards.

The MPCA has received comments regarding the potential cumulative effect of the proposed revisions. One commenter stated:

"Moreover, the MPCA should take into consideration the additional cumulative effects of other proposed regulations now under consideration or which will be under consideration in the near future. The present piecemeal approach to standards development every 5 year permit cycle makes it very difficult for the regulated community to effectively plan to meet changing standards."

And

"In the development of the proposed standard the MPCA should perform a cumulative analysis of the implementation costs."

Although the MPCA acknowledges that the addition of new standards could be considered cumulative, the MPCA does not believe that this is a fair characterization of the concept of cumulative effect required to be analyzed in this Statement. The addition or revision of a water quality standard to reflect current understanding of the pollutant or to improve the effectiveness of the standard does not duplicate an existing standard. Each new or revised standard is addressing a new or additional purpose or replacing an existing standard based on new information. The more accurate question related to assessing the cumulative effect is whether the proposed revisions duplicate an existing rule that achieves the same purpose. The answer to that question is that the proposed revisions do not duplicate an existing rule on either a state or federal level.

H. Agency's efforts to provide additional notification to persons or classes of persons who may be affected by the proposed rules.

Minn. Stat. §14.131 requires that *"The statement must also describe the agency's efforts to provide additional notification under section 14.14, subdivision 1a, to persons or classes of persons who may be affected by the proposed rule or must explain why these efforts were not made."*

The MPCA's plans to provide additional notice to parties who may be affected is discussed in Part 8 of this Statement. (Notice Plan). In that Part the MPCA discusses its efforts to provide, in addition to the GovDelivery notice to interested parties, specific notice to municipal dischargers, tribal communities and organizations with an interest in wild rice.

I. Consultation with the commissioner of management and budget to help evaluate the fiscal impact and fiscal benefits of the proposed rule on local government.

Minn. Stat. § 14.131 requires *"The agency must consult with the commissioner of management and budget to help evaluate the fiscal impact and fiscal benefits of the proposed rule on units of local government.*

The MPCA will consult with the Commissioner of Management and Budget when the rules are approved by the MPCA commissioner and before publication of the Notice of Hearing in the *State Register.*

J. Agency's intent to send a copy of the Statement of Need and Reasonableness to the Legislative Reference Library when the notice of hearing is mailed.

Minn. Stat. §14.131 requires *"The agency must send a copy of the statement of need and reasonableness to the Legislative Reference Library when the notice of hearing is mailed under section 14.14, subdivision 1a."*

The MPCA will send the required documents to the Legislative Reference Library when the notice of hearing is mailed.

Additional statutory mandates for rulemaking.

Statutes in addition to Minn. Stat. § 14.131 also establish specific requirements for information to be addressed in a Statement of Need and Reasonableness.

A. Mandate of Minn. Stat. § 14.002 regarding performance-based standards
B. Mandate of Minn. Stat. § 14.128 regarding local Implementation
C. Mandate of Minn. Stat. § 14.127 requiring determination of the effect of the proposed rule on small cities and small businesses

D. Mandate of Minn. Stat. § 116.07, subd. 2(f) requiring an assessment of the differences between the proposed rules and corresponding federal requirements and rules in states bordering Minnesota and states within EPA Region V

E. Mandate of Minn. Stat. § 116.07, subd. 6 relating to the economic factors affecting feasibility and practicality of any proposed action

F. Mandate of 2015 Minn. Session Law, ch. 4, article 3, subd. 2 requiring enhanced economic analysis and identification of cost-effective permitting

G. Mandate of Minn. Stat. § 115.035 requiring external peer review

A. Mandate of Minn. Stat. § 14.002 regarding performance-based standards

Minn. Stat. § 14.002 requires state agencies, whenever feasible, to *"develop rules and regulatory programs that emphasize superior achievement in meeting the agency's regulatory objectives and maximum flexibility for the regulated party and the agency in meeting those goals."*

Minnesota's existing water quality standards, including the existing sulfate standard, are a performance-based regulatory system, and the proposed revisions continue to embody that system. The water quality standards identify the conditions that must exist in Minnesota's water bodies to support each beneficial use. The proposed revisions do not dictate how a regulated party must achieve the wild rice beneficial use or prescribe how they must operate to ensure compliance. Although in the case of sulfate treatment, there are limited alternatives and options available to meet the standard, the proposed revisions do not dictate any single course. The proposed revisions allow maximum flexibility to regulated parties in choosing how to meet the standards and also allow for variances.

B. Mandate of Minn. Stat. §14.128 regarding local implementation

Minn. Stat. § 14.128 requires an agency to "*determine if a local government will be required to adopt or amend an ordinance or other regulation to comply with a proposed agency rule. An agency must make this determination before the close of the hearing record or before the agency submits the record to the administrative law judge if there is no hearing. The administrative law judge must review and approve or disapprove the agency's determination. "Local government" means a town, county, or home rule charter or statutory city.*"

The state water quality standards are not implemented at the local level and therefore, no changes will be required to local ordinances or regulations in response to the proposed revisions. However, the proposed revisions may affect a local unit of government in their role as the owner/operator of a WWTP, and in that role, the local unit of government may impose additional conditions on discharges to their WWTP. An example would be a city requiring pre-treatment of a high sulfate wastewater or charging higher fees for discharge of sulfate to the municipal wastewater facility. These conditions may be in the form of ordinances or regulations but are not specifically required by the proposed revisions.

C. Mandate of Minn. Stat. § 14.127 requiring the determination of effect of the proposed rule on small cities and small businesses

Minn. Stat. §14.127, subd. 1 requires an agency to "*determine if the cost of complying with a proposed rule in the first year after the rule takes effect will exceed $25,000 for any one business that has less than 50 full-time employees, or any one statutory or home rule charter city that has less than ten full-time employees.*"

The statute requires the MPCA to determine whether any small business or city could incur costs in excess of $25,000 in the first year after the rule takes effect.[30] The answer to that is yes, there could be circumstances where that would happen; however, they are very unlikely.

A small business or city that discharges sulfate to a wild rice water could need to obtain or renew a discharge permit in late 2018 or 2019. Due to the wild rice rule revisions, that discharge permit could include either sulfate effluent monitoring or a sulfate limit. Costs to meet the requirement for sulfate effluent monitoring would be very small, approximately $500 per year of analytical costs. If the discharger must make significant design changes to meet the revised standard or requests a variance, the costs could exceed $25,000.[31]

A useful evaluation of the potential for costs to exceed $25,000 in the first year after adoption of the standard must discuss the multiple factors that could lead to that event. The following discussion explains how the MPCA determined the potential of the proposal to affect small businesses or cities.

Exceptions/Assumptions.

- This discussion does not evaluate the economic effect of the proposed revisions on small businesses that depend on wild rice production. Small businesses such as wild rice harvesters, retailers of wild rice, and businesses associated with waterfowl hunting and wildlife-based tourism could be affected by impairments to the yield and distribution of wild rice. However, in the discussion of the general reasonableness of the proposed revisions, the MPCA has justified its assertion that the proposed revision to the sulfate standard is protective of wild rice. Because the proposed revisions will not cause adverse effects to the quantity, quality or distribution of wild rice, the MPCA is not evaluating the economic perspective of small businesses depending on wild rice.

  The MPCA is basing this assessment on the assumption that the costs of the proposed revisions will only apply to those businesses and cities that discharge sulfate to a wild rice water. This discussion does not consider the economic effect on a small business that does not operate its own WWTP but instead discharges to a municipal treatment plant. Although a small business

[30] Many factors affect when the proposed revisions are adopted and when they will become effective. The MPCA expects to adopt the proposed revisions in mid-2018 and for purposes of this discussion, 2018-2019 is the year following the effective date of the rules.

[31] Note that in the case of major design changes, it is typical that a schedule of compliance is developed to complete the necessary work. In that case, the expenses may not be incurred in the first year.

may incur significant expenses if the municipal plant to which they discharge must upgrade to meet the adopted standards, the MPCA does not expect such expenses to occur in the first year following adoption of the proposed revisions.

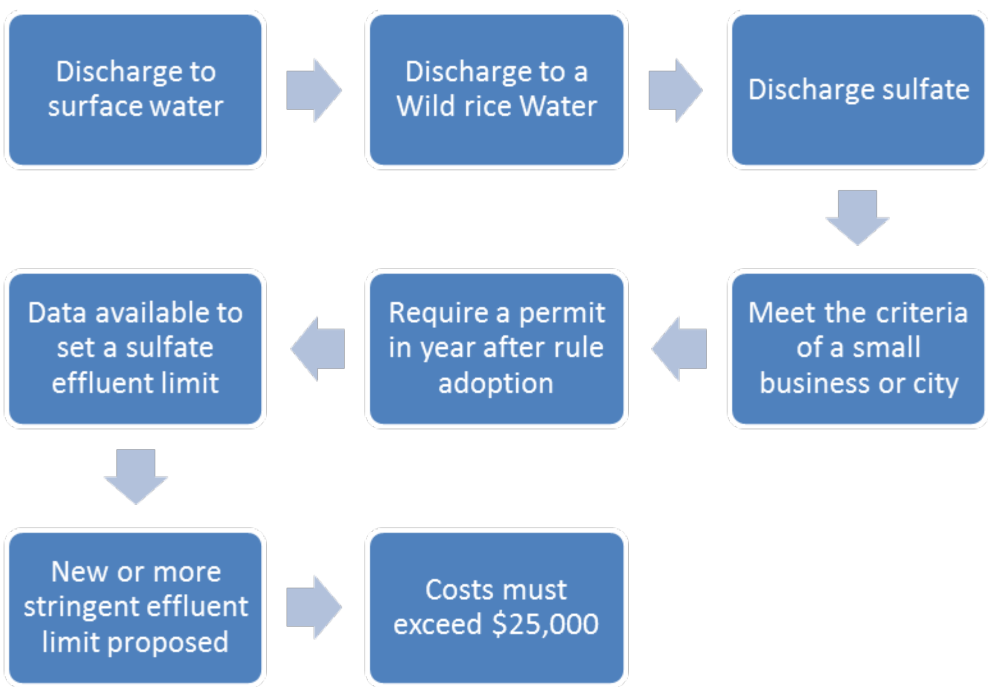
- This discussion does not consider the economic effect of the proposed revisions for a period longer than the first year after adoption. The statutory requirement limits this analysis to the costs incurred in the year following adoption of the proposed revisions.
- This discussion does not consider the volume or concentration of sulfate that must be treated or the conditions in the receiving water on which the sulfate effluent limits will be based. A sulfate value for each wild rice water must be calculated by the application of site-specific variables and as a result, the amount of sulfate that may be discharged will vary. For purposes of simply identifying the small businesses or cities that may be affected by the proposed revisions, the MPCA is not considering the volume or concentrations of sulfate in discharges or what value may apply to a particular receiving water. This level of analysis is beyond the scope of this assessment.
- This discussion assumes that for the year following adoption of the proposed revisions (assumed to be 2018), current costs are maintained and the process of design, construction, and issuance of discharge permits remains the same.
- This discussion assumes that both elements of the proposed revisions (the sulfate standard and the identified wild rice waters) are adopted without significant change from the rules as proposed.
- This discussion does not consider the cost of litigation or penalties that may be incurred after adoption of the proposed revisions.
- This discussion does not consider the cost of research and development of technologies or facility-specific bench studies needed to meet the proposed revised standard. Although the MPCA expects that dischargers will begin the process of anticipating additional sulfate treatment, the costs associated with that planning process are so theoretical that they cannot be estimated with a high degree of accuracy. Because the range of possible responses is so variable (the options may be to cease operation, install treatment, seek a variance, or redesign to a different discharge point), the MPCA cannot anticipate a discharger's long-term plans and responses to a revised standard.

A number of factors determine whether a small business or city will incur costs in excess of $25,000 in the first year after the proposed revisions take effect. For this discussion, the MPCA focused on the following circumstances that will influence the effect of the proposed revised standard on a business or city, when compared to the existing standard:

- The business or city must discharge to a surface water
- The surface water receiving the discharge must be a wild rice water or within a certain range of a wild rice water. For purposes of this evaluation, the MPCA has selected a range of 25 miles.
- The discharge must contain sulfate.

- The affected business must have fewer than 50 full-time employees— affected cities must have fewer than 10 full time employees.
- The business or city must need to obtain a new or re-issued permit within the first year after the rules are adopted.
- The MPCA must have sufficient information available to develop an effluent limit – including sediment data to set the numeric standard for the receiving wild rice water, sulfate levels in the receiving water, and data on sulfate concentrations in the business or city's effluent.
- The application of the adopted sulfate standard must result in effluent limits that are more stringent.
- The business or city must incur costs of more than $25,000 in the first year following adoption of the proposed revisions for planning, installation, or operation activities specifically to meet the revised standard.

Figure 12. Determination of the effect of the proposed revisions on small businesses/cities



In order to make the determination required by the statute, each of the above listed criteria must be met, which successively reduces the number of small business or cities that are potentially affected.

The business or city must discharge wastewater to surface water.

Whether or not a city or business discharges to a surface water is the most fundamental limiting circumstance determining the effect of the proposed revisions. Businesses and cities that do not discharge wastewater will not be directly affected by the proposed revisions and therefore will not bear any cost as a result.[32]

Any business or city that discharges wastewater must obtain an NPDES/SDS permit. Business-related discharges are usually associated with power production, food production, mining, and certain types of manufacturing. Not all NPDES/SDS permits are for a discharge to a receiving water. A city or business may manage wastewater through land application so there is no direct surface water discharge and no potential to affect a wild rice water. A review of MPCA current NPDES/SDS permits shows 569 municipal permits and 517 industrial permits across the state that involve an actual discharge to a surface water.

The business or city must discharge to a wild rice water.

The MPCA is proposing to identify approximately 1,300 lakes, rivers and streams as wild rice waters. Most of these wild rice waters are lakes or streams that do not receive any discharges or industrial wastewater. Approximately 200 to 250 of the proposed wild rice waters may be impacted by a discharger. In addition, the MPCA has evaluated the flow path of dischargers (see Attachment 4) and estimates that 135 dischargers discharge directly to or within 25 miles of a downstream water identified as a wild rice water.[33]

The discharge must contain sulfate.

The MPCA's experience shows that sulfate is widely present in municipal and industrial wastewater, although the volume and concentration of sulfate vary widely.[34] Some types of discharge, (e.g. stormwater, gravel pits, or cooling water) do not have sulfate at levels any higher than the background levels of their source waters. However, for purposes of this assessment, the MPCA conservatively assumes that every identified discharge will contain some level of sulfate.

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[32] *The MPCA recognizes that many small businesses discharge their wastewater to a municipal wastewater treatment plant. Costs incurred by a wastewater treatment plant will be passed on to the dischargers to that system and small businesses will therefore be indirectly affected by the proposed rules. The factors that determine wastewater treatment fees vary according to many factors (wastewater funding structure, the volume and composition of their discharge, the design, size and age of the wastewater treatment plant, etc.). It is not feasible to attempt to assess how, in the first year after adoption, the proposed revisions will affect small businesses that do not directly discharge wastewater to a wild rice water.*

[33] *The MPCA is limiting the expected range of effect to only those dischargers within 25 miles upstream of a wild rice-water solely for purposes of this discussion of potential economic effect. The actual range of effect must be determined on a case-by-case basis. When the proposed revisions are adopted and the MPCA conducts a permit review for implementation of the proposed sulfate standard, the distance between the discharge and the closest wild rice water will be only one of many factors to be evaluated. The effect from any specific discharge, and therefore, the treatment requirements and subsequent costs, will be affected by a number of complex factors, including the concentration and volume of the discharge, the flow and size of the receiving water, seasonal factors, background concentrations, and antidegradation considerations. However, for this discussion, the MPCA is considering the identified dischargers in Attachment 5 to be the potentially affected universe.*

[34] *Sulfate concentrations shown in Table 14 for non-mining industrial discharges range from 74 to over 2,000 mg/L. The range for municipal dischargers is similarly broad, from 9 to 1,660 mg/L (Figure 8)*

The business or city must fit the statutory criteria of being small by having fewer than 50 (business) or 10 (city) employees

The MPCA's assessment finds approximately 135 discharges to or within 25 miles of a proposed wild rice water. The statute requires the MPCA to consider the cost of complying for any business that has fewer than 50 full-time employees or any statutory home rule or charter city that has fewer than 10 full-time employees. It is difficult to determine which cities or businesses will fall within the statutory criteria with any degree of accuracy. The MPCA reviewed readily available information about each of the potentially affected dischargers. In many cases, the business or city listed the number of employees on their website, and the MPCA assumed that information was accurate. In the case of smaller cities and businesses, the MPCA had to make some assumptions. If a city had a population of fewer than 6,000, the MPCA assumed that it had fewer than 10 employees. Where there was no readily available information about a business, the MPCA conservatively assumed that it had fewer than 50 employees. Based on its review of readily available information and conservative estimates, the MPCA estimates that as many as 75 businesses and municipal dischargers have fewer than the statutory limits of employees. Those cities and businesses are identified in Attachment 5.

The small business or city must be affected in the first year after the proposed rules take effect.

Of the approximately 75 currently permitted small businesses and cities that may be affected by the proposed revisions, fewer will be subject to the proposed sulfate standard within the first year after the revisions take effect. NPDES/SDS permits are issued to: 1) new or expanding facilities; and 2) existing dischargers. The MPCA issues permits to existing dischargers on a five-year schedule. In the first year after adoption of the rule, only new permits and those permits that are due for renewal may receive effluent limits based on the adopted sulfate standard.

The MPCA estimates that of the approximately 75 existing, small, permitted facilities that discharge sulfate within 25 miles of a wild rice water, more than 60 will at least begin the process of updating their existing permit in 2018. This includes the dischargers whose permits have already expired or will expire in 2018. Additional permittees who expect to renew their permit in 2019 and 2020 may also begin the process of planning and may incur costs in anticipation of the adoption of a revised sulfate standard. The MPCA does not have any information to indicate it will receive any permit applications in 2018 for new discharges to a wild rice water.

The process of permit issuance/renewal involves setting effluent limits, developing and reviewing plans and specifications, permit notice and approval, and construction activities. Many of these activities and the costs associated with them are inherent to the nature of wastewater treatment. These activities will result in costs regardless of the adoption of the proposed revisions. However, for purposes of this discussion, the MPCA assumes that dischargers will incur some amount of additional design and review costs solely as a result of the proposed revisions. The MPCA believes that although it will actually issue very few permits within the first year after the proposed revisions go into effect, in some cases dischargers may have to make a significant initial investment in planning and preliminary design work in advance of receiving the permit.

Data must be available to set a sulfate effluent limit.
The main driver of costs would be the implementation of a sulfate effluent limit in a permit and the need to take steps to implement the limit or to request a variance. However, before any facility receives an effluent limit the following information must be available:

- Sediment data to calculate the numeric sulfate standard for the wild rice water;
- Ambient sulfate data for the wild rice water; and
- Sulfate effluent concentrations.

Only a fraction of permittees that discharge upstream of any wild rice waters are currently monitoring their effluent for sulfate. For the majority of facilities that do not currently have effluent monitoring, the MPCA anticipates that the earliest sulfate limits could be implemented is 2023. Because of the need to collect this data, the MPCA believes it is very unlikely for any small facility to receive a limit in 2018.

***The small business or city must comply with more stringent effluent limits than are currently required*.**
When the proposed revisions are adopted, there will be two possible scenarios regarding effluent limits.

1. The discharger will receive an effluent limit that is more stringent than the limit that would be required under the existing standard, because the equation-based sulfate value is more stringent than the existing 10 mg/L standard; or
2. The discharger will receive an effluent limit that is less stringent than a limit based on the current standard of 10 mg/L.

Only in the case of outcome 1 will the proposed rules will result in either higher treatment costs to meet the more stringent effluent limit or the need for a variance. In outcome 2, while a discharge still may need to undertake actions to meet the standard, these will be lower than those that would be incurred to meet the existing standard. The extent of the costs will depend on the nature of the discharge and the calculated sulfate limit.

It is not possible to determine which of the scenarios will apply to any specific small business or city until the MPCA evaluates the situation for each discharger and determines actual effluent limits. Although the MPCA can reasonably expect that in some cases sulfate effluent limits will not be more stringent, there is no way to make that determination until all variables have been considered. For purposes of this evaluation, the MPCA conservatively assumes that all the identified dischargers will have to either meet more stringent sulfate discharge limits or apply for variances.

The small business or city must spend more than $25,000 to comply with the standard.
The cost to treat wastewater to remove sulfate is extremely high. The most effective treatment option at this time is a RO membrane treatment system. The cost of designing, building and operating a RO system will certainly exceed $25,000. However, permittees will not incur the full cost of treatment or design/build in 2018 (the first year after adoption of the proposed rules).

The MPCA expects that those facilities that meet the above criteria may incur costs in 2018 for a contractor or designer to begin the process of evaluating their discharge and treatment options. They may also begin the process of bench-scale studies and facility design; although a variance application is more likely. Although the cost of these activities cannot be estimated because of the extent of the variables, the MPCA expects that they will be significant and may exceed $25,000. It may be possible that many or most of these facilities would qualify for a variance from the sulfate requirements. In that case, the facility would not immediately incur treatment costs, but would still incur costs to obtain a variance. The cost to obtain a variance involves the fee charged by the MPCA, in this case only for non-municipal dischargers, as well as the cost of developing the variance proposal.[35] Those costs could exceed $25,000, especially for an industrial facility.

Conclusion.

The MPCA finds that the regulatory threshold of $25,000 may be exceeded for some small businesses and cities in the first year after adoption of the proposed revisions. Although the number of potentially affected small businesses and cities is relatively small compared to all the permitted facilities in Minnesota, and there are many factors and variables that will affect the impact of the adopted revisions, the MPCA expects that in at least some cases, the cost of proposed revisions will exceed the regulatory threshold.

D. Mandate of Minn. Stat. § 116.07, subd. 2(f) requiring assessment of differences between the proposed rule and standards in similar states

Minn. Stat. § 116.07, subd 2 (f) requires "*In any rulemaking proceeding under chapter 14 to adopt standards for air quality, solid waste, or hazardous waste under this chapter, or standards for water quality under chapter 115, the statement of need and reasonableness must include:*

(1) an assessment of any differences between the proposed rule and:

(i) existing federal standards adopted under the Clean Air Act, United States Code, title 42, section 7412(b)(2); the Clean Water Act, United States Code, title 33, sections 1312(a) and 1313(c)(4); and the Resource Conservation and Recovery Act, United States Code, title 42, section 6921(b)(1);

(ii) similar standards in states bordering Minnesota; and

(iii) similar standards in states within the Environmental Protection Agency Region 5; and

(2) a specific analysis of the need and reasonableness of each difference."

This requirement is the same as the requirement in Minn. Stat. § 14.131 and is discussed in that part of this Statement.

E. Mandate of Minn. Stat. § 116.07, subd. 6 relating to economic factors affecting feasibility

Minn. Stat. § 116.07, subd. 6 requires *"In exercising all its powers the Pollution Control Agency shall give due consideration to the establishment, maintenance, operation and expansion of business, commerce, trade, industry, traffic, and other economic factors and other material matters affecting the feasibility*

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[35] *The proposed rules provide a waiver from the variance fee for municipal dischargers.*

and practicability of any proposed action, including, but not limited to, the burden on a municipality of any tax which may result therefrom, and shall take or provide for such action as may be reasonable, feasible, and practical under the circumstances."

The MPCA has met the requirements of this statute by the discussions provided in this Part regarding the possible economic effect of the proposed rules.

F. Mandate of Minn. Session Law chapter 4, article 3, subdivision 2 requiring enhanced economic analysis and identification of cost-effective permitting

2015 Minn. Session Law, chapter 4, article 3, subdivision 2 authorized funds for "*enhanced economic analysis in the water quality standards rulemaking process, including more specific analysis and identification of cost-effective permitting."*

The MPCA has considered the effect of the proposed revisions as they relate to the MPCA's permit process for both industrial dischargers and municipal dischargers and recognizes that for some dischargers, the proposed revisions may result in substantial costs.

Cost-effective considerations regarding municipal wastewater treatment permits

EPA estimates that Minnesota communities will need $11 billion in water infrastructure improvements over the next two decades. This funding is necessary to replace aging wastewater and drinking water systems, upgrade treatment facilities to meet higher standards, and expand systems to accommodate growth. Approximately 60 percent of the needed improvements are outside the Twin Cities area.

The $11 billion figure does not factor in costs that municipal dischargers might incur to comply with the proposed revisions. The MPCA expects that in most cases, dischargers can only meet the proposed sulfate standard by using membrane treatment. The MPCA recognizes that the current options for treating sulfate will be costly and complex.

Beyond the costs of design, construction, and operation, there are substantial public policy implications associated with widespread membrane treatment at either municipal or industrial wastewater treatment facilities to treat sulfate. Membrane treatment is an energy intensive process that would increase the carbon footprint of a wastewater treatment facility. In addition, annual operation and maintenance costs of a membrane treatment system are very expensive – estimated to be over 1 million dollars per year. Membrane treatment would also increase sludge disposal volumes, which, if incinerated or disposed in landfills, will increase the burden on Minnesota waste disposal facilities. In addition, membrane filtration requires highly skilled operators. Many Minnesota municipalities already report difficulty in retaining qualified wastewater operators, and that difficulty could increase if wastewater operators capable of operating membrane processes were required.

Cost-effective considerations regarding industrial wastewater treatment permits

Industrial dischargers could encounter substantial treatment costs if sulfate effluent limits are included in NPDES/SDS permits. Industries most likely to be affected include ethanol producers, food processors, power plants, ferrous (taconite) mining and processing, and any potential non-ferrous mining. The taconite industry on the Mesabi Iron Range is likely to be the most affected of the industrial categories for reasons including the prevalence of wild rice in that region, the amount of sulfate generated by mining and processing, the aggregate volume of water discharged, and the elevated sulfate concentrations from legacy mining. Taconite mining is fundamental to the economy on the Mesabi Iron Range, which extends from roughly Grand Rapids in the west to Babbitt in the east.

Seepage discharges from stockpiles, tailings basins, and mine pit dewatering may be of such a scale and complexity that it may not be possible to achieve in-stream attainment of the sulfate standard for all sources within a relatively short and predictable period (e.g. 10-20 years). At this point, the MPCA does not know what the numeric standard will be for any specific water body. There is also a wide range of point and non-point sources of sulfate discharge, especially those from the taconite industry. Some discharges are controlled and seasonal, while many others are uncontrolled and have significant variability. Any treatment system would need to be sized to accommodate the maximal or near-maximal flow rate at each discharge.

Variances to address costs

Variances are a mechanism by which the MPCA can address the permitting costs associated with the implementation of new or revised standards. Variances from water quality standards are a permitting tool to deal with uncertain or costly treatment alternatives. Variances are temporary modifications to the water quality standard or effluent limit. Although a variance may allow the temporary modification of a standard, a variance can never allow the loss of a water's beneficial use. In granting a variance, the MPCA may consider the negative social and economic effects of the standard on the affected community. The MPCA expects variances to become an increasingly necessary component of the permit process as it implements more stringent water quality-based effluent limits, and the socioeconomic impact of those limits is a primary factor to consider.

All variances from a water quality standard are subject to final approval by EPA. The EPA-approved economic analysis required in the state variance process allows the MPCA to distinguish the point at which costs would result in substantial and widespread negative economic and social impact. The information needed to make this determination is very site-specific and cannot be calculated in the abstract

Variances for municipal wastewater treatment plants

The methodology used for demonstrating substantial impact on a municipal discharger is taken from EPA's Interim Economic Guidance for Water Quality Standards (EPA-823-B-95-002). In order to qualify for a variance, a discharger must demonstrate substantial and widespread economic and social impact to render water pollution control compliance infeasible.

Substantial economic impact to a public sector discharger can be demonstrated by calculating two values, which EPA has named the Municipal Preliminary Screener and the Secondary Score. The Municipal Preliminary Screener describes how costly the proposed pollution control investment would be for the municipality relative to the median household income. The Secondary Score depicts the community's overall economic health and ability to take on debt. EPA uses a matrix to assess whether the impact of the proposed pollution control project would be substantial for the community. If the impacts are considered substantial, the municipal WWTP could be considered eligible for the variance.

Figure 13. Assessment of substantial impacts matrix

	Municipal Preliminary Screener		
Secondary Score	Less than 1.0%	Between 1.0 and 2.0%	Greater than 2.0%
Less than 1.5	?	X	X
Between 1.5 and 2.5	--	?	X
Greater than 2.5	--	--	?

In the matrix, "X" indicates that the impact is likely to interfere with economic development. The closer the community is to the upper right corner of the matrix, the greater the likelihood of interfering with economic development. Alternatively, "--" indicates that the impact is not likely to interfere with development and the closer to the lower left corner of the matrix, the smaller the likelihood. Finally, the "?" indicates that the impact is unclear and the applicant will need to justify why the treatment is not prudent or feasible.

The Municipal Preliminary Screener

The Municipal Preliminary Screener estimates the total per household annual pollution control costs to be paid by households (existing costs plus those attributable to the proposed project) as a percentage of median household income. The screener is written as follows:

$$Municipal\ Preliminary\ Screener = \frac{Annual\ pollution\ control\ cost\ per\ household}{Median\ household\ income} \times 100$$

The Secondary Score

The Secondary Score is calculated using six tests related to the debts and revenues of the municipality in question.

Figure 14. Secondary Score

Secondary Indicators	**Weak**	**Mid-Range**	**Strong**
Bond Rating	Below BBB (S&P) Below BAA (Moody's)	BBB (S&P) BAA (Moody's)	Above BBB (S&P) or Baa (Moody's)
Overall Net Debt as Percent of Full Market Value of Taxable Property	Above 5%	2%—5%	Below 2%

Secondary Indicators	Weak	Mid-Range	Strong
Unemployment	More than 1% above National Average	National Average	More than 1% below National Average
Median Household Income	More than 10% below State Median	State Median	More than 10% above State Median
Property Tax Revenues as a Percent of Full Market Value of Taxable Property	Above 4%	2% —4%	Below 2%
Property Tax Collection Rate	< 94%	94% — 98%	> 98%

The Secondary Score is calculated for the community by weighting each indicator equally and assigning a value of 1 to each indicator judged to be weak, a 2 to each indicator judged to be mid-range, and a 3 to each strong indicator. A cumulative assessment score is calculated by summing the individual scores and dividing by the number of factors used. The cumulative assessment score is evaluated as follows:

- less than 1.5 is considered weak
- between 1.5 and 2.5 is considered mid-range
- greater than 2.5 is considered strong

Using Preliminary Screener Values to Estimate Variance Eligibility for Municipal WWTPs

The MPCA has used the preliminary municipal sulfate treatment costs analysis in this regulatory analysis to calculate preliminary screener values. Using conservative assumptions, municipal sulfate treatment is likely to be unaffordable for greater than 97% of municipalities based solely on projected costs. Where the costs are unaffordable, a facility is likely to be eligible for a variance based on socio-economic hardship. When considering that this analysis does not include secondary sulfate treatment costs (pilot testing costs, lack of WWTP sulfate treatment design standards, redesign of conventional wastewater plant, need for new plant construction, power infrastructure needs, etc…) it is likely that actual costs for sulfate treatment would be even more unaffordable.

Assumptions

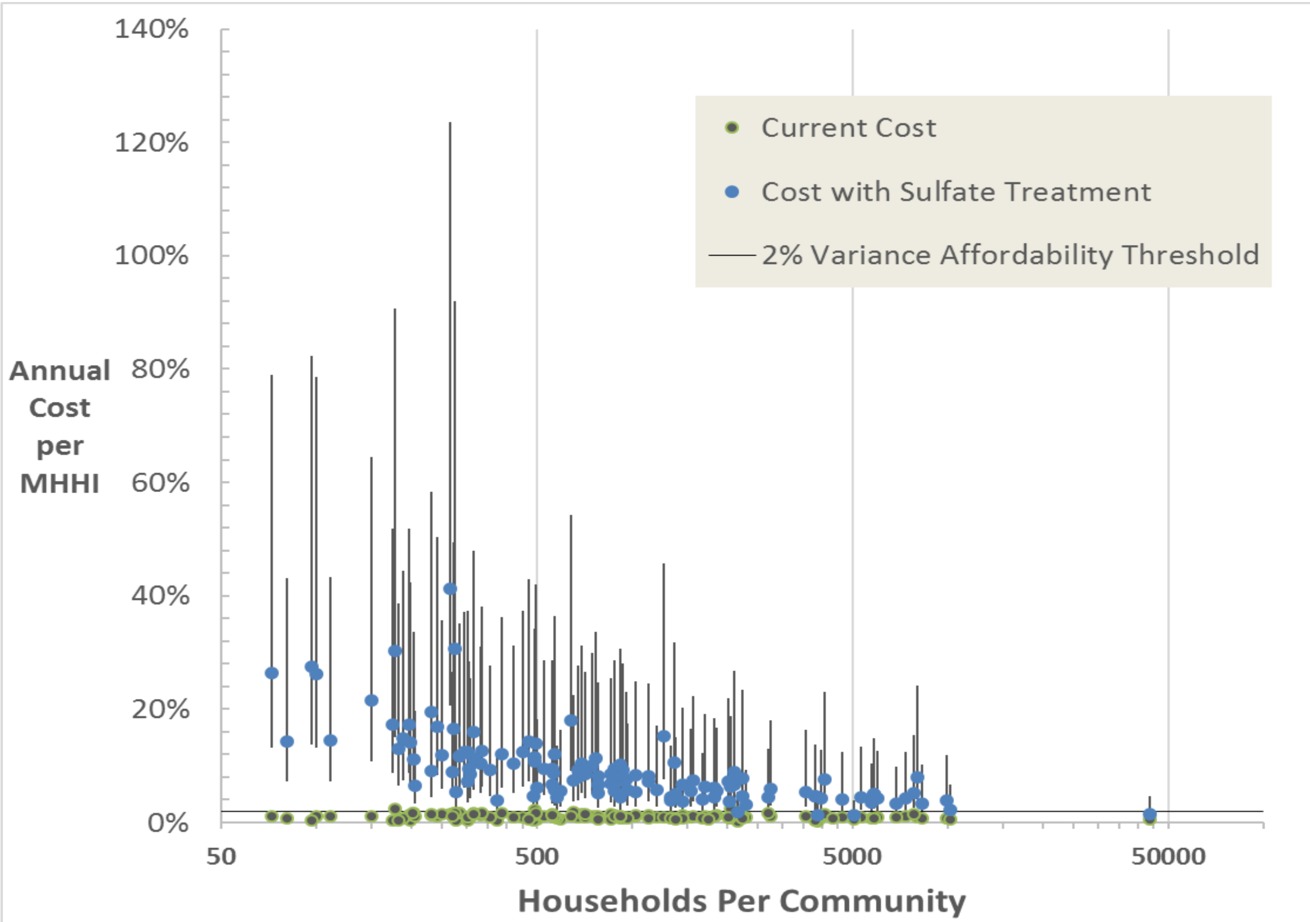
1. The costs estimate is a very high level cost estimate with uncertainties of +100% to -50%.
2. The entire flow will be treated. Treating the entire flow is what would be required to treat to a sulfate limit of less than 10 mg/L.
3. The costs estimates are accurate and scale by flow rate according to the methods described below.
4. The estimated costs are only for RO with evaporation and crystallization. The cost estimates do not include secondary costs of using RO and evaporation with crystallization such as additional power infrastructure needs, the need for advanced secondary treatment, site-specific waste disposal costs, or other factors that could increase costs.

5. If the costs of treatment is greater than 2.0% of median household income, then the cost is likely to be unaffordable using the methods in the EPA Interim Economic Guidance for Water Quality Standards.
6. All costs of treatment are only paid by residential wastewater rate payers.
7. The current wastewater costs per household were taken from the MPCA's Future Wastewater Infrastructure Needs and Capital Costs report to the legislature. (MPCA 2016).

The cost of sulfate treatment as a percentage of Median Household Income (MHHI) for the municipalities that monitor for salty parameters is visualized in Figure 15. The black line at 2% represents the affordability threshold above which a community is likely to be eligible for a variance based on community socioeconomic hardship. If the cost of treatment as a percentage of MHHI is greater than 5%, then the municipality is very likely to receive a variance based on socioeconomic hardship.

Only four municipalities in the sample have costs below the 2% of MHHI threshold when sulfate treatment is included. All of these four communities have upper error bars that are above the 2% threshold, indicating that variance eligibility based solely on affordability is likely. These communities have a relatively high MHHI (greater than $63,000 annually) compared to the rest of the municipalities (median community MHHI is $44,503). These four municipalities all have costs greater than 1% of MHHI, which puts in them in the “Uncertain” to be eligible for a variance category, not the “Unlikely” to be variance eligibility category.

Figure 15. The costs of sulfate treatment as a percentage of MHHI. The error bars represent +/- 100% and 50% of the projected costs.



Variances for industrial wastewater treatment plants

The MPCA's methodology used for demonstrating substantial impact on a private-sector industrial treatment plant is also taken from EPA's Interim Economic Guidance for Water Quality Standards (EPA-823-B-95-002). Just as is the case for a municipal discharger, in order to qualify for a variance, a private sector discharger must demonstrate substantial and widespread economic and social impact to render water pollution control compliance infeasible. However, in the private-sector case, the process for assessing substantial and widespread impact is different.

The key question to evaluate whether economic impacts are substantial is whether the industrial discharger has the ability to pay for the pollution control, or whether the pollution control project is affordable. The primary measure of affordability concerns the profitability of the discharger and how much its earnings will decline due to pollution control expenditures. The "profit test" is equal to earnings before taxes divided by revenues and is calculated with and without the costs of pollution control:

$$Profit\ Test = \frac{Earnings\ before\ Taxes}{Revenues}$$

In the calculation of this test with pollution control costs, consideration can be given to the degree that the discharger can raise prices to cover pollution control costs. Evaluating the Profit Test entails considering whether the loss of profit may be substantial enough that there is a chance that employment will be lost and local purchases by the discharger reduced.

There are then three secondary measures that assess liquidity, solvency, and leverage to provide additional information about the financial health of the discharger and thus help to determine whether the pollution control project is affordable. The test for liquidity involves calculation of the Current Ratio by dividing current assets (assets that could be converted into cash within a year) by current liabilities (liabilities that need to be paid within a year):

$$Current\ Ratio = \frac{Current\ Assets}{Current\ Liabilities}$$

Generally, a current ratio greater than two indicates strong liquidity where the discharger can generally cover its short-term obligations.

The test for solvency involves calculating Beaver's Ratio, which is the discharger's cash flow (the cash available in a given year, usually calculated by adding any depreciation expense to the discharger's net after-tax income) divided by its total debt:

$$Beaver's\ Ratio = \frac{Cash\ Flow}{Total\ Debt}$$

Generally, a Beaver's Ratio greater than 0.20 indicates that the discharger is solvent, while a Beaver's Ratio between 0.15 to 0.20 indicates that future solvency is uncertain, and a Beaver's Ratio below 0.15 reflects a possibility that the discharger may be insolvent (i.e., go bankrupt).

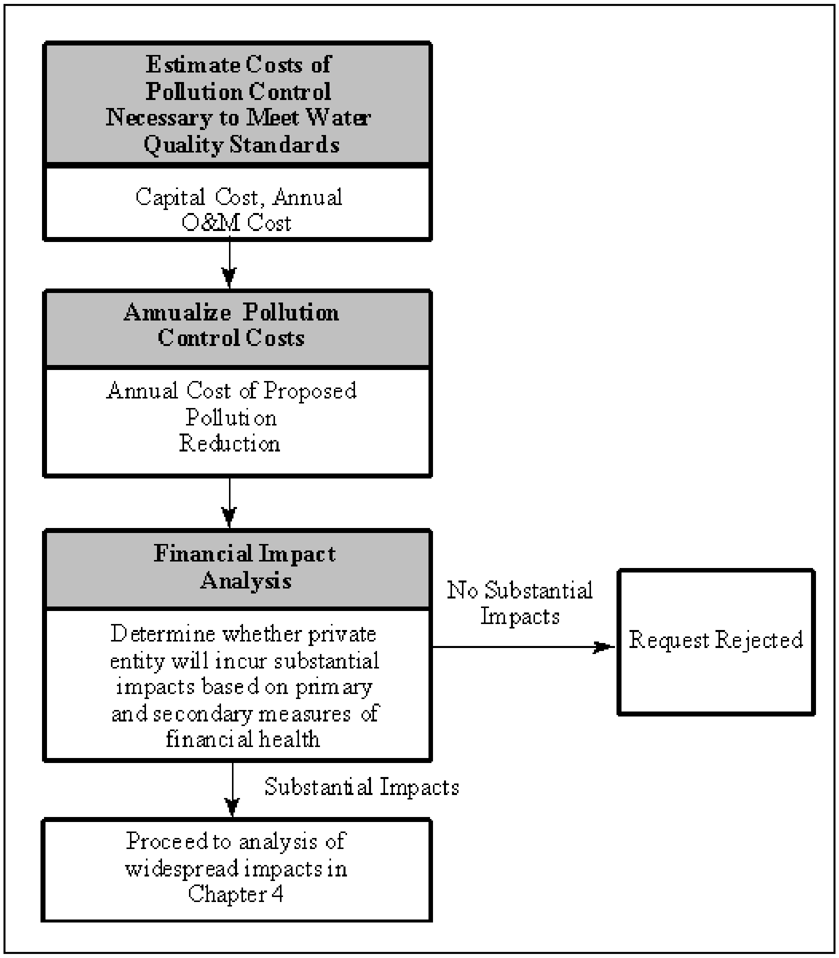
Finally, the test for leverage involves calculating the Debt to Equity Ratio, which is the discharger's long-term liabilities (long-term debt that is not due to be paid within the next year) divided by owners' equity:

$$Debt\ to\ Equity\ Ratio = \frac{Long-Term\ Liabilities}{Owners'\ Equity}$$

There are no generally accepted Debt to Equity Ratio values that apply to all types of economic activity, so this ratio should be compared with the ratio of firms in similar businesses. If the discharger's ratio compares favorably with the median or upper quartile for similar businesses, it should be able to borrow additional funds.

Although the Profit Test is considered first, all four of these measures—profitability, liquidity, solvency and leverage—should be compared to industry benchmarks and considered jointly to obtain an overall picture of the economic health of the discharger to assess whether complying with the effluent limit based on the water quality standard would have substantial economic impacts. Figure 16 from the EPA Interim Economic Guidance for Water Quality Standards, illustrates the entire process for evaluating whether socioeconomic impacts are substantial for an industrial WWTP.

Figure 16. Measuring substantial impacts (private entities)



Streamlined variance process

The MPCA is aware that sulfate effluent limits could prompt variance requests and is considering a streamlined variance process for sulfate effluent limits. The MPCA's planned streamlined sulfate variance process will define the information required for obtaining final variance approval from EPA and allow ample time for an affected discharger to consider their permitting options. The streamlined process will reduce permitting uncertainty and application review time and thus result in more cost-effective permitting. The streamlined variance process will not change the criteria for obtaining a variance but would make the application process easier and more understandable.

G. Mandate of Minn. Stat. § 115.035 relating to external peer review

Minn. Stat. § 115.035 requires: *When the commissioner convenes an external peer review panel during the promulgation or amendment of water quality standards, the commissioner must provide notice and take public comment on the charge questions for the external peer review panel and must allow written and oral public comment as part of the external peer review panel process. Documentation of the external peer review panel, including the name or names of the peer reviewer or reviewers, must be included in the statement of need and reasonableness for the water quality standard. If the* *commissioner does not convene an external peer review panel during the promulgation or amendment of water quality standards, the commissioner must state the reason an external peer review panel will not be convened in the statement of need and reasonableness.*

Minnesota Statute § 115.035 requires that the MPCA commissioner convene an external peer review panel during the promulgation or amendment of a water quality standard, or to state in the SONAR why such a panel was not convened.

The MPCA conducted an external peer review on the state-sponsored wild rice study in 2014, prior to the statute that addresses such reviews. The peer review was very useful, in that it recommended specific additional analyses of the study data, analyses that the MPCA subsequently performed and is relying upon in the rulemaking. The MPCA initiated the peer review by contracting with a Massachusetts firm, Eastern Research Group, that usually convenes review panels for federal agencies, for a peer review panel to examine the data and preliminary conclusions of the wild rice study. The MPCA prepared a preliminary interpretation of the data (Exhibit 5), created a series of charge questions for the panel, (Exhibit 7) and Eastern Research Group found seven scientists with expertise appropriate to address the questions. The scientific expertise included environmental chemistry, toxicology, and wetland plant ecology. One of the experts was from the Netherlands, two from Florida, one from Ohio, one from Manitoba, and two professors from the University of Minnesota (none of whom had been involved in the MPCA wild rice study). The names and affiliations of the peer reviewers are provided in Table 19.

Table 19. Names of the scientists on the 2014 panel that reviewed the MPCA's preliminary interpretation of the data collected during the 2012-2013 wild rice study.

Arts	Gertie H.P.	Alterra, Wageningen University and Research Centre, Netherlands
Axelrad	Donald	Florida A&M University
*Brezonik	Patrick	University of Minnesota (retired)
Fennessy	Siobhan	Kenyon College
Galatowitsch	Susan	University of Minnesota
Hanson	Mark	University of Manitoba
Pollman	Curtis	Aqua Lux Lucis, Inc.

*Meeting Technical Chair

The report of the peer review panel (Exhibit 9), released in September 2014 included many suggestions for the improvement of MPCA's analysis and interpretation of the data regarding the effect of sulfate on wild rice. In March 2015, the MPCA issued a draft proposal (Exhibit 10) with a revised interpretation and solicited comments. In July 2016, in response to the received comments, the MPCA again released a revision to its analysis of the effect of sulfate on wild rice in the form of a draft TSD for this rulemaking (Exhibit 12), and again solicited comments. The interpretation was finalized as the final TSD (Exhibit 1).

MPCA use of peer-reviewed scientific literature

The MPCA's assessment of the effect of sulfate on wild rice is largely based on the larger scientific understanding of the role of sulfate in the aquatic environment, as published in peer-reviewed scientific journals. MPCA staff worked with contractors to apply this larger understanding to the wild rice-specific data collected under the state-funded study. The final interpretation of the data, as presented in this Statement and TSD, was also influenced by the report of the external peer review panel.

The TSD is therefore based on the larger scientific understanding in combination with wild rice-specific information derived from the state-sponsored study. This wild rice-specific information is new to the scientific world and has been prepared for publication, as is usual in the culture of scientific research. Four manuscripts, prepared chiefly by the scientists who conducted the research under contract with the MPCA, and co-authored by MPCA scientists, have been submitted to peer-reviewed scientific journals. These four manuscripts, and the data on which they are based, serve as the scientific foundation of the proposed sulfate standard revisions. The first manuscript submitted, was accepted for publication after peer review at the journal *Ecological Applications* (Exhibit 19). The other three manuscripts were submitted simultaneously to the *Journal of Geophysical Research: Biogeosciences*. The three manuscripts were submitted together because they refer to each other, and therefore must be published simultaneously. Two of these three manuscripts (Exhibits 18 and 35) have been accepted for publication, whereas the third manuscript (Exhibit 36) is being revised in response to suggestions by the journal's anonymous peer reviewers. When the third is formally accepted, the three manuscripts will be published by the journal. The MPCA does not consider the peer review conducted by the journals to be within the scope of Minn. Stat. § 115.035 because it is not controlled by MPCA. The conduct of peer review by scientific journals is significantly different from an external peer review panel, as described above. Perhaps the most important difference is that the journal editor chooses the reviewers, whose identities remain anonymous in virtually all cases. The usual procedure is for the editor to receive the reviews, which are not released to the public, and to make a judgment about whether the manuscript is acceptable for publication, and, if so, whether any revisions are necessary prior to publication. Revised manuscripts may or may not be sent back to the peer reviewers for second or third rounds of reviews before an editor makes a final decision on acceptance. Note that while it is possible to list the names of reviewers on an external peer review panel, that information is not available when scientists publish their findings in a traditional scientific journal.

11. Comments Received

The MPCA has been in the process of developing the proposed standards for many years. As a result, there have been many opportunities for public review and comment. As discussed in Part 1.A (Background) and Part 8 (Public Participation), the MPCA has sought review and comment at a number of points in the process. The MPCA received and reviewed comments from the public, scientific community, businesses, environmental groups, and other governmental units.

Major points where public comments were generated were the:

- release of a pre-rulemaking draft proposal (March 2015);
- RFC (October 2015); and
- release of the draft TSD (July 2016).

Comments were also received in response to posting the draft rule language and regulatory analysis on the web and sharing them with the Wild Rice Advisory Committee. The MPCA received more than 600 comments in response to the RFC and posted them and the comments relating to the draft TSD on the rulemaking webpage for public review.

In the discussion of the need for the proposed revisions (Part 2) and in the discussion of the alternatives considered (Part 10.C), the MPCA discusses some of the specific comments received. Appendix 1 of the MPCA's Draft TSD (Exhibit 12) also provides a discussion of the key themes of the comments received.

12. Attachments, authors, witnesses, exhibits and references.

A. Attachments

- Attachment 1. Excerpt of Minnesota Laws relating to wild rice
- Attachment 2. Compiled list of proposed wild rice waters and source information
- Attachment 3. List of MPCA meetings relating to the development of the proposed rules
- Attachment 4. MPCA Memorandum regarding the analysis of potential effluent limit reviews
- Attachment 5. MPCA list of potentially affected wastewater dischargers

B. Authors (MPCA)

- David Bael
- Baishali Bakshi
- Gerald Blaha
- William Cole
- Elise Doucette
- Patricia Engelking
- Stephanie Handeland
- Elizabeth Kaufenberg
- Scott Kyser
- Shannon Lotthammer
- Phillip Monson
- Carol Nankivel
- Catherine Neuschler
- Michael Schmidt
- Marta Shore
- Edward Swain

C. Witnesses

The MPCA intends to hold public hearings regarding the proposed revisions. The MPCA anticipates having the listed authors testify as witnesses in support of the need for and reasonableness of the MPCA's proposal. The specific credentials of the MPCA's staff scientists are provided as an appendix to the MPCA's TSD (Exhibit 1).

- Adonis Neblett, General Counsel to the MPCA.
- Shannon Lotthammer, Division Director of the MPCA's Environmental Analysis and Outcomes Division.
- Catherine Neuschler, Manager of the MPCA's Water Assessment Section, Environmental Analysis and Outcomes Division.
- Steven Weiss, supervisor, Effluent Limits Unit, Water Assessment Section, Environmental Analysis and Outcomes Division.
- Gerald Blaha, MPCA staff.
- Edward Swain, MPCA staff.
- Phillip Monson, MPCA staff.
- Patricia Engelking, MPCA staff.
- Elizabeth Kaufenberg, MPCA staff.
- Scott Kyser, MPCA staff.

D. Exhibits

1. MPCA Final Technical Support Document – Refinements to Minnesota's Sulfate Water Quality Standard to Protect Wild Rice (June 2017)
2. Excerpted Laws of Minnesota specifically relating to wild rice rulemaking
3. Correspondence from Minnesota Chamber of Commerce, President David Olson, and attached petition for rulemaking, memorandum in support of the petition, summons to the Minnesota Pollution Control Agency, and complaint for declaratory and injunctive relief. (December 17, 2010)
4. MPCA, Wild Rice Sulfate Standard Study-Summary and Next Steps (December 2013) https://www.pca.state.mn.us/sites/default/files/wq-s6-42u.pdf
5. MPCA Wild Rice Sulfate Standard Study Preliminary Analysis (March 2014) https://www.pca.state.mn.us/sites/default/files/wq-s6-42w.pdf
6. MPCA Analysis of the Wild Rice Sulfate Standard Study: Draft for Scientific Peer Review (June 9, 2014) https://www.pca.state.mn.us/sites/default/files/wq-s6-42z.pdf
7. MPCA Charge for Peer Review (June 2014) https://www.pca.state.mn.us/sites/default/files/wq-s6-43a.pdf

8. MPCA Scientific Peer Review of Wild Rice Sulfate Standard Study and MPCA Analysis-Purpose and Process (March 2014) https://www.pca.state.mn.us/sites/default/files/wq-s6-42x.pdf
9. Eastern Research Group Summary Report of the Meeting to Peer Review MPCA's Draft Analysis of the Wild Rice Sulfate Standard Study, submitted to the Minnesota Pollution Control Agency (September 25, 2014) https://www.pca.state.mn.us/sites/default/files/wq-s6-43i.pdf
10. MPCA Proposed Approach for Minnesota's Sulfate Standard to Protect Wild Rice (Draft Proposal) (March 24, 2015) https://www.pca.state.mn.us/sites/default/files/wq-s6-43l.pdf
11. Request for Comments on Planned Amendments to Water Quality Sulfate Standard to Protect Wild Rice and Identification of Wild Rice Waters, Minnesota Rules Chapters 7001, 7050, 7052, and 7053. *State Register*, 40 SR 465. (October 26, 2015) https://www.pca.state.mn.us/sites/default/files/wq-rule4-15a.pdf
12. MPCA Draft Technical Support Document: Refinements to Minnesota's Sulfate Water Quality Standard to Protect Wild Rice. (July 18, 2016) https://www.pca.state.mn.us/sites/default/files/wq-s6-43v.pdf
13. MPCA Preliminary Structured Rules for Public Discussion (December 2016) https://www.pca.state.mn.us/sites/default/files/wq-s6-44a.pdf
14. MPCA Draft Cost Analysis Components of Regulatory Analysis, Proposed Sulfate Standard for Protection of Wild Rice. (December 2016) https://www.pca.state.mn.us/sites/default/files/wq-s6-43z.pdf
15. MPCA Staff Initial Post-Hearing Responses (October 14, 1997)
16. MPCA Staff Final Post-Hearing Responses (October 22, 1997)
17. MPCA SONAR for Great Lakes Initiative July 29, 1997 (pp.22-24)
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20. Minnesota Pollution Control Agency Call for Sulfate and Wild Rice Monitoring Data for the 2013 Assessment Cycle, *State Register,* 37 SR 1438 (April 1, 2013)
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23. Minnesota Wild Rice Management Workgroup List of 350 Important Wild Rice Waters (May 4, 2010)
24. 1854 Treaty Authority Wild Rice Waters in 1854 Ceded Territory (March 24, 2016)
25. Minnesota Department of Natural Resources Aquatic Plant Management Database (Wild rice waters excerpt- March 2, 2017, July 22, 2016, March 13, 2013)
26. MPCA Biomonitoring Field Site Data (May 19, 2017)
27. University of Minnesota/MPCA Wild Rice Field Survey Sites Proposed as Wild Rice Waters (2013)
28. Minnesota Biological Survey Database (2/22/2017)
29. MPCA Compilation of the Results of MPCA 2013 call for data (May 22, 2017)
30. MPCA List of the Permittee Monitoring Reports and Literature Reviews Used As Sources to Identify Wild Rice Waters (March 2017)
31. List of wild rice waters identified in Minn. R. 7050.0470(May 2017)
32. Excerpt from the MPCA's Draft TSD (Exhibit 12) Relating to Feeding Requirements of Waterfowl (July 18, 2016)
33. Excerpt of Arizona State Law Journal. The Repercussions of Orality in Federal Indian Law. (Summer 1999)
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38. MPCA Compilation of Notes of Tribal Meetings (January 31, 2017, August 26, 2015, March 12, 2012, March 7, 2011)

39. Minnesota Pollution Control Agency Environmental Justice Framework 2015-2018 (December 17, 2015) https://www.pca.state.mn.us/sites/default/files/p-gen5-05.pdf
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13. Conclusion

In this SONAR, the MPCA has established the need for and the reasonableness of each of the proposed amendments to Minn. R. chs.7050 and 7053. The MPCA has provided the necessary notifications and in this SONAR documented its compliance with all applicable administrative rulemaking requirements of Minnesota statute and rules.

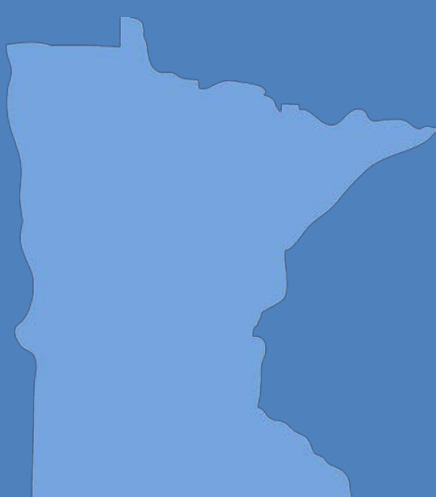
Based on the forgoing, the proposed amendments are both needed and reasonable.

7/17/17

Date

John Linc Stine, Commissioner
Minnesota Pollution Control Agency

Final Technical Support Document: Refinements to Minnesota's Sulfate Water Quality Standard to Protect Wild Rice



CLEAN WATER LAND & LEGACY AMENDMENT

MINNESOTA POLLUTION CONTROL AGENCY

August 11, 2017

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MPCA staff thank the researchers who obtained the data on which this document relies. The researchers produced large quantities of high-quality data in a compressed time frame. Research was led by Amy Myrbo at the University of Minnesota Twin Cities campus, John Pastor and Nathan Johnson at the University of Minnesota Duluth campus, Daniel Engstrom and Jill Coleman Wasik at the St. Croix Watershed Research Station of the Science Museum of Minnesota, and Jeff Brenner of the Environmental Laboratory of the Minnesota Department of Health.

This document benefited greatly from a peer review (ERG, 2014) of an earlier MPCA report that analyzed the data (MPCA, 2014). The peer reviewer panel was comprised of Drs. Patrick Brezonik (chair), Gertie Arts, Donald Axelrad, Siobhan Fennessy, Susan Galatowitsch, Mark Hanson, and Curtis Pollman. MPCA subsequently contracted with Dr. Pollman for help in the further analysis of the field data, an effort that resulted in one of the four publications produced from the MPCA-sponsored wild rice research (Pollman et al., in press).

This document benefited from oral and written comments by the participants of the Wild Rice Standards Study Advisory Committee, which met over 20 times from 2011 through 2017. In addition, the analysis benefited from comments by technical staff from Minnesota Tribal staff and staff from the Great Lakes Indian Fish and Wildlife Commission.

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Document number: wq-rule4-15n

Availability of manuscripts based on MPCA-sponsored research that are cited in this document

From 2011-2013 MPCA sponsored extensive research into the effect of elevated sulfate and sulfide on wild rice and potential wild rice habitat. Much of the research was carried out by researchers at the University of Minnesota (at both the Duluth campus and Twin Cities campus) and the St. Croix Watershed Research Station of the Science Museum of Minnesota. Four manuscripts were prepared for publication in peer-reviewed scientific journals. A paper by Pastor et al. (see below) was published in January 2017. A group of three papers that refer to each other were submitted to the Journal of Geophysical Research. Because they refer to each other, they cannot be published until all three are accepted for publication. As of August, 2017, two of the three papers have been accepted, and one is still in review.

The MPCA is not posting the manuscripts on the MPCA website, because it is unethical to publish a scientific paper more than once, and most journals now regard the posting of a paper on a website as a publication. However, sharing a copy of a manuscript is not considered to be a publication. Therefore, copies of the four manuscripts are available from the MPCA, and may be requested but must not be posted on a website.

Published:

(Pastor et al., 2017) Pastor, J., B. Dewey, N. W. Johnson, E. B. Swain, P. Monson, E. B. Peters, and A. Myrbo. 2017. Effects of sulfate and sulfide on the life cycle of *Zizania palustris* in hydroponic and mesocosm experiments, *Ecological Applications*, 27, 321-336. This paper is available from the MPCA.

Accepted for publication:

(Myrbo et al., in press-1) Myrbo, A., E.B. Swain, D.R. Engstrom, J. Coleman Wasik, J. Brenner, M. Dykhuizen Shore, E.B. Peters, and G. Blaha. In press-1. Sulfide generated by sulfate reduction is a primary controller of the occurrence of wild rice (*Zizania palustris*) in shallow aquatic ecosystems. This manuscript is available from the MPCA.

(Pollman et al., in press) Pollman, C.D., E.B. Swain, D. Bael, A. Myrbo, P. Monson, and M. Dykhuizen Shore. In press. The evolution of sulfide in shallow aquatic ecosystem sediments – an analysis of the roles of sulfate, organic carbon, iron, and feedback constraints using structural equation modeling. This manuscript is available from the MPCA.

Submitted, but not yet accepted:

(Myrbo et al., submitted-2) Myrbo, A., E.B. Swain, N.W. Johnson, D.R. Engstrom, J. Pastor, B. Dewey, P. Monson, J. Brenner, M. Dykhuizen Shore, and E.B. Peters. Submitted-2. Increase in nutrients, mercury, and methylmercury as a consequence of elevated sulfate reduction to sulfide in experimental wetland mesocosms. This manuscript is available from the MPCA.

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Introduction

The federal Clean Water Act requires states to designate beneficial uses for all water bodies (i.e. "waters") and develop water quality standards to protect each use. Water quality standards include several components:

- Beneficial uses — identification of how people, aquatic communities, and wildlife use waters.
- Numeric standards — typically the allowable concentrations of specific chemicals in a waterbody, established to protect beneficial uses. Can also include measures of biological health.
- Narrative standards — statements of unacceptable conditions in and on the water.
- Antidegradation protections — extra protection for high-quality or unique waters and existing uses.

Minnesota Rules Chapter 7050 assigns a series of beneficial use classifications to all waters of the state. These use classifications set out the beneficial uses that apply to Minnesota waters. Water use classifications, and their accompanying narrative and numeric standards and antidegradation provisions, make up the state's set of water quality standards. Aquatic life and recreation, industrial uses, agriculture and wildlife, and domestic consumption are some of the beneficial uses that these standards protect. Although there is a lot of commonality among the beneficial uses established by states – for example, every state designates and protects drinking water as a beneficial use – states may also set beneficial uses that reflect the unique nature of their waters and aquatic resources.

Minnesota's Class 4 water quality standards protect the waters of the state so that they are suitable for "the agriculture and wildlife designated uses." One subclass of Class 4 is Class 4A waters (Minn. R. 7050.0224, Subp 2), which must be clean enough "to permit their use for irrigation without significant damage or adverse effects upon any crops or vegetation usually grown in the waters or area." In 1973, Minnesota established a unique beneficial use by establishing a subset of the Class 4A use class called "water used for production of wild rice" and setting a numeric standard to protect the production of the wild rice grain. Wild rice is an important plant species in Minnesota. It provides food for waterfowl, is economically important to those who harvest and market it, and is also an important cultural resource to many Minnesotans.

The specific pollutant from which the "water used for production of wild rice" is protected is sulfate. Sulfate is a natural chemical commonly found in surface and groundwater. It can also be found at varying concentrations in discharges from permitted facilities such as mining operations, municipal wastewater treatment plants, and industrial facilities. The observed relationship between the presence of wild rice in waters with lower sulfate levels, and its absence in waters with elevated sulfate, led to the adoption of the wild rice sulfate standard in 1973.

Minnesota's wild rice sulfate standard came under scrutiny in the 2000s. Of particular interest was better understanding the effects of sulfate on wild rice in order to understand the appropriateness of the standard and its implementation. The need to clarify which waters support the wild rice beneficial use was also identified.

In 2011 the Minnesota Legislature provided $1.5 million in funding for the MPCA to conduct a Wild Rice Sulfate Standard Study to gather additional information about the effects of sulfate and other substances on the growth of wild rice. The legislation also required the MPCA to undertake rulemaking to identify wild rice waters and to make any other needed changes to the sulfate standard following completion of the study.

Following the completion of the Wild Rice Sulfate Standard Study in December 2013, MPCA reviewed the results and developed a preliminary analysis of the research, which it then shared with stakeholders in March 2014 (MPCA, 2014). MPCA staff met with many partners and stakeholders, and continued to refine the analysis of the research based on comments received, review of additional literature and additional statistical analyses. The result of this effort was completion of the Analysis of the Wild Rice Sulfate Standard Study — Draft for Scientific Peer Review in June 2014 (MPCA, 2014).

MPCA then contracted with Eastern Research Group, Inc. (ERG) to convene and facilitate a scientific peer review of the study and analysis. Full details, background documents and the final report from ERG on the scientific peer review process can be found on the MPCA's webpage about the wild rice sulfate standard study.

MPCA refined its analysis based on the peer review and tribal and Advisory Committee feedback, and in March 2015 MPCA released a Draft Proposal for Protecting Wild Rice from Excess Sulfate (MPCA, 2015).

The Draft Proposal included:

- A proposed draft approach to the wild rice water quality standard;
- A draft list of waters where the standard would apply; and
- Draft criteria for adding waters to the list over time as new or additional information becomes available.

The Draft Proposal was shared broadly, including through a Request for Comments (RFC) asking the public for comments and information about wild rice sulfate standard rulemaking.

As a result of comments and questions received following release of the Draft Proposal, MPCA has re-analyzed data from the studies using different statistical approaches. This reanalysis included review of the following:

- Field survey data used to relate wild rice presence to sulfide in the sediment;
- Field survey data that relate sulfate to sulfide;
- Basic assumptions relating sulfate to wild rice;
- Choice of which data set of sites from 2011-2013 field work would be most appropriate to use in analyses; and
- Variables controlling conversion of sulfate to sulfide.

The MPCA then published a draft Technical Support Document (draft TSD; MPCA, 2016) in 2016 as the next step in the ongoing effort to better understand the effects of sulfate on wild rice to inform an evaluation and, as needed, a revision to the standard.

The Draft TSD was shared broadly and the MPCA received partner and stakeholder input. This Final TSD provides the main scientific support for the MPCA's proposed changes to the wild rice sulfate standard. It revises and updates the draft TSD, providing additional analyses and explanations. Some information provided in the Draft TSD has been moved into the Statement of Need and Reasonableness (SONAR, MPCA 2017). Together, the SONAR and this TSD, along with their exhibits and reference materials, support the MPCA's proposed changes to the wild rice sulfate standard.

Chapter 1. Numeric wild rice sulfate standard

This chapter of the TSD focuses on the mechanism by which sulfate impacts wild rice, and the numeric standard for protecting wild rice from excess sulfate. This chapter is organized as follows:

Part A introduces the primary hypothesis that guided MPCA's technical investigation (namely: if sulfate is harmful to wild rice, sulfate acts by being converted to hydrogen sulfide (sulfide) in the sediment in which wild rice grows), and presents evidence that sulfide exerts significant control over the presence and absence of wild rice in Minnesota's shallow aquatic systems.

Part B refutes the argument that it is not necessary to protect wild rice from elevated sulfide, given that there are multiple other environmental stressors affecting the occurrence of wild rice in water bodies aside from sulfide, such as changes in water levels, impacts of watershed development, and the presence of invasive or competitive species.

Part C presents the evidence used to identify 120 micrograms per liter (µg/L) in sediment porewater as the sulfide concentration that is protective of wild rice populations in natural water bodies. Identification of a protective sulfide concentration is a necessary step in the development of a sulfate standard. The next step is to develop a quantitative relationship between sulfate and sulfide.

Part D shows that the relationship between surface water sulfate and porewater sulfide differs among water bodies, and is dependent on sediment concentrations of organic matter and iron.

Part E presents an equation that allows the calculation of a numeric sulfate standard for each wild rice water, as an alternative to maintaining the existing 10 mg/L standard or establishing a different fixed number as the sulfate standard for all wild rice waters.

Part F shows that the equation-based sulfate standard is more accurate than any fixed standard at protecting wild rice from elevated sulfide. Any fixed standard has a higher error rate (being too high or too low than necessary to be protective) than the equation.

A. Confirmation that porewater sulfide is a primary controller of wild rice occurrence

The MPCA began its investigation of the effect of sulfate on wild rice in 2010 by reviewing the scientific literature. After this initial evaluation, MPCA determined that additional studies were needed to better understand the effects of sulfate on the growth of wild rice. In early 2011, MPCA staff scientists prepared a draft research protocol that was designed to further investigate the effects of sulfate on wild rice. On May 9, 2011, MPCA sponsored a discussion of the draft research protocol that included 36 scientists with pertinent expertise (13 from the University of Minnesota, seven from Federal agencies, six from Minnesota tribes, five from the MDNR, and five scientists with other affiliations). The scientists discussed the draft research protocol, which hypothesized that if sulfate is important in controlling the occurrence of wild rice, the active agent would be a result of bacterial conversion of the sulfate to hydrogen sulfide (H_2S) in the sediment where wild rice seeds germinate and grow. In water-saturated sediment, which are usually anoxic, some bacteria that degrade organic matter in the sediment "respire" sulfate, rather than oxygen, producing hydrogen sulfide. The chemical form of hydrogen sulfide varies with pH; below pH 7 H_2S dominates, and above pH 7 the bisulfide ion (HS^-) dominates. For simplicity in this document the sum of the two chemical species is referred to as sulfide.

The 2011 Legislature provide funding to research the effects of sulfate and other substances on wild rice. The research protocol was revised in response to the expert discussion, and finalized on November 8, 2011 (MPCA, 2011). Following a preliminary data collection effort in 2011, in 2012 the MPCA issued a Request for Proposals and ultimately contracted with groups of scientists at the University of Minnesota Duluth and Twin Cities campuses to undertake a study to better understand the effects of sulfate and other substances on wild rice. The MPCA study focused on collecting data on the relationship between sulfate, sulfide, and wild rice through three major parallel study components.

The components each had a specific purpose and associated strengths and limitations (Table 1-1). The study was designed so that the individual components together provided a better understanding of the effects of sulfate on wild rice. The three major study components were:

- Field surveys of wild rice habitats to investigate physical and chemical conditions correlated with the presence or absence of wild rice, including sulfate in surface water and sulfide in the sediment porewater of the rooting zone.
- Controlled laboratory hydroponic experiments to determine the effect of elevated sulfate and sulfide on early stages of wild rice growth and development.
- Outdoor container (mesocosm) experiments using natural sediments to determine the multi-year response of wild rice and other variables to a range of sulfate concentrations in the surface water.

Scientists also conducted additional research via a laboratory experiment to examine the effect of temperature on the movement of sulfate between water and sediment.

Table 1-1. Purpose, strengths, and limitations of the components of the MPCA-sponsored wild rice research.

	Field survey	Laboratory hydroponic experiments		Outdoor container experiment	Sediment incubation laboratory experiment
		Sulfate	Sulfide		
Main purpose	Expand understanding of environmental conditions correlated with the presence & absence of wild rice	Evaluate effects of sulfate on wild rice seed germination and growth of seedlings	Evaluate effects of sulfide on wild rice seed germination and growth of seedlings	Evaluate effects of sulfate loading on sulfide and wild rice life cycle, over multiple years	Evaluate effect of temperature on movement of sulfate into and out of underlying sediment
Endpoints	Concentrations of chemicals in surface water, porewater, & sediment (e.g., sulfate & sulfide) vs. wild rice occurrence	Growth of wild rice sprouts (biomass, root and shoot elongation); germination rate of seeds	Growth of wild rice sprouts (biomass, root and shoot elongation); germination rate of seeds.	Growth of wild rice (biomass, plus number and weight of seeds); sulfide concentrations in rooting zone	Sulfate concentrations in overlying water over time; sulfate, iron, sulfide, and anion tracers in sediment porewater; simple model
Key strengths	Most reflective of actual environmental conditions; multiple wild rice stands and breadth of characteristics sampled	Controlled dose-response experiment; controlled exposure to known concentrations of SO_4	Controlled dose-response experiment; controlled exposure to known concentrations of sulfide	Controlled dose-response experiment. Includes natural sediment matrix as rooting environment; involves entire growth cycle, multiple years	Controlled experiment with natural sediment and water
Key limitations	Least controlled; annual visit for most sites, 3x/year for a subset; not definitive on cause and effect	Only evaluates early growth stages; leading hypothesis is that sulfate is converted to sulfide, which is directly toxic	Only evaluates early growth stages; unable to simultaneously keep roots anaerobic and shoots aerobic	Eventual steady states with various sulfate loads may not mimic the environment, since there is no loading of other key constituents, such as iron, from groundwater or the watershed.	Provides preliminary assessment of sediment from two sites that may inform, but is not fully transferrable to other sites; no groundwater movement; no wild rice plants grown
Reference	Myrbo et al. (in press-1.)	Pastor et al. (2017)		Pastor et al. (2017); Myrbo et al. (submitted-2)	DeRocher & Johnson (2013) Report to the MPCA.

Impact of porewater sulfide on plants and animals

In 2010, when the MPCA began its investigation on the impact of elevated sulfate and sulfide on wild rice, MPCA could find no scientific information specific to sulfide impacts on wild rice. However, elevated sulfide is a well-documented concern for other aquatic plants that root in sediment (reviewed by Lamers et al., 2013).

EPA has provided guidance on surface water criteria for sulfide, setting a level of 2 micrograms per liter (µg/L) as the maximum that can be present in a surface water before sulfide is likely to harm aquatic life. Though EPA produced this value 30 years ago (EPA, 1986), remarkably little attention has been given since then to the potential toxicity of sulfide to benthic animals and aquatic plants that root in sediment. In a major review, Bagarinao (1992) concluded that sulfide had been "…largely overlooked as an environmental factor for aquatic organisms." In a discussion of sediment toxicity testing, Wang and Chapman (1999) also observed that the biological implications of sulfide in sediments are poorly understood and "all too often ignored."

Little information has been developed about how sulfide controls the occurrence of plants and animals in water-saturated sediments and soils. A recent review (Kinsman et al., 2015) concluded that the potential toxicity of porewater sulfide is likely shaping the plant and animal communities of aquatic ecosystems, yet little data has been collected. In an exception to the paucity of data, Simkin et al. (2013) showed that porewater sulfide controlled the distribution of wetland plants more than nutrients. In their introduction, they wrote "…it is puzzling that there has not been more work to investigate the possible role of sulfide as a master variable controlling plant community composition within inland wetland ecosystems." Lamers et al. (2013), in a review of sulfide toxicity to aquatic plants, pointed out that traditional toxicity testing generally neglects the chemistry of the rooting zone.

Aquatic plants that root in marine sediment have evolved in a high-sulfate, high-sulfide environment. Ocean water averages 2,800 mg/L sulfate, so anoxic bacteria in marine sediment can potentially produce high concentrations of sulfide as bacteria degrade sedimentary organic matter. Recently, elevated sulfide has been implicated as the causative agent in a worrying global decline of marine seagrasses, which in some ways are a marine analog to wild rice. Seagrasses, which are perennial, and wild rice, which is an annual plant, are distantly related monocots that both inhabit shallow waters, although seagrasses are often totally submerged. Seagrasses colonize shallow coastal areas worldwide, providing habitat for animals and numerous ecological services. Seagrasses successfully live in the presence of high sediment sulfide by producing high amounts of oxygen through photosynthesis and transporting that oxygen to the roots, which detoxifies the sulfide by converting it back to sulfate. As a result, seagrasses require some of the highest light levels of any plant group (Orth et al., 2006). The primary hypothesis to explain the global decline of seagrasses is that sulfide toxicity is occurring more often as a result of a variety of human activities, including those that reduce underwater light or oxygen levels. In freshwater systems, elevated sulfide could be a result of sulfate pollution, so it makes sense to regulate sulfate in freshwaters. But because sulfate is uniformly high in ocean water, factors other than sulfate have been implicated in increased sulfide production or toxicity. Seagrasses are particularly vulnerable to any processes that reduce light availability, such as eutrophication or dredging of sediment (Orth et al., 2006). In addition, factors that enhance porewater sulfide concentrations have been implicated in the decline of seagrasses, including increased temperature (Koch and Erskine, 2001), increased sediment organic matter (Govers et al., 2014), and iron-poor sediment (Marbà et al., 2008). Sulfide concentrations are greater in iron-poor sediment because iron can remove sulfide from solution. It is thought that only dissolved sulfide is potentially toxic to plants and animals.

Evidence that elevated sulfide can exclude wild rice from otherwise suitable habitat

The MPCA-sponsored field survey of potential wild rice habitat, conducted 2012-2013 (Myrbo et al., in press-1), involved sampling 108 different sites and quantifying 65 field variables (Table 1-2). Some waterbodies were sampled on more than one date. For statistical purposes, a sub-set of the data (called "Class B") was identified where each waterbody is represented by the sample closest to August 11 (the median sample date), in an effort to control for any seasonal variability. Myrbo et al. used the Class B dataset to evaluate the relationship between wild rice presence (or absence) and environmental variables through binary logistic regression (Table 1-3). In addition, Myrbo et al. correlated wild rice density at a site to the environmental variables through nonparametric Spearman tests (Table 1-3).

Field data used for statistical tests of variables that may control wild rice

The Class B data set was used for statistical tests that correlate the presence or density of wild rice against environmental variables that may control wild rice. Class B was used because this data set is the best available approximation of a random sample of potential wild rice waters that includes porewater sulfide and other variables pertinent to wild rice hypotheses. The primary hypothesis prior to conducting the MPCA field survey was that sulfide, rather than sulfate, controlled wild rice presence and absence (MPCA, 2011). It was essential to sample sites that did not have wild rice, in addition to sites with wild rice, so that variables that control the absence of wild rice could be assessed (see analysis below for further discussion of this point). Therefore, sampling only known wild rice sites would not have allowed the assessment of potentially important variables such as sulfate and sulfide. Furthermore, there was no existing data on porewater sulfide in wild rice habitat, and incomplete data on sulfate in surface waters, although the general trend of sulfate concentrations across Minnesota was known. Since it was likely that porewater sulfide was a function of sulfate in surface water, the field survey was conducted to sample a range of sulfate in waterbodies that could potentially host wild rice. Since it had been noted by naturalists and scientists that both white and yellow waterlilies co-occur with wild rice (Pillsbury and McGuire, 2007), the presence of waterlilies was used to identify potential wild rice habitat when wild rice plants could not be found in a waterbody (for further discussion, see below). Therefore, in an effort to determine the effect of elevated sulfate on wild rice, known waters with wild rice (which tended to be low in sulfate) were sampled, plus potential wild rice habitat where elevated sulfate was suspected based on geography or local land use, resulting in the Class B data set. The representativeness of the Class B data can be assessed by comparing quantile sulfate concentrations against other data sets (Table 1-2). Class B includes data from both lakes and streams. The distribution of sulfate concentrations in the Class B data set is appreciably higher than wild rice lakes, but closely approximates the randomized survey of Minnesota lakes conducted by the EPA in 2012 (Table 1-2).

In general, Minnesota streams and rivers have higher concentrations of sulfate than lakes; randomized EPA surveys found that the median, or typical, stream sulfate concentration is 17.0 mg/L, compared to 3.0 mg/L in lakes. The median concentration in Class B streams of 10.0 mg/L is appreciably higher than the median of Class B lakes, 4.1 mg/L, but not as high as the EPA's random survey. It is unclear why the Class B stream data did not better follow the distribution of sulfate across Minnesota, but it may be because a smaller number of streams were sampled than lakes (27 compared to 81) and because the field crews were mainly sent to sites known to host wild rice (80% of stream sites had wild rice, compared to 55% of lakes).

Overall, the Class B data set is the best available approximation of a random sample of potential wild rice waters. Extrapolation of the data is mainly performed later in this TSD to assess the accuracy of models that relate sulfate in surface water to sulfide in porewater.

Table 1-2. Summary statistics for sulfate concentrations in various datasets.

Data Set	Quantile Sulfate Concentration (mg/L)			Number of sites
	25%	50%	75%	
Lakes with reported wild rice (Available sulfate data for lakes listed in MDNR, 2008)	1.0	1.8	3.6	520
All Minnesota Lakes (2012 EPA National Lakes Assessment)	0.3	3.0	13.1	50
Class B Lakes	1.0	4.1	14.6	81
Class B Streams	1.6	10.0	16.6	27
All Minnesota Streams and Rivers (2008 EPA National Rivers and Streams Assessment)	2.0	17.0	47.3	52
All Class B waterbodies (Lakes and Streams)	1.2	5.9	15.6	108

When the field crews could not find wild rice in a waterbody, they sampled the water and sediment at a location where wild rice would most likely be growing if it were to grow in that waterbody. These "non-wild rice" sampling locations were usually identified by the presence of either white or yellow waterlilies. The presence of waterlilies is taken to indicate that the habitat is similar to the habitat required by wild rice, because waterlilies and wild rice frequently co-occur (Pillsbury and McGuire, 2009). In addition, in an analysis of 1,753 MDNR aquatic plant surveys from shallow Minnesota lakes, the odds of finding wild rice where there are water lilies are 27 times the odds of finding wild rice where there are no water lilies, with a 95% confidence interval of 20-36 times. This high odds ratio is strong evidence that wild rice and waterlilies share many habitat requirements, although it appears that waterlilies may have a higher tolerance to elevated sulfide concentrations.

Statistical evaluation of variables that may control wild rice

Binary logistic regression (BLR) is the classic method for scientists to identify environmental variables that control the suitability of habitat for a particular species of interest (Hosmer and Lemeshow, 1989; Peeters and Gardeniers, 1998; van der Heide et al., 2009). BLR is "binary" in the sense that it classifies field sites as having, or not having, the species of interest—in this approach, the density of the species is irrelevant to the classification. Conservation biologists use binary information (presence/absence) in the analysis of habitat suitability; density is rarely used because representative density data are difficult to obtain and density can be a function of factors unrelated to the long-term suitability of the habitat. For example, even in excellent wild rice habitat the density of wild rice in a given year can be reduced by a hydrologic event or by animals that use wild rice for food or for nesting material. The entire wild rice plant provides food during the summer for herbivores such as Canada geese, trumpeter swans, muskrats, beaver, white-tailed deer, and moose, and the stems are harvested for nesting material by loons, red-necked grebes, and muskrats (MDNR, 2008, p. 9).

The field survey quantified the wild rice density (stems/m^2) in four 1-m diameter circles around the boat where the sediment samples were collected; this does not represent the entire waterbody. The field crew did not attempt to sample a site that was "typical" of the wild rice bed, which would have been difficult to determine. Rather, it was considered adequate to take the canoe or small boat anywhere into the wild rice bed for sampling of the water and sediment. There was no reason to expect that the wild rice density at the sampling site would be well correlated with any single environmental parameter, because wild rice density fluctuates significantly from year to year for many reasons, such as temporary nitrogen immobilization in plant litter, hydrologic fluctuation, herbivory, and other disturbances (Tables 1-6 and 1-7).

Using BLR, Myrbo et al. (in press-1) identified 12 variables that may be important in controlling the presence or absence of wild rice, as they were all significant at the 0.05 probability level or better (Tables 1-2 and 1-3). To examine the relationships among all the field variables, a Spearman correlation matrix was calculated (Table 1-4), which revealed that many of the 12 variables are correlated with each other. Because Spearman correlations are not designed for binary data, the correlation matrix included the wild rice density (stems/m^2), despite the fact that the density variable just represents wild rice density around the boat at the sediment sampling site and did not characterize the wild rice bed as a whole. Somewhat surprisingly, the Spearman correlations between wild rice stem density and environmental variables generally agreed the BLR results, although sometimes at lower significance levels (Table 1-4).

Identification of three causative variables in wild rice presence/absence

Myrbo et al. (in press-1) concluded that, out of the 12 identified potentially causative variables, there are just three factors that have direct effects on wild rice — and that the other potentially causative variables are actually correlated with the truly causative factors. The three causative factors are porewater sulfide, surface water transparency, and surface water temperature. These can be understood as having effects on wild rice that, although independent of each other, also interact, especially in reinforcing correlations with other variables such as a negative correlation with total nitrogen in the surface water (see Table 1-5). Surface water nitrogen is an example of a field variable that does not act directly on wild rice, but nevertheless is significantly correlated with the absence of wild rice because it has mechanistic relationships to more than one of the three directly causative variables (Table 1-5).

The available evidence, coupled with the established scientific understanding of the biogeochemical processes of shallow aquatic ecosystems, suggest that the three causative variables act as follows: Elevated porewater sulfide reduces the growth of wild rice, either by direct toxicity or indirectly by impairing nutrient uptake (Pastor et al., 2017); water transparency below 30 cm essentially excludes wild rice from a waterbody due to light limitation (Myrbo et al., in press-1); and elevated temperatures limit the geographic range of this species of wild rice, *Zizania palustris* (Myrbo et al., in press-1).

Regarding the temperature effect, although the measured temperature variable was summer surface water temperature, the actual mechanism is more likely that the sites with higher summer temperatures also are the sites where winters fail to be sufficiently cold. The seeds of *Zizania palustris* are said to need at least three months of submersion in near-freezing water in order to break dormancy (Cardwell et al., 1978), but the needed winter and spring temperatures to break dormancy are incompletely understood (Atkins et al., 1987; Kovach and Bradford, 1992). Atkins et al. (1987) performed an experiment that incubated wild rice seed at 5 C for 5, 6, and 7.5 months, and found the highest germination after 7.5 months, but did not investigate other incubation temperatures. They also found that germination rates were greater in diurnally fluctuating temperatures rather than in constant temperatures.

Cultivated varieties of Minnesota's wild rice are grown successfully in the Central Valley of California, which has a warmer summer than Minnesota (Fig. 1-1), indicating that high summer temperatures are likely not the limitation of wild rice range. But the winters of the Central Valley of California are too warm to break the seed dormancy, so Central Valley wild rice farmers store the seed for the next growing season over the winter under water in refrigerated facilities (Marcum, 2007). Therefore, a reasonable hypothesis generated by the observed negative correlation of wild rice occurrence with temperature is that the southern border of the wild rice range may be limited by too-warm winter temperatures, in addition to a progressively greater loss in potential shallow-water habitat due to geographic patterns in both geology and land use. MDNR (2008, p. 30) suggested that climate change-caused increases in winter temperatures could threaten the occurrence of wild rice at the southern portion of its range, due to inadequate seed exposure to cold temperatures. The strongest temperature effect of climate change in Minnesota is warming winters (Seeley, 2006, p. 84).

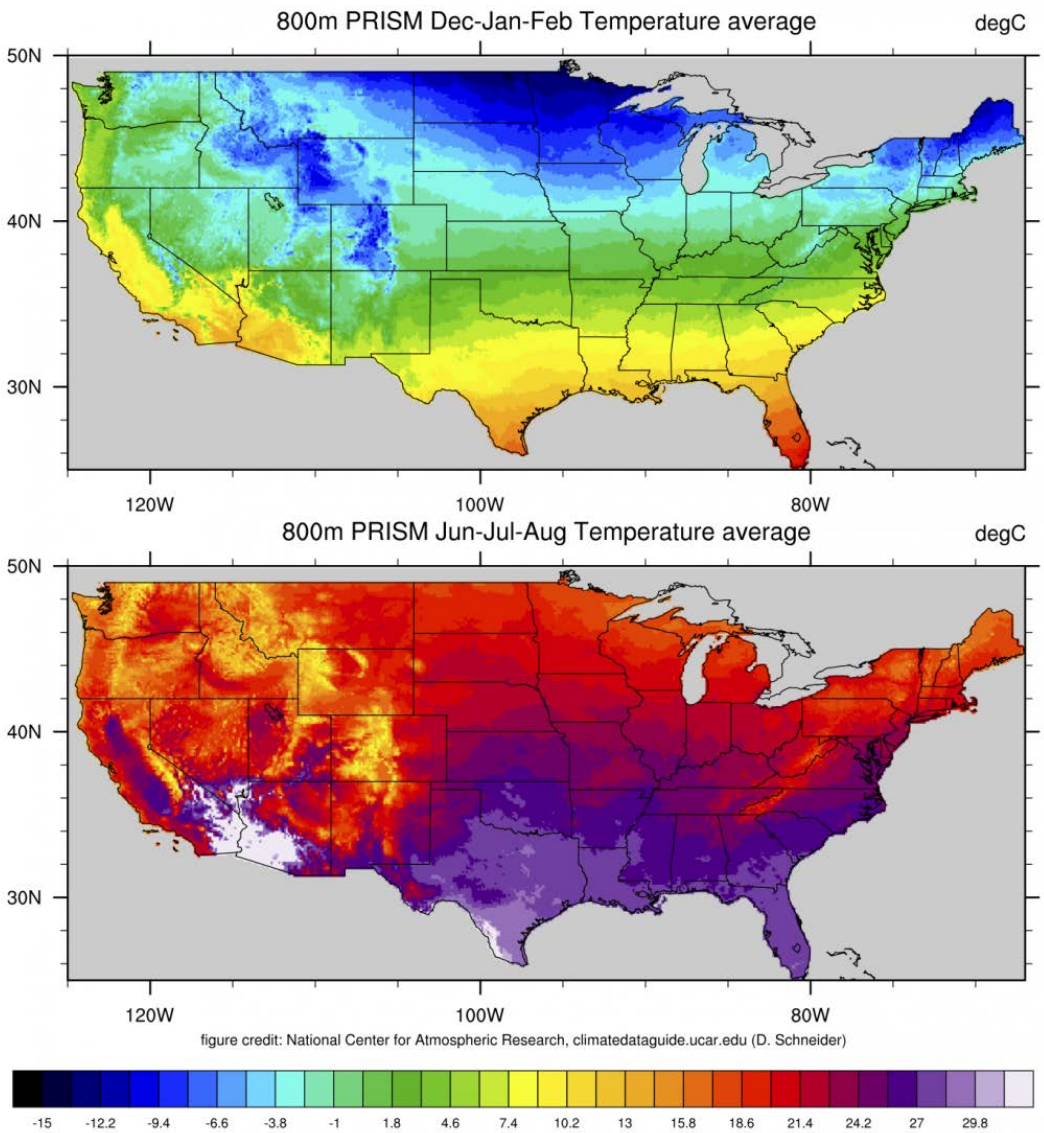


Figure 1-1. Average temperatures across the United States in winter (top) and in summer (bottom). From https://climatedataguide.ucar.edu.

Interaction of the three causative variables with other environmental variables

Even though the three causative variables may act independently of each other, there are likely interactions among the three variables, plus secondary effects that are correlated with wild rice presence/absence but are not causative (Myrbo et al., in press-1). For instance, additions of sulfate to waterbodies increases sulfide production, which interacts with iron to release phosphate that had been associated with iron. Furthermore, sulfate-stimulated microbes decompose sedimentary organic matter that would have not otherwise decomposed, which releases the nutrients phosphorus and nitrogen to the surface water, allowing increased phytoplankton growth. Therefore, sulfide production is correlated with increased phytoplankton, which reduces water transparency, inhibiting wild rice growth. Elevated phosphorus and nitrogen in surface water are significantly correlated with the absence of wild rice in waterbodies. These correlations most likely occur because a) the nutrients were released as a result of sulfate-enhanced decomposition of organic matter, producing toxic levels of sulfide (Myrbo et al., submitted-2), and b) their increased concentrations in surface water produced lower water transparency, which limits wild rice growth (Myrbo et al., in press-1; Table 1-5).

The production of sulfide, while negative for wild rice growth at higher porewater concentrations, also affects other variables, causing other observed correlations with wild rice (Tables 1-2, 1-3, and 1-4). These sulfide-related correlations with wild rice can be either negative, such as between wild rice and porewater potassium (K), or positive, such as the positive correlation of wild rice with porewater iron. The latter is the easiest to understand, because dissolved sulfide and dissolved iron react with each other to form a solid precipitate of iron sulfide. When porewater iron is high, sulfide is low, resulting in a positive correlation between porewater iron and wild rice, which is weaker ($p < 0.01$) than the negative correlation between porewater sulfide and wild rice ($p < 0.001$).

By performing multiple binary logistic regression (MBLR) of variables against the presence/ absence of wild rice, it is possible to determine if a variable acts independently of the three causative variables, or is simply correlated with one or more of the causative variables. In MBLR, porewater iron does not improve a model with just porewater sulfide as the predictor, and therefore the positive correlation of porewater iron with wild rice is likely just caused by the effect of sulfide on wild rice. Similarly, the significant correlation of wild rice with the concentration of total sulfur in the sediment ($p=0.048$) is probably a consequence of the strong correlation between total sulfur and porewater sulfide ($p<0.001$). The addition of the variable total sulfur to a regression does not improve the explanatory power of a regression just based on porewater sulfide, indicating that total sulfur is negatively correlated with wild rice because it is correlated with porewater sulfide, the actual causative factor (Myrbo et al., in press-1).

The negative correlations of porewater potassium (K) and surface water total nitrogen (TN) with wild rice are likely the result of their positive correlations with porewater sulfide (Table 1-5). These correlations are most easily understood in terms of the role that sulfide production plays in shallow aquatic systems: when sulfate-respiring bacteria dominate microbial activity, sulfide production is proportional to the decomposition of sedimentary organic matter, which releases the nutrients contained in the decaying plants, including potassium and nitrogen (Myrbo et al., in press-1; Myrbo et al., submitted-2; Lamers et al., 1998). In the field survey data, porewater sulfide is also positively correlated with surface water potassium and porewater concentrations of total nitrogen, ammonia, and silica (Table 1-4), all of which are released as plants decompose. The controlled sulfate-addition outdoor mesocosm experiment provides evidence that sulfide production also mobilizes phosphorus from the sediment into the overlying water, an effect supported by a positive correlation between sediment acid-volatile sulfide (AVS) and surface water phosphorus in the field data (Table 1-4). (Note that when sulfide is produced, it can either stay in the porewater or precipitate with iron; AVS is the sum of the two forms).

The strong correlation between porewater potassium with the absence of wild rice (Tables 1-4, 1-5) is remarkable, as potassium is an essential plant nutrient and therefore it is unlikely that the association is based on toxicity to wild rice. Rather, it is likely that the association is a result of the simultaneous mobilization of potassium with the production of sulfide as plant matter is decomposed simultaneously with the conversion of sulfate converted to sulfide by bacteria. Potassium does not bond covalently with organic compounds and is readily leached out of dead organic matter (Troeh and Thompson, 2005). Silica phytoliths dissolve as plant matter decomposes, allowing additional potassium that had been trapped within the phytoliths to be released into sediment porewater (Nguyen et al., 2015). Wild rice and other wetland macrophytes develop abundant phytoliths that release dissolved silica upon the decomposition of the plant tissue (Struyf and Conley, 2009). Porewater silica, potassium, and sulfide are all significantly correlated with each other (Table 1-4). The negative correlation of porewater potassium with wild rice may be magnified by its additional positive correlation with elevated water temperature (Table 1-5), which plausibly not only accelerates decomposition , but also the dissolution of silica phytoliths in the decomposing organic matter (Kamatani, 1982; Gudasz et al., 2010).

The release of potassium as sulfide is produced during the decomposition of plants is the likely explanation for an observed negative correlation between elevated potassium in surface water and wild rice growth and abundance metrics (Walker and Tuominen, 2014). Walker and Tuominen surveyed wild rice density and sampled surface water lakes and streams in northeastern Minnesota, but did not sample porewater sulfide.

Even though nutrients that limit plant growth (phosphorus and nitrogen) are not toxic to wild rice, the release of plant nutrients associated with the conversion of sulfate to sulfide can increase phytoplankton growth, reducing the light available to wild rice. Water transparency is negatively correlated both with the occurrence of wild rice and wild rice density (Table 1-3). In the field survey data, water transparency is negatively correlated with surface water phosphorus and nitrogen, but not with porewater sulfide. The lack of correlation with porewater sulfide implies that lowered transparency is negative for wild rice regardless of the porewater sulfide concentration, a conclusion confirmed in MBLR analysis (Myrbo et al., in press-1). Aside from phytoplankton abundance, transparency is also controlled by water color, with which it is highly correlated (Spearman's rho= -0.68). Water color is also negatively correlated with the stem density of wild rice, but is not correlated with porewater sulfide (Table 1-4).

The temperature of the surface water measured when each site was sampled is negatively correlated with the presence of wild rice, but temperature is not correlated with porewater sulfide or transparency (Tables 1-2, 1-3, and 1-4), suggesting that temperature limits the range of wild rice independently of porewater sulfide and transparency. In MBLR, water temperature improves a model based on porewater sulfide, suggesting that temperature acts independently of sulfide. Higher temperatures may increase sulfide production by enhancing the activity of the microbial community, but that effect is already accounted for in the concentration of sulfide, so temperature must have an independent negative effect on wild rice (Myrbo et al., in press-1). Consistent with the overall climatic patterns across Minnesota, the surface water temperature variable is negatively correlated with both latitude and longitude (Table 1-4). Although wild rice occurrence is correlated with the measured surface water temperature during the summer field surveys, as discussed above the actual mechanism acting on wild rice habitat may be winters that fail to be sufficiently cold to break seed dormancy (sites with warmer summer temperatures would be the same sites with warmer winter temperatures).

Minnesota varieties of wild rice grow well in the warmer summer temperatures of the California Central Valley, but the Central Valley winter is too warm to break the dormancy of wild rice seeds. Therefore, the correlation in the field survey between higher summer temperatures and lower probability of wild rice occurrence is more likely due to overly warm winter temperatures than overly warm summers. In the field survey data, temperature is not correlated with other variables that are known to control wild rice occurrence (sulfide and water transparency), and therefore elevated temperatures seem to have an independent negative effect on wild rice occurrence.

How access to oxygen may allow wild rice to detoxify sulfide

Wetland plants, including wild rice, have adaptations to survive long-term rooting in anoxic sediment, a condition that is fatal to virtually all terrestrial plants. Wetland ecologists recognize the production of sulfide in anoxic sediment as one of the major challenges facing plants that root in water-saturated soils (Ponnamperuma, 1972; Kirk, 2004; van der Valk, 2012). To deal with elevated sulfide, wetland plants have adaptations that allow them to decrease the toxicity of sulfide, increasing their chances of successful growth and reproduction. Wetland plants can detoxify sulfide by two broad routes involving oxygen: 1) releasing oxygen from their roots to oxidize porewater sulfide, thereby decreasing sulfide concentrations and associated toxicity, and/or 2) transporting oxygen to their roots to allow internal detoxification of sulfide that has penetrated the root tissue.

Each of these detoxification mechanisms require oxygen to be transported to the roots of the plants. Oxygen is moved to the roots of wetland plants through specialized tissue, aerenchyma, that forms a conduit from the leaves to the roots. Plants adapted to growth in water-saturated soil (or sediment), such as wild rice, transport oxygen to tissues under water and to the roots because there is no oxygen in the sediment. On a volumetric basis, the maximum oxygen content of water is at least 27 times lower than in the atmosphere (Caraco et al., 2006).

Wild rice could obtain oxygen to send to the roots from either the atmosphere (if it has grown enough to reach the water surface) or photosynthetically-produced oxygen, or both. Experiments with another grass genus, *Phragmites,* have shown that release of oxygen from roots is much greater if the plant has access to the atmosphere, rather than being completely submerged (Armstrong et al., 1999). There is no evidence that wild rice would not also transport more oxygen to the roots when emergent from water compared to completely submerged. In the *Phragmites* experiments, oxygen transport to the roots by submerged plants was always at least 40% less than in plants that emerged into the atmosphere. Submerged plants released more oxygen from roots when illuminated, due to photosynthesis, but the roots of emergent plants released more oxygen even in the dark night than the roots of illuminated submerged plants during the day.

Access to the atmosphere could help explain the large difference between the apparent toxicity of sulfide to wild rice as measured in a hydroponic test in which wild rice seedlings were completely submerged (Pastor et al., 2017) and a hydroponic test in which wild rice seedlings were allowed to emerge into the atmosphere (Fort et al., 2017). The lesser toxicity of sulfide in the latter experiment would be explicable if the wild rice seedlings were able to use the elevated oxygen concentrations from the atmosphere to enhance internal detoxification. However, under natural conditions, the seedlings (a maximum of 21-days old) would not have access to the atmosphere because the stems would not yet have elongated sufficiently to reach the water surface. Perhaps neither hydroponic test perfectly mimicked the natural environment, given that it is not definitively known to what sediment depth wild rice seedlings begin development. If seeds germinate at depth in the anoxic sediment, the elongating stem has the potential to be exposed to elevated sulfide; it should not be assumed that only the roots are exposed elevated sulfide. When seeds ripen in the fall, plants drop their seed into the water. The individual seeds sink into the water, oriented by a rudder-like awn, and work their way into soft sediment near the parent plant (Aiken et al., 1988). Viable wild rice seeds can stay buried for multiple years in the sediment. Little is known about the environmental cues that causes a seed to germinate, after which it utilizes the energy stored in its starch to elongate its stem upward out of the sediment and through the overlying water to the surface of the waterbody. Oelke et al., (1982) observed that seeds may germinate and emerge successfully from sediment while buried in up to “3 inches in flooded soil” (7.6 cm). Meeker (2000) performed experiments where he examined the ability of seeds to successfully germinate and emerge after burial at sediment depths of 0 cm (the control), 4 cm, or 8 cm. Seeds buried 4 cm emerged from the sediment at a similar rate to the control, but the 8 cm treatment emergent rate was significantly lower. Meeker was not studying exposure to sulfide, so it is unknown what the porewater sulfide concentration was in his experiments.

Pastor et al. (2017) began their experiments with 1- to 2-cm long germinated seeds and exposed the whole seedling to the sulfide treatment. Fort et al. (2017) sprouted wild rice seed at a depth of 1 cm in the hydroponic solution and provided a trellis so that the developing seedling could emerge into the atmosphere, which allowed access to the atmosphere much earlier in development than would occur in nature. In contrast, the hydroponic exposure in the Pastor et al. experiment may actually mimic the exposure of seeds that germinate while buried in up to “3 inches in flooded soil” (Oelke et al., 1982) (7.6 cm). In the three Pastor et al. hydroponic experiments, the controls (zero sulfide) grew to 11 to 14 cm (Pastor, 2013), but the seedlings in the highest sulfide treatments only grew to a maximum of 5.3 to 7.6 cm, a similar distance that germinated wild rice might elongate through anoxic sediment with elevated sulfide concentrations. Thus, the Pastor et al. experiment may mimic the sulfide exposure of seeds that germinate while buried under 8 cm of sediment.

In an outdoor mesocosm experiment, sulfide was significantly lower in sediments with wild rice, indicating that adult wild rice releases oxygen from its roots, oxidizing sulfide (Myrbo et al. mesocosm paper, submitted-2). However, wild rice plants may not need to oxidize the entire pool of elevated sulfide in the porewater to reduce sulfide toxicity if the plant can increase the supply of oxygen to roots and submerged tissues, detoxifying sulfide through the second route. Given the *Phragmites* finding, the ability of wild rice to transport oxygen to the roots and detoxify sulfide would likely be enhanced once the growing seedling reaches the water surface, where it not only can access much higher oxygen concentrations, but where it can photosynthesize at higher rates, producing more oxygen. Therefore, germination in shallow water might allow wild rice to detoxify porewater sulfide more efficiently, both internally and externally. Internal detoxification of sulfide has not been looked for in wild rice, but has been demonstrated in plant tissues from other wetland plants (Lee, 2003; Lamers et al., 2013).

Two mechanisms of internal detoxification of sulfide have recently been described in plants: (1) the conversion of sulfide to the amino acid cysteine by the enzyme OAS-TL C (Alvarez et al., 2012), and (2) the oxidation of sulfide by sulfur dioxygenase (SDO), which produces thiosulfate (Krüssel et al., 2014). The first mechanism does not depend on oxygen availability. The second mechanism, the enzyme SDO, not only requires oxygen, but the detoxification of sulfide can be quantified by measuring the consumption of oxygen (Krüssel et al., 2014; Birke et al., 2015).

In summary, it likely that wild rice is better able to detoxify sulfide after a seedling has grown long enough to reach the atmosphere at the water surface, at which time it grows a floating leaf. The floating leaf can be the source of oxygen that is sent to the roots, where SDO can detoxify sulfide by combining sulfide with oxygen. Wild rice is unusual among grasses in that the stem develops before the root, probably because the seedling may have to grow between 50 and 100 cm before reaching the water surface, at which time floating leaves supply oxygen and energy for root development (Aiken, 1986; Pastor et al., 2017).

Wild rice may be able to tolerate higher levels of porewater sulfide when the seedlings can reach the water surface faster, which would be aided by shallower water and more nitrogen availability. This may be a reason for the lack of an observed negative sulfide effect on cultivated wild rice, since cultivated wild rice is fertilized with nitrogen and water levels are managed. In addition, there is evidence that wetland plants fertilized with nitrogen can better oxidize sulfide around the roots, reducing the potential toxicity (Howes et al., 1986). Five of seven cultivated paddies sampled during the MPCA-sponsored field study exhibited dense wild rice stands where porewater sulfide exceeded 120 µg/L, the concentration identified as protective for natural stands of wild rice. The sulfate standard to protect wild rice needs to maintain porewater sulfide at levels low enough to allow growth and reproduction in natural waters of varying depths and nutrient contents.

Table 1-3. Correlations of field variables with wild rice and porewater sulfide. For sites where multiple samples were collected, the site is represented by the closest sample to August 11, in either 2012-2013 (termed the "Class B" data set; N=108). The variables are ordered by the significance of the variable's correlation with the presence or absence of wild rice, as measured by binary logistic regression (Myrbo et al., in press-1). (PW=porewater; SW=surface water; Sed=Sediment; *=p <0.05; **=p <0.01; ***=p <0.001).

	Spearman Correlation with Field Variable				Binary Logistic Regression for the presence/absence of wild rice	
Field Variable	**Porewater sulfide Correlation (rho)**	**PW sulfide Correlation significance**	**Wild rice density Correlation (rho)**	**Wild Rice Density correlation significance**	**Regression P value**	**Regression significance**
PW K	0.46	***	-0.36	***	0.0008	***
PW sulfide	1.00		-0.35	***	0.0012	**
Water Depth (m)	0.11	not sig	-0.24	*	0.0028	**
Transparency (cm)	-0.07	not sig	0.24	*	0.0031	**
SW TN	0.22	*	-0.23	*	0.0054	**
Sed Se % dry	0.08	not sig	-0.22	*	0.0059	**
SW Temp	0.17	not sig	-0.17	not sig	0.0077	**
PW Fe	-0.58	***	0.21	*	0.0109	*
SW pH	0.28	**	-0.24	*	0.0200	*
SW TP	0.05	not sig	-0.11	not sig	0.0353	*
Latitude	-0.06	not sig	0.19	*	0.0376	*
Sed TS % dry	0.40	***	-0.21	*	0.0483	*
PW Na	0.33	***	-0.25	**	0.0670	not sig
PW Zn	-0.08	not sig	-0.09	not sig	0.0746	not sig
SW Cl	0.29	**	-0.18	not sig	0.0783	not sig
SW K	0.29	**	-0.08	not sig	0.0922	not sig
Sed Cu % dry	0.00	not sig	-0.14	not sig	0.0940	not sig
Sed Al % dry	-0.05	not sig	-0.11	not sig	0.1109	not sig
Sed AVS % dry	0.29	**	-0.10	not sig	0.1317	not sig
SW sulfate	0.44	***	-0.17	not sig	0.1475	not sig
Sed NAI P % dry	-0.06	not sig	-0.04	not sig	0.1958	not sig
Longitude	-0.15	not sig	-0.16	not sig	0.2141	not sig
SW Ca	-0.06	not sig	0.22	*	0.2489	not sig
PW As	-0.43	***	0.15	not sig	0.2642	not sig
Sed TP % dry	0.07	not sig	-0.10	not sig	0.2697	not sig
SW Alkalinity	0.22	*	0.24	*	0.2786	not sig

(continued)

	Spearman Correlation with Field Variable				Binary Logistic Regression for the presence/absence of wild rice	
Field Variable	Porewater sulfide Correlation (rho)	PW sulfide Correlation significance	Wild rice density Correlation (rho)	Wild Rice Density correlation significance	Regression P value	Regression significance
PW TN	0.31	**	-0.23	*	0.2963	not sig
Sed % Coarse of ORG	-0.06	not sig	0.05	not sig	0.3360	not sig
Sed % Fine of ORG	0.05	not sig	-0.05	not sig	0.3575	not sig
Sed Zn % dry	-0.06	not sig	-0.03	not sig	0.3825	not sig
PW Ca	-0.01	not sig	0.22	*	0.4443	not sig
PW NH_4	0.33	***	-0.22	*	0.4505	not sig
Sed TEFe % dry	-0.35	***	-0.01	not sig	0.4795	not sig
PW DOC	-0.05	not sig	-0.01	not sig	0.4865	not sig
Sed Org P % dry	0.07	not sig	-0.08	not sig	0.5468	not sig
PW Si	0.33	***	-0.02	not sig	0.5548	not sig
PW Cu	-0.09	not sig	-0.07	not sig	0.5704	not sig
SW Na	0.26	**	-0.05	not sig	0.5859	not sig
SW Conductance	0.35	***	0.12	not sig	0.6028	not sig
SW Color	-0.11	not sig	-0.20	*	0.6122	not sig
PW TP	0.12	not sig	-0.06	not sig	0.6341	not sig
Sed TIC % dry	0.20	*	0.05	not sig	0.6519	not sig
Sed Inorg LOI	-0.16	not sig	-0.04	not sig	0.6668	not sig
Sed coarse org % dry	0.07	not sig	0.08	not sig	0.6737	not sig
Sed TN % dry	0.14	not sig	-0.08	not sig	0.6807	not sig
SW Fe	-0.33	***	0.02	not sig	0.6827	not sig
Sed fine org % dry	0.09	not sig	-0.07	not sig	0.6971	not sig
SW Mg	0.40	***	0.10	not sig	0.7151	not sig
Sed coarse inorg % dry	-0.15	not sig	0.00	not sig	0.7194	not sig
Sed fine inorg % dry	0.11	not sig	0.07	not sig	0.7267	not sig
Sed Water content	0.15	not sig	-0.07	not sig	0.7274	not sig
Sed Exchangeable P % dry	0.17	not sig	-0.03	not sig	0.7350	not sig
Sed % Coarse INORG	-0.15	not sig	-0.05	not sig	0.7489	not sig
PW Mn	-0.30	**	0.10	not sig	0.7608	not sig
Sec Ca % dry	0.21	*	0.08	not sig	0.7614	not sig

(continued)

Field Variable	Spearman Correlation with Field Variable				Binary Logistic Regression for the presence/absence of wild rice	
	Porewater sulfide Correlation (rho)	PW sulfide Correlation significance	Wild rice density Correlation (rho)	Wild Rice Density correlation significance	Regression P value	Regression significance
Sed % Fine of INORG	0.15	not sig	0.06	not sig	0.7661	not sig
Sed TOC % dry	0.10	not sig	-0.06	not sig	0.7854	not sig
Sed Mg % dry	0.23	*	0.09	not sig	0.8195	not sig
Sed Apatite P % dry	0.08	not sig	0.01	not sig	0.8495	not sig
PW pH	0.03	not sig	-0.04	not sig	0.8976	not sig
Sed org LOI	0.08	not sig	-0.06	not sig	0.9263	not sig
Sed CO_3 LOI	0.25	**	0.06	not sig	0.9677	not sig
PW Mg	0.33	***	0.11	not sig	0.9843	not sig
Sed As % dry	-0.13	not sig	0.17	not sig	0.9913	not sig
Sed Mn % dry	-0.06	not sig	0.13	not sig	0.9915	not sig

Table 1-4. Spearman correlation coefficients for selected environmental variables measured at the field sites. **For sites where multiple samples were collected, the site is represented by the closest sample to mid-August, 2012-2013 (Class B; N=108) sw=surface water; pw=porewater; sed=sediment.**

Spearman Correlation Coefficients P < 0.05 if > 0.19 P < 0.01 if>0.25 P < 0.001 if > 0.33; N = 108	Wild Rice (stems/m2)	Latitude	Longitude	Water Depth (m)	Transparency (cm)	sw pH	sw Temperature	sw Conductance	sw Ca	sw Mg	sw K	sw Na	sw Fe	sw sulfate	sw Cl	sw Alkalinity	sw TP	sw TN	sw Color	pw pH	pw sulfide	pw DOC	pw K	pw Na	pw Fe	pw Mn	pw TP	pw TN	pw NH4	pw Si	pw As	pw Cu	pw Zn	sed Water	sed TS % dry	sed AVS % dry	sed Fe % dry	sed Zn % dry	sed As % dry	sed Cu % dry	sed TP % dry	sed TN % dry	sed TOC % dry
Wild Rice (stems/m2)		0.19	-0.16	-0.24	0.24	-0.24	-0.17	0.12	0.22	0.10	-0.08	-0.05	0.02	-0.17	-0.18	0.24	-0.11	-0.23	-0.20	-0.04	-0.35	-0.01	-0.36	-0.25	0.21	0.10	-0.06	-0.23	-0.22	-0.02	0.15	-0.07	-0.09	-0.07	-0.21	-0.10	-0.01	-0.03	0.17	-0.14	-0.10	-0.08	-0.06
Latitude	0.19		0.05	-0.38	0.13	-0.21	-0.51	-0.21	-0.11	-0.14	-0.30	-0.20	0.20	0.09	-0.54	-0.15	-0.31	-0.25	0.03	0.10	-0.06	-0.06	-0.25	-0.16	0.07	-0.08	-0.26	-0.30	-0.16	-0.28	-0.08	-0.19	0.05	0.01	0.15	-0.09	0.14	0.14	0.19	0.00	-0.04	0.02	0.11
Longitude	-0.16	0.05		0.00	-0.22	-0.38	-0.19	-0.43	-0.16	-0.55	-0.38	0.03	0.55	0.16	-0.03	-0.61	0.06	0.09	0.52	-0.07	-0.15	0.08	-0.41	0.01	0.32	0.30	-0.02	-0.36	-0.27	-0.35	0.04	0.04	0.27	-0.09	-0.06	0.05	0.42	0.42	-0.01	0.40	0.03	-0.08	-0.04
Water Depth (m)	-0.24	-0.38	0.00		0.22	0.16	0.19	-0.05	-0.02	-0.07	-0.07	-0.06	-0.20	-0.03	0.09	-0.09	-0.02	-0.02	-0.20	-0.04	0.11	0.00	0.03	0.00	0.02	0.04	0.05	0.03	0.03	0.10	-0.10	-0.02	0.13	0.13	0.10	0.08	0.09	0.01	-0.05	0.08	0.01	0.17	0.09
Transparency (cm)	0.24	0.13	-0.22	0.22		-0.05	-0.08	0.08	0.09	0.07	-0.18	-0.16	-0.34	-0.07	-0.19	0.11	-0.58	-0.61	-0.68	-0.09	-0.07	-0.21	-0.10	-0.25	0.04	-0.08	-0.26	-0.20	-0.17	0.07	-0.13	0.03	-0.11	0.10	0.03	-0.13	-0.10	-0.16	0.02	-0.12	-0.14	0.06	0.10
sw pH	-0.24	-0.21	-0.38	0.16	-0.05		0.35	0.31	-0.03	0.45	0.44	0.40	-0.39	0.32	0.38	0.27	0.04	0.05	-0.26	0.32	0.28	-0.24	0.45	0.27	-0.31	-0.11	0.11	0.34	0.30	0.26	-0.03	-0.12	-0.21	-0.18	-0.04	0.08	-0.45	-0.41	-0.27	-0.33	-0.25	-0.24	-0.28
sw Temperature	-0.17	-0.51	-0.19	0.19	-0.08	0.35		0.14	0.01	0.22	0.33	0.12	-0.23	0.04	0.35	0.17	0.27	0.23	-0.06	-0.21	0.17	0.09	0.33	0.18	-0.09	0.09	0.26	0.34	0.26	0.29	0.20	0.05	-0.04	0.02	-0.08	0.11	-0.06	-0.07	0.08	0.06	0.14	-0.06	-0.06
sw Conductance	0.12	-0.21	-0.43	-0.05	0.08	0.31	0.14		0.61	0.89	0.63	0.61	-0.53	0.45	0.56	0.87	0.11	-0.17	-0.41	0.26	0.35	-0.28	0.42	0.42	-0.31	-0.05	0.20	0.18	0.16	0.32	0.00	-0.11	-0.19	-0.21	0.04	0.36	-0.35	-0.37	-0.11	-0.39	-0.20	-0.23	-0.30
sw Ca	0.22	-0.11	-0.16	-0.02	0.09	-0.03	0.01	0.61		0.37	0.13	0.22	-0.31	0.10	0.19	0.65	0.24	-0.26	-0.23	0.09	-0.06	-0.35	-0.01	0.05	-0.06	0.17	0.22	-0.04	-0.04	0.08	0.14	-0.13	-0.03	-0.05	0.04	0.20	-0.03	-0.14	0.07	-0.22	-0.04	-0.02	-0.10
sw Mg	0.10	-0.14	-0.55	-0.07	0.07	0.45	0.22	0.89	0.37		0.68	0.52	-0.55	0.46	0.50	0.85	0.05	-0.15	-0.41	0.31	0.40	-0.25	0.50	0.35	-0.35	-0.12	0.11	0.23	0.22	0.38	-0.01	-0.16	-0.24	-0.17	0.08	0.35	-0.37	-0.37	-0.08	-0.35	-0.17	-0.20	-0.26
sw K	-0.08	-0.30	-0.38	-0.07	-0.18	0.44	0.33	0.63	0.13	0.68		0.61	-0.40	0.37	0.66	0.51	0.14	0.13	-0.21	0.28	0.29	-0.09	0.61	0.49	-0.34	-0.13	0.05	0.18	0.08	0.19	-0.05	0.06	-0.16	-0.23	-0.05	0.21	-0.41	-0.34	-0.19	-0.30	-0.22	-0.25	-0.30
sw Na	-0.05	-0.20	0.03	-0.06	-0.16	0.40	0.12	0.61	0.22	0.52	0.61		-0.19	0.63	0.74	0.36	0.17	-0.07	-0.16	0.35	0.26	-0.16	0.34	0.73	-0.13	0.15	0.15	-0.03	-0.05	0.09	0.02	-0.12	0.03	-0.46	-0.12	0.31	-0.27	-0.28	-0.26	-0.26	-0.34	-0.51	-0.52
sw Fe	0.02	0.20	0.55	-0.20	-0.34	-0.39	-0.23	-0.53	-0.31	-0.55	-0.40	-0.19		-0.15	-0.24	-0.57	0.13	0.26	0.68	-0.04	-0.33	0.40	-0.41	-0.15	0.45	0.16	0.09	-0.09	-0.08	-0.36	0.24	0.03	0.40	-0.01	-0.09	-0.02	0.56	0.44	0.19	0.31	0.22	0.03	0.10
sw sulfate	-0.17	0.09	0.16	-0.03	-0.07	0.32	0.04	0.45	0.10	0.46	0.37	0.63	-0.15		0.41	0.21	0.05	-0.09	-0.09	0.32	0.44	-0.27	0.25	0.48	-0.31	0.00	0.02	-0.12	0.02	0.00	-0.06	-0.31	0.04	-0.35	0.12	0.45	-0.12	-0.15	-0.15	-0.08	-0.22	-0.41	-0.41
sw Cl	-0.18	-0.54	-0.03	0.09	-0.19	0.38	0.35	0.56	0.19	0.50	0.66	0.74	-0.24	0.41		0.32	0.24	0.09	-0.09	0.12	0.29	-0.14	0.46	0.60	-0.22	0.09	0.18	0.15	0.07	0.14	-0.09	0.04	-0.06	-0.27	-0.09	0.24	-0.32	-0.28	-0.32	-0.28	-0.21	-0.28	-0.34
sw Alkalinity	0.24	-0.15	-0.61	-0.09	0.11	0.27	0.17	0.87	0.65	0.85	0.51	0.36	-0.57	0.21	0.32		0.11	-0.23	-0.46	0.21	0.22	-0.31	0.35	0.20	-0.31	-0.08	0.16	0.20	0.18	0.37	0.06	-0.17	-0.20	-0.08	0.04	0.26	-0.33	-0.38	0.01	-0.37	-0.09	-0.10	-0.17
sw TP	-0.11	-0.31	0.06	-0.02	-0.58	0.04	0.27	0.11	0.24	0.05	0.14	0.17	0.13	0.05	0.24	0.11		0.52	0.48	0.06	0.05	0.12	0.08	0.18	-0.05	0.24	0.51	0.11	0.07	0.03	0.29	-0.06	0.22	-0.17	-0.10	0.29	0.13	0.09	0.05	0.14	0.20	-0.14	-0.17
sw TN	-0.23	-0.25	0.09	-0.02	-0.61	0.05	0.23	-0.17	-0.26	-0.15	0.13	-0.07	0.26	-0.09	0.09	-0.23	0.52		0.61	-0.05	0.22	0.26	0.15	0.12	-0.18	-0.13	0.27	0.28	0.23	0.07	0.04	0.08	-0.02	0.10	0.07	0.08	0.00	0.14	-0.04	0.15	0.24	0.10	0.05
sw Color	-0.20	0.03	0.52	-0.20	-0.68	-0.26	-0.06	-0.41	-0.23	-0.41	-0.21	-0.16	0.68	-0.09	-0.09	-0.46	0.48	0.61		-0.06	-0.11	0.39	-0.20	-0.04	0.21	0.12	0.23	0.04	0.01	-0.20	0.19	0.16	0.16	0.01	-0.04	0.04	0.37	0.38	0.09	0.28	0.24	0.05	0.07
pw pH	-0.04	0.10	-0.07	-0.04	-0.09	0.32	-0.21	0.26	0.09	0.31	0.28	0.35	-0.04	0.32	0.12	0.21	0.06	-0.05	-0.06		0.03	-0.30	0.12	0.19	-0.11	-0.04	0.03	-0.13	0.03	-0.24	0.09	-0.09	-0.04	-0.47	-0.16	0.14	-0.22	-0.35	-0.28	-0.25	-0.40	-0.46	-0.50
pw sulfide	-0.35	-0.06	-0.15	0.11	-0.07	0.28	0.17	0.35	-0.06	0.40	0.29	0.26	-0.33	0.44	0.29	0.22	0.05	0.22	-0.11	0.03		-0.05	0.46	0.33	-0.58	-0.30	0.12	0.31	0.33	0.33	-0.43	-0.09	-0.08	0.15	0.40	0.29	-0.35	-0.06	-0.13	0.00	0.07	0.14	0.10
pw DOC	-0.01	-0.06	0.08	0.00	-0.21	-0.24	0.09	-0.28	-0.35	-0.25	-0.09	-0.16	0.40	-0.27	-0.14	-0.31	0.12	0.26	0.39	-0.30	-0.05		-0.03	-0.15	0.42	0.20	0.23	0.23	0.08	0.09	0.24	0.23	0.16	0.10	-0.12	-0.10	0.31	0.33	0.17	0.20	0.22	0.11	0.19
pw K	-0.36	-0.25	-0.41	0.03	-0.10	0.45	0.33	0.42	-0.01	0.50	0.61	0.34	-0.41	0.25	0.46	0.35	0.08	0.15	-0.20	0.12	0.46	-0.03		0.58	-0.37	-0.12	0.22	0.43	0.40	0.34	-0.11	0.05	-0.17	-0.11	0.03	0.11	-0.38	-0.30	-0.20	-0.15	-0.09	-0.14	-0.18
pw Na	-0.25	-0.16	0.01	0.00	-0.25	0.27	0.18	0.42	0.05	0.35	0.49	0.73	-0.15	0.48	0.60	0.20	0.18	0.12	-0.04	0.19	0.33	-0.15	0.58		-0.25	-0.01	0.15	0.12	0.13	0.11	-0.01	-0.02	-0.03	-0.35	-0.05	0.23	-0.20	-0.25	-0.16	-0.18	-0.18	-0.35	-0.36
pw Fe	0.21	0.07	0.32	0.02	0.04	-0.31	-0.09	-0.31	-0.06	-0.35	-0.34	-0.13	0.45	-0.31	-0.22	-0.31	-0.05	-0.18	0.21	-0.11	-0.58	0.42	-0.37	-0.25		0.60	0.13	-0.18	-0.19	-0.19	0.48	0.06	0.12	-0.15	-0.31	0.00	0.63	0.34	0.24	0.22	0.08	-0.13	-0.07
pw Mn	0.10	-0.08	0.30	0.04	-0.08	-0.11	0.09	-0.05	0.17	-0.12	-0.13	0.15	0.16	0.00	0.09	-0.08	0.24	-0.13	0.12	-0.04	-0.30	0.20	-0.12	-0.01	0.60		0.27	-0.16	-0.17	-0.08	0.40	-0.13	0.22	-0.29	-0.29	0.06	0.29	0.15	-0.02	0.15	-0.02	-0.29	-0.27
pw TP	-0.06	-0.26	-0.02	0.05	-0.26	0.11	0.26	0.20	0.22	0.11	0.05	0.15	0.09	0.02	0.18	0.16	0.51	0.27	0.23	0.03	0.12	0.23	0.22	0.15	0.13	0.27		0.62	0.60	0.33	0.26	-0.02	0.00	-0.01	0.02	0.30	0.14	0.17	0.09	0.18	0.34	-0.02	-0.04
pw TN	-0.23	-0.30	-0.36	0.03	-0.20	0.34	0.34	0.18	-0.04	0.23	0.18	-0.03	-0.09	-0.12	0.15	0.20	0.11	0.28	0.04	-0.13	0.31	0.23	0.43	0.12	-0.18	-0.16	0.62		0.88	0.54	-0.08	0.10	-0.21	0.32	0.22	0.14	-0.14	0.03	0.07	0.02	0.37	0.29	0.26
pw NH4	-0.22	-0.16	-0.27	0.03	-0.17	0.30	0.26	0.16	-0.04	0.22	0.08	-0.05	-0.08	0.02	0.07	0.18	0.07	0.23	0.01	0.03	0.33	0.08	0.40	0.13	-0.19	-0.17	0.60	0.88		0.42	-0.11	0.02	-0.26	0.28	0.30	0.22	-0.07	0.06	0.11	0.11	0.37	0.23	0.20
pw Silica	-0.02	-0.28	-0.35	0.10	0.07	0.26	0.29	0.32	0.08	0.38	0.19	0.09	-0.36	0.00	0.14	0.37	0.03	0.07	-0.20	-0.24	0.33	0.09	0.34	0.11	-0.19	-0.08	0.33	0.54	0.42		-0.01	0.08	-0.20	0.23	0.16	0.18	-0.14	-0.04	0.11	0.07	0.21	0.19	0.14
pw As	0.15	-0.08	0.04	-0.10	-0.13	-0.03	0.20	0.00	0.14	-0.01	-0.05	0.02	0.24	-0.06	-0.09	0.06	0.29	0.04	0.19	0.09	-0.43	0.24	-0.11	-0.01	0.48	0.40	0.26	-0.08	-0.11	-0.01		0.06	0.10	-0.39	-0.51	-0.09	0.28	-0.04	0.17	-0.05	-0.06	-0.38	-0.36
pw Cu	-0.07	-0.19	0.04	-0.02	0.03	-0.12	0.05	-0.11	-0.13	-0.16	0.06	-0.12	0.03	-0.31	0.04	-0.17	-0.06	0.08	0.16	-0.09	-0.09	0.23	0.05	-0.02	0.06	-0.13	-0.02	0.10	0.02	0.08	0.06		-0.22	0.01	-0.20	-0.19	0.01	-0.05	0.01	-0.02	0.00	0.04	0.06
pw Zn	-0.09	0.05	0.27	0.13	-0.11	-0.21	-0.04	-0.19	-0.03	-0.24	-0.16	0.03	0.40	0.04	-0.06	-0.20	0.22	-0.02	0.16	-0.04	-0.08	0.16	-0.17	-0.03	0.12	0.22	0.00	-0.21	-0.26	-0.20	0.10	-0.22		-0.15	-0.13	0.00	0.26	0.13	0.01	0.14	-0.04	-0.16	-0.08
sed Water	-0.07	0.01	-0.09	0.13	0.10	-0.18	0.02	-0.21	-0.05	-0.17	-0.23	-0.46	-0.01	-0.35	-0.27	-0.08	-0.17	0.10	0.01	-0.47	0.15	0.10	-0.11	-0.35	-0.15	-0.29	-0.01	0.32	0.28	0.23	-0.39	0.01	-0.15		0.76	0.10	0.24	0.55	0.51	0.40	0.72	0.93	0.94
sed TS % dry	-0.21	0.15	-0.06	0.10	0.03	-0.04	-0.08	0.04	0.04	0.08	-0.05	-0.12	-0.09	0.12	-0.09	0.04	-0.10	0.07	-0.04	-0.16	0.40	-0.12	0.03	-0.05	-0.31	-0.29	0.02	0.22	0.30	0.16	-0.51	-0.20	-0.13	0.76		0.42	0.15	0.41	0.40	0.29	0.56	0.71	0.70
sed AVS % dry	-0.10	-0.09	0.05	0.08	-0.13	0.08	0.11	0.36	0.20	0.35	0.21	0.31	-0.02	0.45	0.24	0.26	0.29	0.08	0.04	0.14	0.29	-0.10	0.11	0.23	0.00	0.06	0.30	0.14	0.22	0.18	-0.09	-0.19	0.00	0.10	0.42		0.38	0.28	0.32	0.26	0.30	0.04	0.02
sed Fe % dry	-0.01	0.14	0.42	0.09	-0.10	-0.45	-0.06	-0.35	-0.03	-0.37	-0.41	-0.27	0.56	-0.12	-0.32	-0.33	0.13	0.00	0.37	-0.22	-0.35	0.31	-0.38	-0.20	0.63	0.29	0.14	-0.14	-0.07	-0.14	0.28	0.01	0.26	0.24	0.15	0.38		0.70	0.64	0.64	0.52	0.24	0.30
sed Zn % dry	-0.03	0.14	0.42	0.01	-0.16	-0.41	-0.07	-0.37	-0.14	-0.37	-0.34	-0.28	0.44	-0.15	-0.28	-0.38	0.09	0.14	0.38	-0.35	-0.06	0.33	-0.30	-0.25	0.34	0.15	0.17	0.03	0.06	-0.04	-0.04	-0.05	0.13	0.55	0.41	0.28	0.70		0.64	0.76	0.68	0.49	0.57
sed As % dry	0.17	0.19	-0.01	-0.05	0.02	-0.27	0.08	-0.11	0.07	-0.08	-0.19	-0.26	0.19	-0.15	-0.32	0.01	0.05	-0.04	0.09	-0.28	-0.13	0.17	-0.20	-0.16	0.24	-0.02	0.09	0.07	0.11	0.11	0.17	0.01	0.01	0.51	0.40	0.32	0.64	0.64		0.47	0.66	0.47	0.52
sed Cu % dry	-0.14	0.00	0.40	0.08	-0.12	-0.33	0.06	-0.39	-0.22	-0.35	-0.30	-0.26	0.31	-0.08	-0.28	-0.37	0.14	0.15	0.28	-0.25	0.00	0.20	-0.15	-0.18	0.22	0.15	0.18	0.02	0.11	0.07	-0.05	-0.02	0.14	0.40	0.29	0.26	0.64	0.76	0.47		0.59	0.32	0.37
sed TP % dry	-0.10	-0.04	0.03	0.01	-0.14	-0.25	0.14	-0.20	-0.04	-0.17	-0.22	-0.34	0.22	-0.22	-0.21	-0.09	0.20	0.24	0.24	-0.40	0.07	0.22	-0.09	-0.18	0.08	-0.02	0.34	0.37	0.37	0.21	-0.06	0.00	-0.04	0.72	0.56	0.30	0.52	0.68	0.66	0.59		0.64	0.69
sed TN % dry	-0.08	0.02	-0.08	0.17	0.06	-0.24	-0.06	-0.23	-0.02	-0.20	-0.25	-0.51	0.03	-0.41	-0.28	-0.10	-0.14	0.10	0.05	-0.46	0.14	0.11	-0.14	-0.35	-0.13	-0.29	-0.02	0.29	0.23	0.19	-0.38	0.04	-0.16	0.93	0.71	0.04	0.24	0.49	0.47	0.32	0.64		0.94
sed TOC % dry	-0.06	0.11	-0.04	0.09	0.10	-0.28	-0.06	-0.30	-0.10	-0.26	-0.30	-0.52	0.10	-0.41	-0.34	-0.17	-0.17	0.05	0.07	-0.50	0.10	0.19	-0.18	-0.36	-0.07	-0.27	-0.04	0.26	0.20	0.14	-0.36	0.06	-0.08	0.94	0.70	0.02	0.30	0.57	0.52	0.37	0.69	0.94	
sed Se % dry	-0.22	-0.07	0.38	0.05	-0.21	-0.30	0.13	-0.29	-0.06	-0.26	-0.20	-0.18	0.20	-0.05	-0.13	-0.27	0.21	0.26	0.29	-0.34	0.08	0.16	-0.11	-0.09	0.10	0.18	0.11	-0.06	0.00	0.13	-0.07	-0.10	0.17	0.44	0.35	0.27	0.57	0.73	0.50	0.81	0.64	0.34	0.38

Table 1-5. The 12 field variables that are significantly correlated with the presence/absence of wild rice, as determined through binary logistic regression (Myrbo et al., in press-1). Below the name of each field variable is the nature of the correlation with wild rice presence (positive or negative) and the average value at the sites with wild rice present and at sites with wild rice absent. The Spearman correlation coefficient is termed "rho." (*=p<0.01; **=p<0.01; ***=p<0.001)

Field Variable (positive or negative correlation with wild rice presence) Site averages: Present, Absent	Significance of binary logistic regression with wild rice presence/ absence (p value)	Likely reason for correlation with wild rice presence/absence	Spearman Correlations					
			Porewater Sulfide rho	Significant?	Water Transparency rho	Significant?	Water Temperature rho	Significant?
Porewater sulfide (negative) 165, 795 µg/L	0.0012	Elevated porewater sulfide is correlated with the absence of wild rice most likely because elevated sulfide reduces the growth of wild rice.	1.00		-0.07	not sig	0.17	not sig
Surface water temperature (negative) 22.1, 24.4 ºC	0.0077	Elevated surface water temperature is negatively correlated with wild rice occurrence, independent of water transparency. Temperature is weakly correlated with porewater sulfide (rho= 0.17); warmer summer and winter temperatures likely have a negative effect on wild rice that is independent of sulfide.	0.17	not sig	-0.08	not sig	1.00	
Latitude (positive) 46.6, 46.1 degrees	0.0376	Minnesota has strong latitudinal gradients in many environmental factors, but latitude's strongest correlation in this data set is with water temperature (transparency, sulfate, and sulfide are not significantly correlated). It is most likely that northern latitude sites are correlated with the presence of wild rice presence because they are colder.	-0.06	not sig	0.13	not sig	-0.51	***
Water transparency (positive) 84, 66 cm	0.0031	Reduced transparency is correlated with the absence of wild rice, independent of porewater sulfide and surface water temperature. Wild rice is rarely observed at transparencies below 30 cm.	-0.07	not sig	1.00		-0.08	not sig
Porewater potassium (negative) 3.5, 6.1 mg/L	0.0008	There is no reason to expect that elevated porewater potassium (K) is harmful to wild rice, as it is a plant nutrient. Rather, it is likely that porewater K is simply correlated with porewater sulfide because sulfide production is associated with enhanced decomposition of organic matter, which releases the plant nutrients K, N, and P. The negative correlation of porewater K with wild rice is magnified by its additional correlation with temperature, which could be driving non-sulfide related organic decomposition, which would also release K to porewater.	0.46	***	-0.10	not sig	0.33	***

(continued)

Field Variable (positive or negative correlation with wild rice presence) Site averages: Present, Absent	Significance of binary logistic regression with wild rice presence/ absence (p value)	Likely reason for correlation with wild rice presence/absence	Spearman Correlations					
			Porewater Sulfide		Water Transparency		Water Temperature	
			rho	Significant?	rho	Significant?	rho	Significant?
Surface water total nitrogen (negative) 0.9, 1.2 mg/L	0.0054	There is no reason to expect that elevated nitrogen is directly harmful to wild rice, although elevated N likely encourages growth of algae or macrophytes that shade or compete with wild rice. Total nitrogen is correlated with all 3 causative factors that are negative for wild rice occurrence, in that it is not only associated with reduced transparency, but it is also correlated with sulfide and temperature, which are both associated with enhanced decomposition of sediment organic matter.	0.22	*	-0.61	***	0.23	*
Surface water total phosphorus (negative) 41, 62 µg/L	0.0353	There is no reason to expect that elevated phosphorus is directly harmful to wild rice, although elevated P likely encourages growth of algae or macrophytes that shade or compete with wild rice. Total phosphorus is not only correlated with reduced transparency, but it also correlated with water temperature, which is associated with enhanced decomposition of organic matter.	0.05	not sig	-0.58	***	0.27	**
Porewater Fe (positive) 11.0, 7.0 mg/L	0.0109	Porewater iron is negatively correlated with porewater sulfide, which is most likely the causative factor for the correlation with the occurrence of wild rice.	-0.58	***	0.04	not sig	-0.09	not sig
Sediment total sulfur (negative) 3.9, 6.9 mg/g	0.0483	Sediment total sulfur is positively correlated with porewater sulfide, which is most likely the causative factor.	0.40	***	0.03	not sig	-0.08	not sig
Sediment total selenium (negative) 1.0, 1.3 µg/g	0.0059	The slightly higher selenium at sites without wild rice is most likely caused by the co-precipitation of selenium and sulfur by sulfate-reducing bacteria, as shown by Hockin and Gadd (2003). Selenium is correlated with sediment total sulfur (rho=0.35, $p < 0.001$)).	0.08	not sig	-0.21	*	0.13	not sig

(continued)

Field Variable (positive or negative correlation with wild rice presence) Site averages: Present, Absent	Significance of binary logistic regression with wild rice presence/ absence (p value)	Likely reason for correlation with wild rice presence/absence	Spearman Correlations: Porewater Sulfide rho	Significant?	Water Transparency rho	Significant?	Water Temperature rho	Significant?
Surface water pH (negative) 7.9, 8.3 pH units	0.0200	It is unlikely that elevated pH (8.3 ± 0.9 at sites without wild rice compared to 7.9 ± 0.8 at sites with wild rice) is harming wild rice. Rather, elevated surface water pH is reflecting elevated water temperature, which reduces the solubility of CO_2, raising the pH. Synergistically, pH is also correlated with porewater sulfide, which is stoichiometrically related to the generation of alkalinity, raising the pH.	0.28	**	-0.05	not sig	0.35	***
Water Depth (negative) 52 , 67 cm	0.0028	Although water depth could control wild rice presence, this metric does not characterize the waterbody, but rather where the field crews took the sample. When wild rice was not present, field crews usually sampled at water lilies, which tended to grow in slightly deeper water than wild rice. The correlation with temperature likely is driven by the tendency of warmer sites to not host wild rice. The significant positive correlation with transparency does not drive the negative correlation with wild rice occurrence, as it is the wrong sign, and therefore inexplicable.	0.11	not sig	0.22	*	0.19	*

B. That other factors affect wild rice does not negate the need to protect wild rice from excess sulfide

Multiple stressors affect wild rice in nature.

Some comments received in regards to the March 2015 Draft Proposal (MPCA, 2015) focused on regulating sulfate. Others suggested that a) it is inappropriate to regulate sulfate without also addressing the many other factors, aside from sulfide, that likely control the presence of wild rice, and b) factors other than sulfate (and sulfide) are more important in controlling the suitability of wild rice habitat. It was further suggested that it is not appropriate to use field data to identify a sulfide concentration that is protective of wild rice both because field data are inherently variable and in light of the multiple stressors that were not studied in the MPCA-sponsored research, especially a) changes in water levels from year to year, b) impacts of development, and c) presence of invasive or competitive species.

It is true that there is more "noise" in field data than in a controlled experiment. Because of this noise, or data variability, it is more challenging to detect a statistically significant impact of a particular stressor in field data; there is more statistical power in controlled laboratory experiments (Chapman, 2002). It is important to conduct controlled laboratory experiments to determine that a particular stressor (such as sulfide) has the potential to negatively affect a species, but the ecological significance of that effect is ambiguous until mesocosm or field data are collected (Chapman, 2002). If, despite environmental variability, a statistically significant relationship is demonstrated in the field that reinforces the laboratory finding, then there is little question that the chemical is important in controlling the occurrence of that species in the environment.

Despite the challenge of documenting a statistically significant relationship in field data, the binary logistic regression (BLR) analysis found a statistically significant negative correlation between the concentration of sulfide in the sediment porewater and the occurrence of wild rice (p=0.001, Table 1-5). Performing *multiple* BLR with more than one variable demonstrated that porewater sulfide is one of three primary independent variables correlated with wild rice occurrence (Myrbo et al., in press-1): porewater sulfide, water transparency, and water temperature. The statistical analysis strongly supports the conclusion that sulfide independently affects wild rice presence and absence (p=0.001; Table 1-3), which implies that limiting sulfate availability has the potential to protect wild rice from elevated sulfide. Analysis of the MPCA field data shows that porewater sulfide is simultaneously controlled by surface water sulfate and sediment concentrations of total organic carbon (TOC) and total extractable iron (TEFe) (Pollman et al., in press; discussed in Part D of this chapter). Interestingly, sulfate, TOC, and TEFe do not have any statistically significant effect on wild rice occurrence when considered individually (p= 0.15, 0.79, and 0.48, respectively; Table 1-3; Myrbo et al., in press-1). These three environmental variables only have a relationship to the occurrence of wild rice when they are considered simultaneously, given that particular combinations of the three can produce excessive concentrations of porewater sulfide (Part E of this Chapter).

Factors that act independently of porewater sulfide may also affect wild rice growth, such as hydrological changes and exotic species (Tables 1-6 and 1-7), but unless a factor has an affect on the relationship between sulfate and sulfide, consideration of such a factor is irrelevant to the mission of protecting wild rice from excess sulfide. The only factors that have been identified that have an effect on porewater sulfide are sulfate, sediment TOC, and sediment iron (Pollman et al., in press). However, one exception may be sites with upwelling groundwater; it has been reported that such sites may be favorable habitat for wild rice (Table 1-6). Consistent upward groundwater flow would break the usual relationship between sulfate in surface water and sulfide in porewater, because sulfate would be less likely to move downwards into the sediment when groundwater is moving upwards. Therefore, at some sites the sulfate concentration of the groundwater may be more important than the surface water in controlling the production of porewater sulfide, but statistical analysis shows that at most sites porewater sulfide is a function of surface water sulfate (Pollman et al., in press). Even if this were not the case, the possibility that groundwater, rather than surface water, controls porewater sulfide in a specific wild rice bed does not negate the validity of the empirically observed, statistically significant, relationship between surface water sulfate, sediment iron, sediment TOC, and porewater sulfide as a general matter (Part D of this chapter, below; Pollman et al., in press).

Table 1-6. Reported environmental requirements for suitable wild rice habitat. Most reports comment on factors affecting the relative growth or density of wild rice rather than factors that control the presence and absence of wild rice, which is how conservation biologists identify factors that are critical to favorable habitat for a species.

Environmental requirement for suitable wild rice habitat (source)	Relevant findings from MPCA-sponsored research
Wild rice grows best when surface water sulfate is less than 10 mg/L	
"No large stands of rice occur in waters having a SO_4 content greater than 10 ppm, and rice generally is absent from water with more than 50 ppm." (Moyle, 1944) "Wild rice has marked preference for the quality of water in which it grows and is not found in prairie waters which have appreciable amounts of sulfate or "alkali" salts. In Minnesota the range is mostly limited to waters with concentration of sulfate or "alkali" salts lower than 10 parts per million of sulfate ion. Plantings of wild rice seed in prairie waters with higher concentrations of sulfates have generally failed. (Moyle and Krueger, 1964)	The effect of sulfate depends on the background sediment chemistry of the particular waterbody. Elevated sulfate sometimes allows excessive porewater sulfide to develop (Myrbo et al., in press-1; Pollman et al., in press).
Wild rice grows best when surface water alkalinity greater than 40 mg/L	
"Best growth is made in carbonate waters having total alkalinity greater than 40 ppm." (Moyle, 1944) "Lakes that have had wild rice for many years usually have the following characteristics: (4) they usually are fairly limy and have a total alkalinity exceeding 40 parts per million (there are stands, however, in softer water);" (Moyle and Krueger, 1964)	There is no statistically significant effect of alkalinity on wild rice presence (Table 1-3; Myrbo et al., in press-1).
High phosphorus can have adverse effects on wild rice	
"Wild rice grows within a wide range of chemical parameters (i.e. alkalinity, salinity, pH, and iron; Meeker 2000). However, productivity is highest in water with a pH of 6.0 to 8.0 and alkalinity greater than 40 ppm. While researchers have observed that natural wild rice stands are relatively nutrient rich, excess levels of some nutrients, especially phosphorus, can have significant adverse effects on productivity (Persell and Swan, 1986)." (MDNR, 2008, p. 14)	Wild rice absence is correlated with elevated surface water pH and phosphorus, which are both associated with high phytoplankton levels, reducing transparency (Table 1-3; Myrbo et al., in press-1).

(continued)

Environmental requirement for suitable wild rice habitat (source)	Relevant findings from MPCA-sponsored research
Nitrogen and phosphorus are limiting nutrients for wild rice	
"Nitrogen and phosphorus are limiting nutrients for wild rice (Carson 2002)." (MDNR, 2008, p. 14). Five years of experimental data as well as a model of N cycling in wild rice ecosystems (Pastor and Walker 2006) suggest that delays in nutrient availability the year following deposition of large amounts of immobilizing litter cause biomass and population oscillations over a cycle potentially four years in length (Walker et al., 2010).	Rooted aquatic plants obtain their nutrients from the sediment, rather than from the surface water (Barko and Smart, 1986). There is no statistically significant relationship between sediment nitrogen or phosphorus and wild rice presence (Table 1-3; Myrbo et al., in press-1). Greater sedimentary N and P may increase growth of individual wild rice plants, but not control presence/absence of wild rice.
Wild rice grows best when carp populations are low	
Judging from lake names, it once grew farther south in central Minnesota where it has probably been exterminated by carp." (Moyle and Krueger, 1964)	No data were collected on carp presence.
"Common carp feed primarily on invertebrates in bottom soils. Their feeding action dislodges plants and suspends fine particles into the water column. The increased turbidity, caused both by disturbed sediments and by algae stimulated by the phosphorus released from disturbed sediments, shades out aquatic plants. Turbidity then increases as non-vegetated lake bottoms are disturbed by wind. The reduction in aquatic vegetation also allows for increased boat traffic and wave action that can further dislodge plants such as wild rice (Pillsbury and Bergey, 2000)." (MDNR 2008, p. 27)	Low water transparency can likely cause the absence of wild rice (Myrbo et al., in press-1).
Wild rice grows best in habitat with moving water	
"The crop grows best in lakes having some water moving through and often is lacking from stagnant lakes and pools. It is frequent along streams and at lake inlets and outlets." (Moyle, 1944)	No data were collected on water movement.
"Lakes that have had wild rice for many years usually have the following characteristics: (2) they are wide enough to have heavy wave action in spring or have a flow of water through them;" (Moyle and Krueger, 1964)	
"Natural wild rice generally requires some moving water, with rivers, flowages, and lakes with inlets and outlets being optimal areas for growth. Seasonal water depth is critical, however. Water levels that are relatively stable or decline gradually during the growing season are preferred. In particular, abrupt increases during the early growing season can uproot plants. Wild rice grows well at depths of 0.5 to 3 feet of water, although some plants may be found in deeper waters (M. McDowell, J. Persell personal communication)." (MDNR, 2008, p. 14)	

(continued)

Environmental requirement for suitable wild rice habitat (source)	Relevant findings from MPCA-sponsored research
Groundwater inflow areas can be favorable habitat for wild rice	
Natural wild rice generally requires moving water, with rivers, flowages, and lakes or wetlands with inlets and outlets being optimal areas for growth. In some areas groundwater flows are apparently adequate to meet the need for flowing water (Norrgard, 2014). Wild rice is in a group of emergent plant species that had a mild statistical association with groundwater inflow areas of lakes (Nichols & Shaw, 2002).	No information was collected on groundwater movement at the field sites. Upward flow would break the usual relationship between surface water sulfate and sulfide, because sulfate would be less likely to move downwards into the sediment when groundwater is moving upwards.
Surface water with high transparency	
Often lacking from bog lakes with dark brown water. (Moyle, 1944) "…clear to moderately colored (stained) water is preferred, as darkly stained water can limit sunlight and may hinder early plant development." (MDNR, 2008, p. 14) "Waters in which wild rice grows are often somewhat brownish or tea-colored — but dark brown water is not favorable, for this cuts down penetration of the light that the first submerged leaves must have if the plant is to grow. In such waters, especially over mucky bottoms, the rice seedlings may be crowded by such submerged plants as coon tail, flat-stemmed pondweed and star duckweed. Waterlilies may invade wild rice stands and shade out the rice." (Moyle and Krueger, 1964)	Lower water transparency is correlated with absence of wild rice (Table 1-3; Myrbo et al., in press-1).
Wild rice occurs in shallow water between 0.5 and 3 feet depth	
"Lakes that have had wild rice for many years usually have the following characteristics: (1) they contain much water shallower than four feet; "(Moyle and Krueger, 1964) "Wild rice grows well at depths of 0.5 to 3 feet of water, although some plants may be found in deeper waters (M. McDowell, J. Persell personal communication)." (MDNR, 2008, p. 14)	Consistent with observations of Myrbo et al. (in press-1).

(continued)

Environmental requirement for suitable wild rice habitat (source)	Relevant findings from MPCA-sponsored research
Wild rice grows best in waters with organic sediment	
"Lakes that have had wild rice for many years usually have the following characteristics: (3) they have an organic bottom a few inches to a few feet thick, overlying a hard bottom;" (Moyle and Krueger, 1964) "Although wild rice may be found growing in a variety of bottom types, the most consistently productive are lakes with soft, organic sediments (Lee, 1986). The high organic matter content with a rather low carbon/nitrogen ratio is necessary to meet the rather high nitrogen needs of wild rice (Carson, 2002). Nitrogen and phosphorus are major limiting nutrients for wild rice (Carson, 2002). Flocculent sediments with nitrogen and phosphorus concentrations less than one gram per square meter are typically incapable of supporting sustained production (Lee, 1986)." (MDNR, 2008, p. 97)	Myrbo et al. (in press-1) found no significant correlations between wild rice occurrence and sediment concentrations of organic matter, nitrogen, or phosphorus, or flocculent sediments (as measured by the water content). Note that Myrbo et al. examined what factors controlled the occurrence of wild rice, not what factors controlled the quality or density of wild rice.
The best wild rice habitat has some summers with high water to reduce the dominance of perennial plants	
"As an annual plant sprouting each year from seed, wild rice can have difficulty competing with aggressive perennial vegetation, particularly where natural hydrologic variation has been reduced. Cattail spp.), particularly hybrid cattail (*Typha* x glauca), yellow water lily (*Nuphar variegata*), and pickerelweed (*Pontederia cordata*) are examples of plants that have been cited as competing with wild rice (Norrgard, David, and Vogt, personal communication)" (MDNR, 2008, p. 91). "Lakes that have had wild rice for many years usually have the following characteristics: (6) the drainage area feeding the lakes is usually fairly large and the outlet such that there is high water in some summers (times when high water drowns out cattails and other perennial emergent plants that would otherwise crowd out the rice);" (Moyle and Krueger, 1964) "Cattails and perennial reeds and rushes will crowd out wild rice if allowed to become established. Such plants should be eradicated in paddies and in wild stands drowned out by occasional flooding. Usually there are years of high water (about one year in four) on wild rice stands that have remained as such for a long period of time." (Moyle and Krueger, 1964) Yellow water lily (*Nuphar variegate*) and *Utricularia vulgaris* occurrence patterns show that these plants prefer environmental conditions similar to optimal rice habitat, indicating that these plants are likely competitors. Resource managers often assert that wild rice competes with perennial plants such as cattails spp.), pickerelweed (*Pontederia cordata* L.), and waterlilies (*Nymphaea* and *Nuphar*) as a major factor in the disappearance of wild rice stands, but this hypothesis has rarely been tested (Pillsbury and McGuire, 2009).	No pertinent information was collected on competition with perennial vegetation or the effect of high water on the control of perennial vegetation.

(continued)

Environmental requirement for suitable wild rice habitat (source)	Relevant findings from MPCA-sponsored research
In most summers the best wild rice habitat does not have an abrupt rise in water level of more than 6 inches	
"Lakes that have had wild rice for many years usually have the following characteristics: (7) water levels which in years of normal or deficient rainfall do not rise sharply (more than 6 inches) at any time during June or July when the wild rice is in the floating-leaf stage." (Moyle and Krueger, 1964) "Water levels that are relatively stable or decline gradually during the growing season are preferred. Abrupt water level increases during the growing season can uproot plants. Wild rice is particularly sensitive to this disturbance during the floating leaf stage. However, some observers feel that water levels kept stable over the long term (multiple years) tend to favor perennial aquatic vegetation over wild rice (David and Vogt, personal communication)." (MDNR, 2008, p. 90) "Water levels that are relatively stable or decline gradually during the growing season are preferred. Abrupt water level increases during the growing season can uproot plants. Wild rice is particularly sensitive to this disturbance during the floating leaf stage. However, some observers feel that water levels kept stable over the long term (multiple years) tend to favor perennial aquatic vegetation over wild rice (David and Vogt, personal communication)." (MDNR, 2008, p. 90)	No pertinent information was collected on the effect of an abrupt increase in water level on the occurrence of wild rice.
Germination of wild rice seeds requires winters with at least 3 months of nearly freezing water	
"As an annual plant, natural wild rice develops each spring from seeds that fell into the water and settled into the sediment during a previous fall. Germination requires a dormancy period of three to four months of cold, nearly freezing water (35 F or colder). Seeds are unlikely to survive prolonged dry conditions." (MDNR, 2008, pp. 14-15). The seed of *Z. palustris* must experience at least 3 months in water at 1 to 3º C (Cardwell et al., 1978).	Warmer summer water temperature is correlated with absence of wild rice, which may be caused by a correlation with winters that are insufficiently cold or long to break seed dormancy (Myrbo et al., in press-1.).
Residential development in a watershed is negative for habitat; deeper habitat may be more sensitive to stress	
Wetlands that have lost most of their rice tended to have an increase in residential development within the watershed, and higher ammonium, pH, and water depth. In general, low density rice wetlands tended to be slightly deeper than other sites. Any additional stress may have caused a decline of rice in deeper wetlands while not affecting the rice in shallower wetlands (Meeker 2000, cited in field survey report by Pillsbury and McGuire, 2009)	Cause and effect not investigated, but if development increases nutrients, reduced transparency would affect deeper habitat more than shallow habitat, and pH is correlated with higher nutrients.

Table 1-7. Reported threats to existing natural stands of wild rice.

Increased external loading of sulfate or phosphorus
An increase in sulfate loading to surface water, causing an exceedance of the existing Minnesota sulfate standard of 10 mg/L (MDNR, 2008, p. 25).
An increase in sulfate loading to a surface water that is particularly efficient at converting sulfate to sulfide, increasing porewater sulfide to toxic levels (this document).
A decrease in transparency due to increased phytoplankton growth caused by a) increased external loading of phosphorus (Myrbo et al., in press-1) or b) increased internal loading of phosphorus caused by increased external sulfate loading (Myrbo et al., submitted-2.).
Shoreline and watershed development
Development may entail threats to wild rice apart from enhanced phosphorus and sulfate loading; increased shoreline development reduces aquatic plant cover (Radomski, 2006), although wild rice was not specifically studied, and mechanisms of loss are not documented. Boat traffic may dislodge wild rice (Pillsbury and Bergey, 2000).
Hydrological threats
Dams that maintain stable water levels can favor perennial vegetation over wild rice. (MDNR 2008, p. 22)
Increases in the frequency of rapid increase in water levels, particularly in early summer (MDNR, 2008, p. 21), "…although wild rice is well-adapted to annual fluctuations in water levels, while other aquatic plants may be less suited to such changes." (MDNR, 2008, p. 24) "The emergent stage begins with the development of one or two floating leaves and continues with the development of several aerial leaves two to three weeks later. The floating leaves are apparent in late May to mid-June in Minnesota, again dependent on water depth, latitude, and weather. It is at this stage of growth that wild rice is most susceptible to uprooting by rapidly changing water levels due to the natural buoyancy of the plant. Rising water levels can significantly stress the plant even if it remains rooted." (MDNR, 2008, p. 88)
Groundwater extraction that dries out wild rice habitat. (MDNR, 2008, p. 25)
Impoundments or beaver activity that raise water level in wild rice beds over 3 feet. (MDNR, 2008, p. 21)
Native and exotic species
Carp feeding action dislodges plants and suspends fine particles into the water column. The increased turbidity, caused both by disturbed sediments and by algae stimulated by the phosphorus released from disturbed sediments, shades out aquatic plants. Turbidity then increases as non-vegetated lake bottoms are disturbed by wind. The reduction in aquatic vegetation also allows for increased boat traffic and wave action that can further dislodge plants such as wild rice (Pillsbury and Bergey, 2000). (MDNR,2008, p. 27)
Grazing by Canada Geese (MDNR 2008, p. 24)
Non-native invasive species may harm wild rice. The common carp dislodges plants and reduces water clarity, both by suspending fine particles and releasing phosphorus that enhances algal growth. Hybrid cattail (*Typha x glauca*), a cross of native and non-native cattail (*Typha latifolia* L. and *Typha angustifolia* L., respectively), competes directly with natural wild rice for shallow-water habitat. These plants aggressively form thick mats of roots that can float as water levels fluctuate. A relatively new threat to natural stands of wild rice is the non-native flowering rush (*Butomus umbellatus* L.). Found in similar habitats as native bulrush (*Scirpus* L. spp.), which it resembles, flowering rush can persist in either emergent or submergent forms. Though its distribution in Minnesota is limited, its range is expanding. Another potential threat to natural wild rice in Minnesota is the non-native form of phragmites, or common reed [*Phragmites australis* (Cav.) Trin.] (MDNR, 2008, pp. 27-29).

(continued)

Climate change

Climate change may harm wild rice:

- By allowing carp to spread north (MDNR, 2008, p. 30).
- By excessive warmth, which decreases the occurrence of cold dormancy in southern portion of range that is required for high germination rates (MDNR, 2008, p. 30, Myrbo et al., in press-1).
- Spread of wild rice diseases, such as brown spot (MDNR, 2008, p. 30).
- Extreme precipitation events that increase water depth abruptly (MDNR, 2008, p. 30-31).

Genetic threat

Because wild rice pollen is airborne, some have expressed concerns about unplanned cross-pollination between cultivated stands and natural stands. At this point in time, however, traditional wild rice breeding programs are not thought to pose a threat to natural stands since the cultivated varieties reflect the selection of genes from within the naturally occurring gene pool (MDNR, 2008, p. 26).

C. Identification of 120 µg/L as the protective sulfide concentration

As part of the MPCA-sponsored wild rice research, data were collected to identify a sulfide concentration that would be protective of wild rice in natural waters. Most published information on sulfide toxicity is about effects on animals. The U.S. Environmental Protection Agency (EPA) established national criteria for sulfide in surface waters of 2.0 µg/L to protect aquatic life (EPA, 1986). It is possible for sulfide to accumulate to this concentration in surface waters that cannot be re-supplied with oxygen from the atmosphere and that have low photosynthetically-produced oxygen, such as the hypolimnion of deeper lakes (Wetzel, 2001) or ice-covered shallow lakes (Scidmore, 1957). However, because exposure to atmospheric oxygen quickly detoxifies sulfide by oxidation to sulfate, surface waters in ice-free shallow lakes that are not thermally stratified are unlikely to exceed this criterion for surface water (2.0 µg/L). The challenge faced here is to identify a porewater sulfide concentration that would be protective of wild rice.

Wild rice habitats are vulnerable to accumulation of sulfide in the sediment porewater in which the plants grow. The vulnerability is the result of the combination of the high oxygen consumption by bacteria in sediment containing decaying plant litter, and the low solubility of oxygen in water (about 10 ppm, compared to 210,000 ppm in the atmosphere). On a volumetric basis, there is 27 times as much oxygen in a liter of air than a liter of water (Caraco et al., 2006). Although the scientific literature has long identified rooted aquatic plants as vulnerable to sulfide toxicity (see review by Lamers et al., 2013), at the start of the MPCA-sponsored research effort in 2011 there was no published information specific to the effect of sulfide on wild rice. There is some information on the toxicity of sulfide to white rice (*Oryza sativa*), which is related to wild rice (*Zizania palustris*) and inhabits similar environments, and therefore faces similar environmental challenges. However, it is unclear how applicable data from white rice are to wild rice. Furthermore, many of the studies identify *toxic* levels of sulfide (e.g., 50% effect levels, or EC50), levels that would result in a significant loss of plants. In contrast, the MPCA needs to identify a *protective* level of sulfide. Lamers et al. (2013) reviewed three publications regarding the toxicity of sulfide to white rice, and reported sulfide toxicity as low as 10 micromoles per liter (320 µg/L, or 0.320 mg/L).

Protective concentrations of a chemical have often been identified by exposing organisms to a range of concentrations, and then calculating the concentration at which a minimal effect is observed, such as a 10% or 20% negative effect on growth relative to a control. Effect concentrations of 10% and 20% are termed EC10 and EC20. In an earlier analysis (MPCA, 2014), MPCA had proposed identifying a protective sulfide concentration based on a 20% negative effect (EC20). However, the independent peer review panel recommended that a more conservative protective concentration, such as EC10 or EC5, would be more appropriate for the protection of wild rice. A more conservative (lower) concentration was recommended because this effort involves identifying a protective concentration of a toxin for a single species, in contrast to an ecological community, which is assumed to have functional redundancy among species.

The MPCA has received comments that the use of EC10 is inappropriately over-protective, and that the EPA recommends that water quality standards be based on EC50 for acute exposure of a chemical, and EC20 or EC25 for chronic exposure (MCC, 2015, pp. 16-19) to protect aquatic life. The commenter is referring to EPA guidelines (EPA, 1985 and EPA, 2010), but those guidelines also anticipate that rote application of the basic procedures may not yield the most appropriate standard. Consequently, the EPA guidance provides flexibility for deviation from the normal procedures. For instance, the guidance (EPA, 1985) states:

> "Such data might affect a criterion if the data were obtained with an important species, the test concentrations were measured, and the endpoint was biologically important."

In this case, the flexibility is needed because of the difference between the MPCA's goal of protecting a singular species, wild rice, and the fact that the EPA guidance is designed to protect 95% of a community's species and to preserve the ecological functioning of the community, and not to protect an individual species. The EPA guidance is meant not only to protect multiple species in an aquatic community, but also to be applied when effect concentration data are available from at least eight different groups of aquatic organisms (EPA, 2010). The data are then graphed as a species sensitive distribution (SSD) and generally the 5th percentile of the distribution (the lowest) is accepted as a matter of policy as the concentration that would maintain the viability of most species. Preference is given to using the lower confidence limit of the 5th percentile (NRC, 2013) as the numeric criteria.

The MPCA is not applying this method to the identification of the protective sulfide concentration for wild rice because: (a) the MPCA is updating an existing standard that is specific to just wild rice, rather than the whole aquatic community; and, (b) even if the goal were to develop a standard to protect the community of organisms that inhabit the sediment of shallow aquatic ecosystems, there are not enough high-quality data on the effect of sulfide to rooted aquatic plants and sediment-dwelling animals to perform such an analysis.

EC10 has been identified as a suitable threshold when the goal is to only allow negligible exposure to a potentially toxic chemical (e.g., Merrington et al., 2014; Hommen et al., 2015). The EPA's Science Advisory Board also notes that EC10 has been used when a protective concentration is calculated for a particular species of concern (SAB, 2008).

MPCA staff calculated EC10 values from the hydroponic, mesocosm, and field data (Fig. 1-2, Table 1-8), which are updated from values presented in earlier MPCA reports, such as the March 2015 Draft Proposal (MPCA, 2015), and the Draft Technical Support Document (MPCA, 2016). The following paragraphs explain those EC10 calculations, which are further detailed in the referenced papers and Appendices 5 – 7.

Table 1-8. Estimates of protective sulfide concentrations for wild rice from hydroponic, mesocosm, and field data, based on change-point analysis, EC10 estimates, and visual identification of a decrease in a graph of the proportion of field sites with wild rice present.

	Data set	Protective Sulfide Concentration (µg/L)	
		Estimate	95% Confidence Interval
Minnesota Chamber-sponsored hydroponic experiment (data from Fort et al., 2017)			
EC10, based on hydroponic experiment (MCC, 2015)*	Hydroponic	963	not given
MPCA-sponsored hydroponic experiment (Appendix 5; data from Pastor et al., 2017)**			
EC10, based on regression of weight gain on average initial sulfide*	Hydroponic	251	<11 - 285
EC10, based on regression of weight gain on time-weighted arithmetic mean of sulfide	Hydroponic	106	<11 - 158
EC10, based on regression of weight gain on time-weighted geometric mean of sulfide*	Hydroponic	39	<11 - 66
MPCA-sponsored mesocosm experiment (Appendix 6; data from Pastor et al., 2017)			
EC10, based on regression of percent of filled seeds	Mesocosm	228	0 - 414
EC10, based on regression of number of plants that germinated	Mesocosm	163	0 - 242
MPCA-sponsored field survey (Appendix 7; data from Myrbo et al., in press-1)			
Visual identification of reduction in proportion of waterbodies with wild rice present (N=108)	All sites	120	not applicable
Change-point analysis, based on wild rice density (N=67)	All sites with wild rice	112	25 - 368
EC10, based on binary logistic regression of wild rice presence (transparent sites, N=96)	Transparency > 30 cm	93	14 - 239
EC10, based on binary logistic regression of wild rice presence (all sites, N=108)*	All sites	58	<11 - 117

*Estimates identified in the text as deserving less weight in the weighing of multiple lines of evidence.
**Data from three experiments were merged for the logistic regressions.

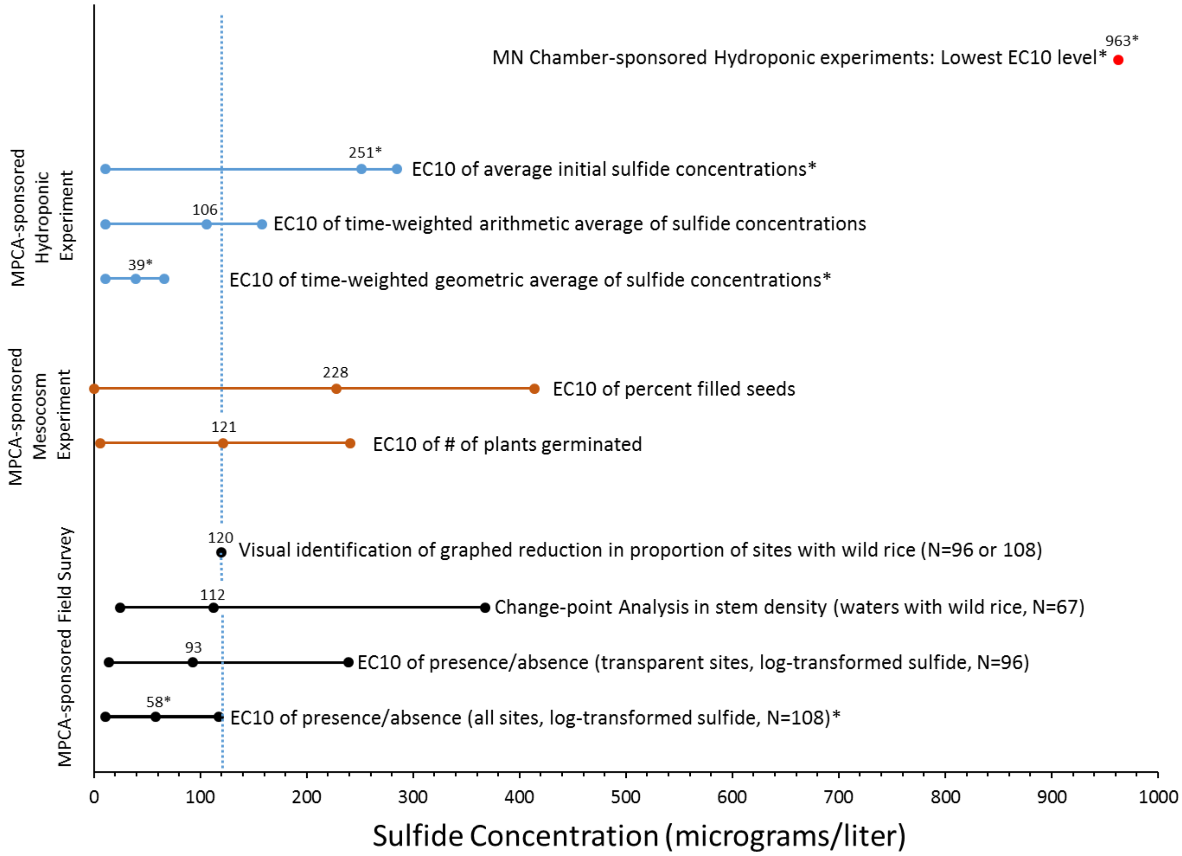


Figure 1-2. Estimates of protective sulfide concentrations for biological endpoints from hydroponic, mesocosm, and field data, based on EC10 estimates, change-point analysis, and visual examination of trends. Estimates marked with an asterisk (*) are identified in the text as deserving less weight in the weighing of multiple lines of evidence.

MPCA-sponsored hydroponic experiments: estimates of protective sulfide concentrations

Three different hydroponic EC10 values were produced by combining growth data from multiple experiments and performing logistic regressions (Ritz et al., 2015). EC10 estimates were made for three different representations of sulfide exposure (initial concentration, arithmetic average, and geometric average) yielding EC10 values of 251, 106, and 39 µg/L, respectively (Appendix 5). The peer review panel (ERG, 2014) concluded that the use of the initial concentration EC10 (251 µg/L) is not warranted, and that it would be more defensible to use either of the time-weighted EC10 values (39 or 106 µg/L). Their reasoning was based on the observation that the sulfide concentrations were measured every two to three days when the hydroponic solution was renewed, and concentrations declined significantly between hydroponic renewals, so that the plants were only exposed to the initial concentration for a short time. The photosynthesizing seedlings produced oxygen that decreased the sulfide concentrations between renewals, especially at low concentrations of sulfide.

The EC10 based on the time-weighted geometric average is lower than the arithmetic average (39 µg/L, compared to 106 µg/L) because a geometric average assumes that the rate of sulfide oxidation was faster at first, and then declined. There is no evidence for a changing oxidation rate, so an EC10 of 106 µg/L is most defensible. Furthermore, it has been argued that calculation of a geometric average is rarely appropriate when calculating average chemical concentrations for investigations of environmental impact (Parkhurst, 1998). Parkhurst points out that geometric averages are biased low, which accounts for the unusually low EC10 sulfide concentration of 39 µg/L. Accordingly, the arithmetic average of 106 µg/L is the most defensible EC10 estimate derived from the hydroponic data. (These EC10 values supersede estimates reported earlier in draft MPCA documents of 299, 160, and 71 µg/L, which were calculated with normalized data from each of the three experiments. Further examination of the results indicated that normalizing the data skewed the results, so this updated analysis uses the raw data.)

Of the three approaches to analyzing the hydroponic data, the EC10 estimate that is based on the time-weighted arithmetic average sulfide concentrations (106 µg/L) is likely the most reliable estimate (Fig. 1-2). Note that the EC10 is determined by calculating the sulfide concentration associated with a 10% decrease in wild rice growth relative to the growth in the control treatments. The control growth rate is taken as the flat area of "no effect" observed at the lowest sulfide concentrations (for example, the flat area in the left side of the logistic curve in Fig. 1-3).

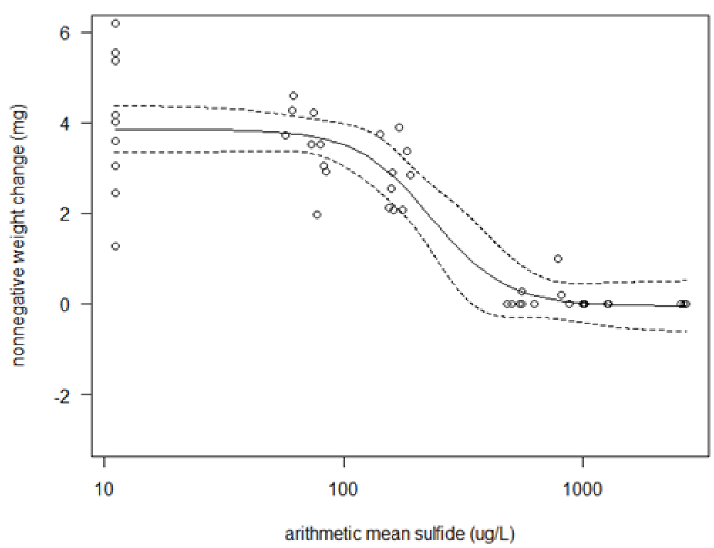


Figure 1-3. Logistic fit of wild rice seedling weight gain against time-weighted arithmetic average sulfide concentrations, using package *drc* in R. Raw data from three experiments are merged together. The EC10 was 106 µg/L, with a 95% confidence interval of 11 to 158 µg/L.

MPCA-sponsored mesocosm experiments: estimates of protective sulfide concentrations

The MPCA-sponsored mesocosm experiments (described in Pastor et al., 2017) yielded two statistically-significant effects of sulfide on wild rice, (1) percent filled, or viable, seeds and (2) number of plants that emerged in the spring. Calculation of EC10 values from linear regressions (Appendix 6) yields EC10 values of 228 and 121 µg/L, respectively, with relatively wide 95% confidence intervals (Fig. 1-2, Table 1-8).

MPCA-sponsored field survey: estimates of protective sulfide concentrations

The field survey of 108 different waterbodies offers several different ways to identify potential protective sulfide concentrations (Appendix 7): binary logistic regression (BLR), change-point analysis, and a visual examination of a graph of the proportion of sites with wild rice present—a non-statistical approach suggested by the 2014 independent peer review panel.

The EC10 derived from a binary logistic regression of wild rice presence/absence of the field data is less precise than expected because when the sulfide data are log-transformed to achieve an appropriate statistical distribution, the curve does not exhibit a flat area of "no effect" at the lowest sulfide concentrations (Fig. 1-4; see Appendix 7 for a comprehensive presentation). Because there is no flat area of no effect, the calculated EC10 value is dependent on selection of the baseline value from which to calculate a 10% effect.

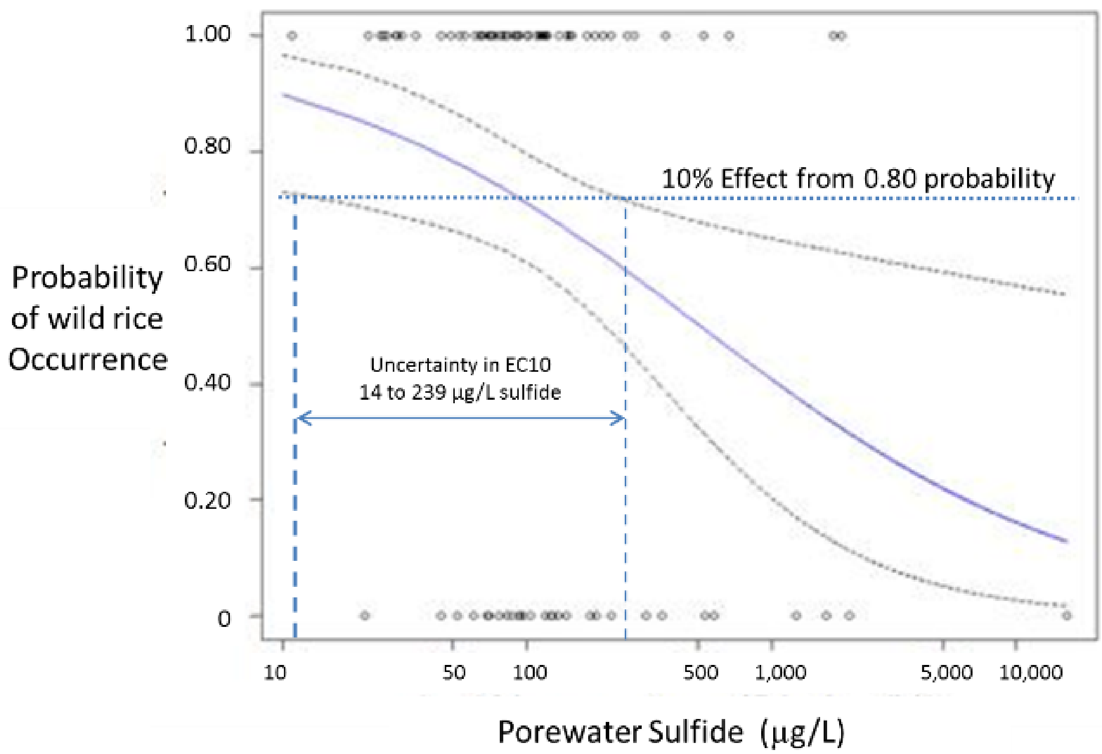


Figure 1-4. Binary logistic regression of the presence and absence of wild rice for field survey sites with water transparency greater than 30 cm (Class B data, N=96). The uncertainty of the EC10 estimate (93 µg/L) was quantified by identifying the range of sulfide concentrations that contain a given EC10 wild rice proportion in their 95% confidence interval based on the binary logistic regression

In the absence of a flat area of the curve, MPCA defined the baseline value as the proportion of sites with wild rice for the 10 sites with the lowest sulfide concentrations (0.80; Appendix 7). Given that definition, binary logistic regression can be used to identify two different protective sulfide concentrations depending on whether low-transparency (< 30 cm water transparency) sites that would not support wild rice are included (Table 1-8). These EC10 values are 58 µg/L for all sites, and 93 µg/L for the 96 sites with sufficient transparency to support wild rice. It is not reasonable to calculate a protective sulfide concentration with data from sites that would not support wild rice no matter how low the sulfide concentration is. Therefore, regression of just sites that would support wild rice, yielding an EC10 of 93 µg/L (95% confidence interval 14 – 239 µg/L), is the most defensible EC10 in this case.

A change-point analysis of wild rice density against sulfide yields an EC10 of 112 µg/L (95% confidence interval 25 – 368 µg/L), which is broadly compatible with the EC10 of 93 µg/L derived from the sites that have suitable transparency to support wild rice.

The third way in which the field data were used to identify a protective sulfide concentration was a non-statistical approach involving direct examination of the data. Visual identification of a reduction in the proportion of sites with wild rice present yields a value of 120 µg/L (Fig. 1-5), which is compatible with both the field survey EC10 based on wild rice presence/absence (93 µg/L, confidence interval of 14 - 239 µg/L) and change-point analysis based on wild rice density (112 µg/L, confidence interval of 25 – 368 µg/L; Table 1-8, Fig. 1-2).

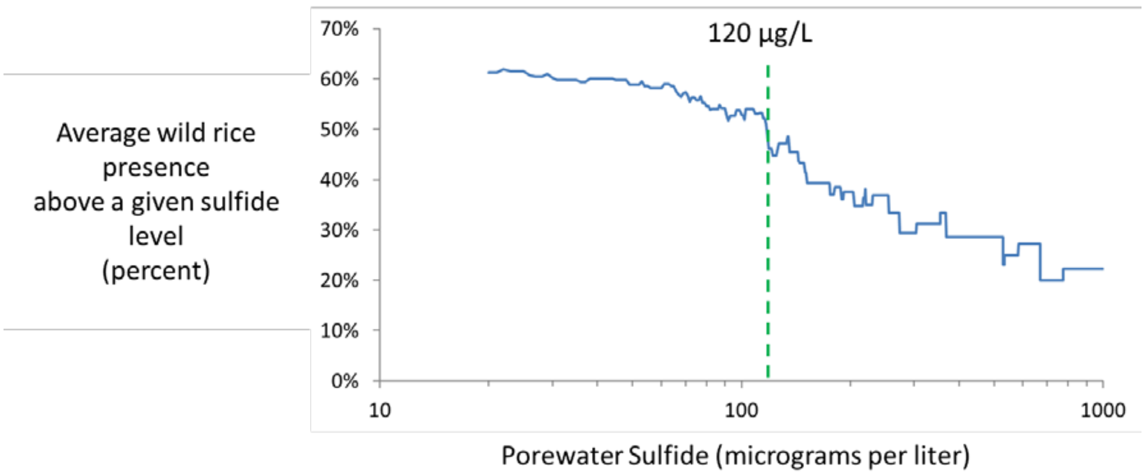


Figure 1-5. Empirical examination of the average proportion of sites with wild rice above a given porewater sulfide concentration (sites excluded with transparency < 30 cm). There is a noticeable decline in the proportion of sites with wild rice when sulfide exceeds 120 micrograms per liter (vertical dashed line).

Minnesota Chamber-sponsored hydroponic experiment: estimate of protective sulfide concentrations

A 21-day hydroponic study was sponsored by the Minnesota Chamber of Commerce (Fort Environmental Laboratory, 2015; Fort et al., 2017) in which wild rice seeds from a Minnesota lake were germinated in solution with a range of sulfide concentrations. Fort et al. (2017) did not calculate effect concentrations, but an EC10 of 963 µg/L was calculated from the Fort study data (MCC, 2015), suggesting that sulfide is less toxic to wild rice than was found in the three MPCA-sponsored studies (hydroponic, outdoor mesocosm, and field survey).

MPCA staff reviewed the design and results of the Fort hydroponic experiments to explore whether there were differences in the experimental approaches that could help account for these differing results. One potential explanation for the difference in the observed toxicity effects lies in the way that the germinated seeds were exposed to sulfide. In the Fort study, seeds were placed on a mesh that was submerged 1 cm in an aquarium open to the atmosphere that initially contained an anaerobic hydroponic solution of a given sulfide concentration; the solution was renewed and monitored daily. During the 21-day experiment, the sprouts were enabled to grow above the surface of the water, into the room air, as the mesocotyl (stem) developed and elongated. As the Fort study report states, “The mesocotyl developed in aerobic conditions under this design. Plastic wire mesh was placed inside the aquaria to provide a trellis to support vegetative growth above the hypoxic culture media." (Fort Environmental Laboratory, 2015, p. 14).

MPCA staff hypothesize that once the wild rice sprouts emerged into the room air, access to oxygen in the room air allowed the sprouts to internally detoxify sulfide by oxidizing it to non-toxic forms of sulfur (see *How access to oxygen may allow wild rice to detoxify sulfide*, in Part A of this chapter). There is evidence in the scientific literature that aquatic plants can detoxify sulfide through two broad routes that require oxygen. Aquatic plants have special channels in the stem for transporting air, called aerenchyma, for this purpose (Colmer, 2003). Access to the atmosphere is significant because the atmosphere is 21% oxygen (210,000 parts per million, ppm), in contrast to the availability of oxygen in water (a maximum of about 10 ppm). However, as noted in Part A of this chapter, under natural conditions 21-day old wild rice plants would not have access to the atmosphere because the seeds germinate in water that is much deeper than 1 cm, and the stems would not yet have elongated sufficiently to reach the water surface.

Uncertainty surrounding potential sulfide concentrations to protect wild rice

MPCA examined the range of EC10 and change-point estimates from MPCA-sponsored research on hydroponic, mesocosm, and field data (39 to 251 µg/L), plus the EC10 of 963 µg/L estimated from the Fort et al. (2017) hydroponic study (MCC, 2015). The discussion above identifies potential protective concentrations on which there are reasons to place less weight when considering the balance of evidence: two of the three MPCA-sponsored hydroponic EC10 values, the EC10 derived from field survey data that included low-transparency sites that would not support wild rice, and the Minnesota Chamber-sponsored hydroponic experiment. Those estimates with lower weight are identified with asterisks in Fig. 1-2 and Table 1-8.

In a review of plant toxicity endpoints, Clark et al. (2004) suggested that although plant growth is an important metric, successful reproduction is the most important metric in assessing the toxicity of a substance to an annual plant, such as wild rice. In the MPCA-sponsored investigations into the effect of sulfide on wild rice, the best metrics of successful growth and reproduction are (1) the percent of filled seeds (an indicator of seed viability) in the mesocosm experiment, (2) the number of plants that germinated in the mesocosm experiment, (3) the occurrence of wild rice in the field survey, and (4) the density of wild rice in the field survey. The estimates of protective sulfide concentrations from these metrics broadly agree with each other (Fig. 1-2).

The MPCA acknowledges that there is uncertainty in all of the EC10 calculations. The EC10 estimates from the field survey are uncertain due to the lack of a flat curve at low sulfide concentrations (Fig. 1-3). The EC10 derived from the MPCA-sponsored hydroponic experiment is uncertain because (1) sulfide concentrations declined during exposures and (2) the whole seedling was exposed to sulfide, which may not occur in nature except when the plant is germinating from a seed buried several inches in the anoxic sediment. The EC10 values derived from the outdoor mesocosms do not suffer from any obvious flaw, although it should be acknowledged that the mesocosms were not perfect mimics of the environment in that porewater sulfide concentrations were probably not in steady state. Pastor et al. (2017) point out that mesocosms cannot be perfect mimics of natural wild rice waters and be in steady state with controlling variables, because the watershed sources of iron were cut off even as sulfate kept being supplied. As a result, porewater sulfide concentrations increased over time, rather than reaching a steady-state concentration.

In addition, recent publications question whether EC10 can be used as a precise estimate of “no effect,” “negligible effect” or a “protective concentration” (e.g., Hommen et al., 2015; Fox and Landis, 2016). In addition to considering the multiple EC10 values and the change-point estimate, MPCA used a more empirical approach to identify a potential protective sulfide concentration by directly examining the field data for a visual threshold that might be used to identify a protective concentration—an approach explicitly recommended by the peer review panel (ERG 2014, p. 6). The data were examined for a threshold by calculating the average proportion of sites with rice above any given sulfide concentration (Fig. 1-4; Appendix 7), and the pattern simply examined, without any statistical analysis. Such an examination shows that although the percent of sites with wild rice declines as sulfide increases, the decline is relatively slow until the sulfide concentration exceeds 120 µg/L, where there is a notable drop in the percentage of sites with wild rice present. While a small uptick in the proportion of sites with wild rice occurs between 130-150 µg/L, the percentages never return to the 60% or greater that are observed below 120 µg/L (Fig. 1-5).

Identification of 120 µg/L as the protective sulfide concentration

Based on the analyses described above, MPCA proposes 120 µg/L as the protective concentration of sulfide. Not only is 120 µg/L at a visual break in the proportion of sites with wild rice, but it is within the range of the most defensible estimates of protective sulfide concentrations: 106 µg/L (from hydroponic experiments), 91 µg/L (the field survey EC10 based on wild rice presence), 112 µg/L (the field survey change-point based on wild rice density), 121 µg/L (EC10 based on mesocosm plant germination), and 228 µg/L (EC10 based on mesocosm seed viability) (Fig. 1-2; Table 1-8).

Of the 67 sites sampled in the field survey where wild rice was present, 73% had sulfide concentrations below 120 µg/L. The median sulfide concentration was 85 µg/L, and the average was 165 µg/L; 10% of sites had sulfide concentrations above 235 µg/L. In contrast, the median and average sulfide concentration at sites without wild rice was 126 and 795 µg/L, respectively. It is important to keep in mind that porewater sulfide is not the only environmental variable that affects the presence of wild rice, as discussed above. The analysis of the MPCA field data showed that reduced water transparency and elevated temperature also are associated with the absence of wild rice (Myrbo et al., in press-1), and other factors such as large carp populations and unfavorable hydrology have also been associated with the absence of wild rice (Table 1-6).

D. Relationship between surface water sulfate and porewater sulfide

The relationship between sulfate and sulfide is mediated by biology and chemistry, leading to a situation where superficially there seems to be little relationship between the two.

In the sediment of waterbodies, sulfate in the overlying water can diffuse into the underlying sediment and be converted by bacteria to sulfide. Diffusion of sulfate into sediment and the net retention of sulfur in sediment (as sulfide or as iron sulfide) has been shown in numerous lakes to be a function of the sulfate concentration (Urban et al., 1994). Based on that information, in a survey of many waterbodies one might expect porewater sulfide concentration to be strongly and directly correlated to sulfate concentration in the surface water. However, a plot of porewater sulfide against surface water sulfate (Fig. 1-6) shows only that when sulfate is low, sulfide is also low. But when sulfate is high, sulfide can range anywhere from low to high. This wedge-shaped distribution of data makes sense when one considers that sulfide must be produced from a sulfur-bearing chemical, and that sulfate is relatively mobile and available for the anaerobic bacteria that convert sulfate to sulfide. These bacteria necessarily can produce only limited quantities of sulfide when sulfate concentrations are low.

When sulfate concentrations are higher, there are two possible processes that may serve to limit sulfide concentrations. First, organic matter may be in short supply, limiting the bacteria's active metabolism and subsequent production of sulfide. Second, even if the bacteria are not limited by the availability of organic matter and do produce sulfide, sulfide may be removed from the porewater by precipitation with iron (Pollman et al., in press). As a result, sulfide concentrations associated with waters high in sulfate range from low to high.

Sulfide can also be produced in sediment by the putrefaction of sedimentary sulfur-bearing protein, which has been demonstrated by Dunnette (1989), who studied two eutrophic lakes. Dunnette found that putrefaction accounted for 5% and 57% of the sedimentary sulfide production in the two lakes. However, the overwhelming majority of sulfur retention in oligotrophic lake sediments can be accounted for by the conversion of sulfate to sulfide (Urban et al., 1994). Natural wild rice waters are normally low in nutrients, in contrast to the lakes studied by Dunnette, and so the findings of Dunnette may not be pertinent. Regardless, the following sections demonstrate that a satisfactory model can be developed that predicts porewater sulfide from just sulfate in surface water, sediment organic matter, and sediment iron.

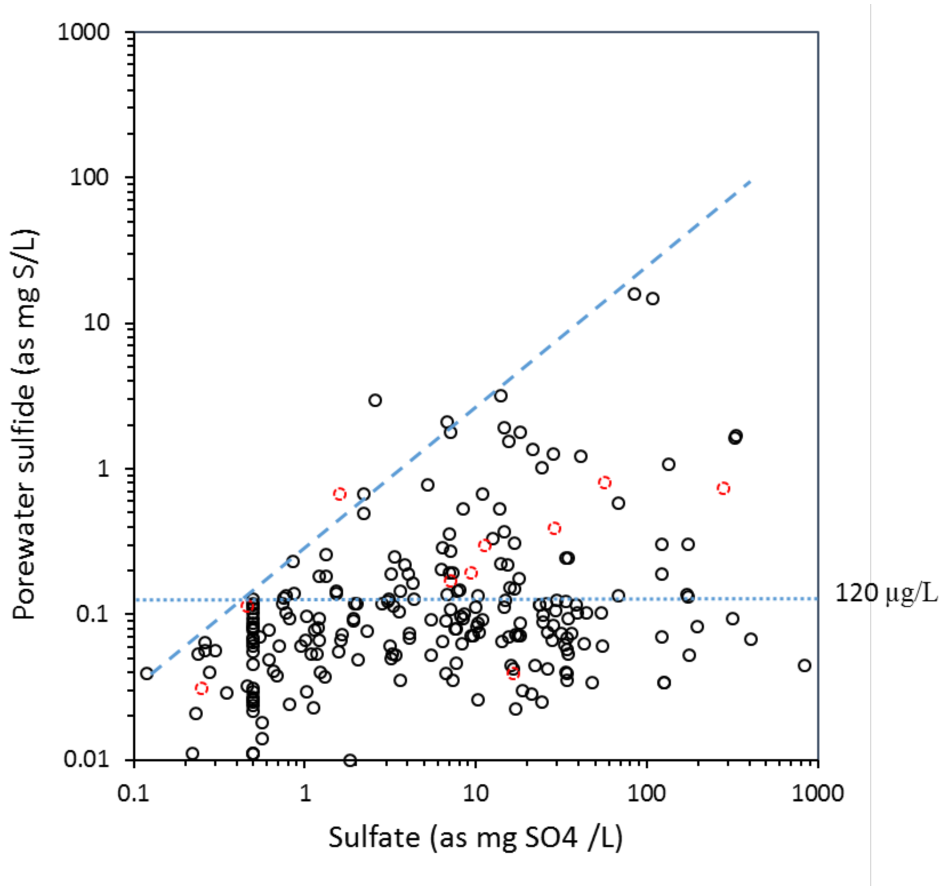


Figure 1-6. Relationship between sulfate in surface water and sulfide in porewater. The dashed line describes the empirically-observed highest net efficiency for the conversion of sulfate to sulfide (Class G data, plus cultivated paddies; N=233). Black symbols = natural waterbodies; Red dashed symbols = cultivated wild rice paddies. The protective sulfide concentration of 120 µg/L is shown.

Use of field data to model the effect of increasing sulfate in surface water

In the development of the research protocol (MPCA, 2011), potentially important environmental variables were identified based on a conceptual model of the processes relating sulfate and sulfide (graphically presented in Fig. 1-7). It has long been known that sulfate, organic matter and iron control porewater sulfide (e.g., Canfield, 1989; Giordani et al., 1996; Eldridge and Morse, 2000). In the interest of also collecting data to evaluate alternative hypotheses, in addition to measuring surface water sulfate, porewater sulfide, dissolved organic carbon (DOC), sediment organic carbon, and dissolved and sediment iron, over 60 other field variables were measured at each field site (Table 1-3).

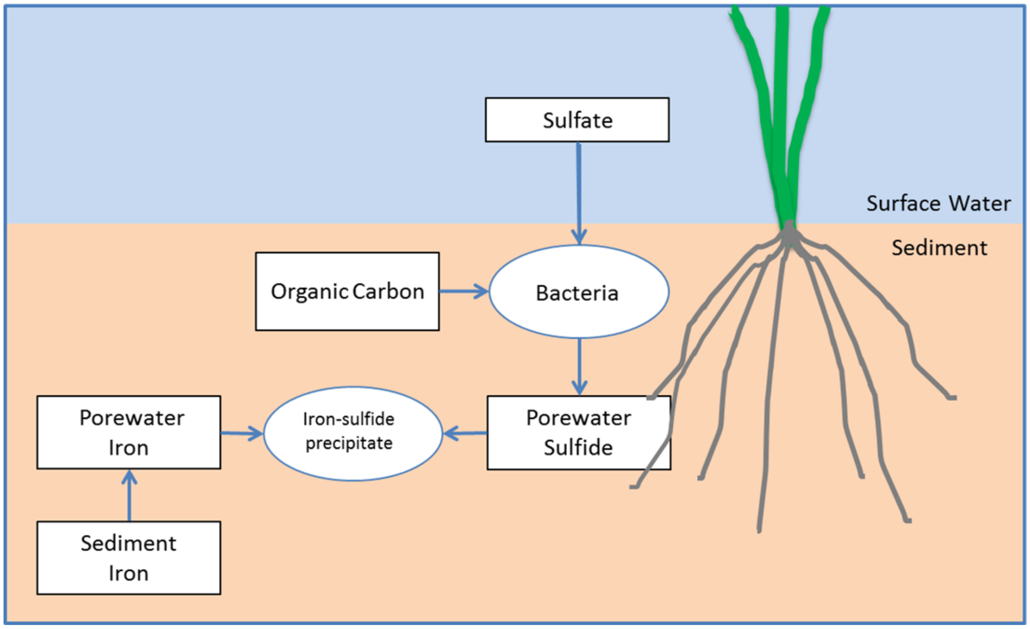


Figure 1-7. Conceptual model of the primary variables affecting the relationship between surface water sulfate and porewater sulfide. As bacteria utilize the energy in organic carbon, they respire sulfate, releasing sulfide. If iron is available, iron-sulfide precipitates form, which detoxifies the sulfide.

MPCA considered two different approaches to modeling the relationship between sulfate in surface water and sulfide in the sediment porewater underlying that surface water: mechanistic and statistical. A mechanistic model uses first principles of chemistry, physics, and biology to quantitatively describe the relationship between variables; to accomplish such a mechanistic model, a relatively complete understanding of the pertinent processes is required. In contrast, a statistical model is developed by fitting field data to mathematical relationships hypothesized by *a priori* understandings of likely chemical, physical, and biological processes operating in the environment (EPA, 2009a).

Mechanistic models, despite the goal of being based on first principles, often are empirically modified with field data to produce more accurate predictions, a process called calibration or parameter estimation (EPA, 2009a). In contrast, a statistical model is fundamentally based on the empirical relationships observed in the field between the variables of interest.

MPCA relied on a model of the statistical relationships of empirically observed data because a statistical model was judged likely to be more reliable than a mechanistic model given the greater data requirements for calibrating a mechanistic model and incomplete knowledge of the processes affecting the net conversion of sulfate to porewater sulfide. The most pertinent attempt to mechanistically model the water-sediment system concerned the potential toxicity of porewater sulfide to seagrass (Eldridge and Morse, 2000), a marine aquatic plant that is analogous to wild rice. A mechanistic model of the chemistry, physics, and biology of a marine system is exactly the same as modeling a freshwater system, except the concentration of sulfate is much higher (about 2,800 mg/L compared to Minnesota's wild rice waters, which range from below 1 to above 500 mg/L). Eldridge and Morse adapted a general model of the decomposition of organic matter by an array of bacteria that respired oxygen, nitrate, iron, and sulfate. The model required input of the concentrations of 13 different chemical species (e.g., organic matter, sulfate, porewater iron, oxygen, alkalinity), and predicted porewater sulfide as one of the seven calculated chemical species, from the simultaneous simulation of 24 different reactions. The model was run to a steady state and the results were compared to environmental data. The modeling was a success in the sense that comparing model results to empirical data reveals how well the processes are understood. For example, the model fit the measured sulfide better when the model included oxygen release from the roots of the seagrass.

It might have been possible to adapt a mechanistic model like that of Eldridge and Morse (2000) to wild rice, run it to steady state, and compare to the environment. But the model is very complicated and requires a great deal of data to run. The point of developing such a model is to assess how well the processes are understood, and to determine which processes need to be included in the model in order to come close to the observed data. MPCA has a different goal, which is to find a practical model that can relate sulfate to sulfide, to protect wild rice from elevated sulfate concentrations that result in in porewater sulfide concentrations that harm wild rice. Therefore, MPCA did not pursue a mechanistic model approach.

Assumption that sulfate, TOC, iron, and sulfide are in a steady state at field sites

Wild rice waters are dynamic ecological systems, with continuous external loading of sulfate and iron, coupled with variable amounts of annual production of wild rice plants, followed by variable decomposition. Yet it is likely that for decades most wild rice waters have experienced relatively constant processes, such as watershed loading of nutrients and sulfate, and soil erosion that carries organic matter and iron. Sulfate concentrations do fluctuate seasonally, but the field data from the MPCA study showed that sulfide concentrations do not fluctuate to a statistically significant degree. It is likely that porewater sulfide is a function of the long-term (e.g., year or more) average sulfate concentration.

It is common, when modeling relatively undisturbed ecosystems, to assume there is not much net change over seasons or years in the concentrations of important variables (e.g., Eldridge and Morse, 2000). In the case of the MPCA field survey, it is reasonable to assume that most of the 108 different sites have experienced no significant recent change in average surface water sulfate or sediment concentrations of TOC, iron, or sulfide. Monthly sampling at 15 different wild rice waters showed no significant change in TOC, iron or porewater sulfide from June through September (Myrbo et al., in press-1). When there is no significant change in concentrations over time, environmental modelers term a dynamic system to be in a “steady state” (Schnoor, 1996, pp. 4-5).

Both mechanistic and statistical modelers often rely on the assumption that a system is in steady state. For instance, in their mechanistic model Eldridge and Morse (2000) assumed that sulfate, organic matter, iron, and sulfide, among other variables, were in steady state. MPCA made the same steady-state assumption to pursue a statistical model that empirically relates the variables that are known to control porewater sulfide (sulfate, sediment organic carbon, and sediment iron). Although the model is based on concentrations of the variables, each concentration reflects the balance between continual input and loss. For instance, the concentration of sediment iron in the model (average concentration in the top 10 cm of the sediment) reflects the balance between new iron arriving to the sediment (inputs), and burial that pushes the layer of recently deposited material successively deeper in the sediment until it is deeper than 10 cm (losses).

Development of a statistical model using structural equation modeling (SEM)

At the suggestion of the peer review panel (ERG, 2014, p. 6), the MPCA employed structural equation modeling (SEM) to test the hypothesized conceptual model (Fig. 1-7). SEM is often referred to as “causal analysis” because it provides a framework for testing hypotheses with empirical data collected in field surveys (Iriondo et al., 2003). The structural equation (SE) model that was developed supports the hypothesis that there is a dynamic relationship between production of sulfide from sulfate and precipitation as iron-sulfide solids. A key result from the model is that variations in three external variables (sulfate, sediment TOC, and sediment iron) contribute nearly equally to the observed variations in porewater sulfide (Pollman et al., in press). The model provides strong evidence that development of a sulfate standard to protect wild rice from elevated sulfide should quantitatively consider the effects of ambient concentrations of sediment iron and organic carbon, in addition to surface water sulfate.

The SE model was validated by conducting a jackknife analysis where the model was refit by withholding a single observation from model estimation, and then using the refit model to predict the log10-transformed value for porewater sulfide. The out-of-sample predictions closely matched the predictions obtained from the fully calibrated model, and also found no problems with unusually influential single observations. In addition, models based on alternative hypotheses and involving additional variables (phosphorus, acid volatile sulfide, dissolved organic carbon) were evaluated and found to offer no advantage over the original hypothesis in the prediction of porewater sulfide (Pollman et al., in press).

In summary, structural equation modeling found that porewater sulfide is controlled equally by the concentrations of surface water sulfate, sediment iron, and sediment organic carbon. Thus, all three variables need to be considered when developing a strategy to ensure sulfide remains at or below a protective level in the sediment of wild rice beds.

E. Development of an equation to calculate a numeric sulfate standard for each wild rice water

The consideration of multiple variables in calculating a numeric concentration for a water quality standard is becoming more common as the scientific understanding of the environment improves. For instance, over time EPA's guidance for developing standards for ammonia has progressed from initially considering a fixed concentration to the present recommendation of adjusting ammonia concentrations for both the pH and temperature of the ambient water (EPA, 2013). Similarly, EPA's 2007 aquatic life freshwater criterion for copper is based on a model termed the Biotic Ligand Model (EPA, 2007 revision). This metal bioavailability model uses receiving waterbody characteristics and monitoring data to develop a numeric copper standard. Input data include temperature, pH, dissolved organic carbon, major cations (Ca, Mg, Na, and K), major anions (SO_4 and Cl), alkalinity, and sulfide.

When the consideration of multiple variables allows the calculation of a significantly more accurate numeric water quality standard, it can make sense to utilize that scientific understanding. The structural equation modeling effort demonstrates that porewater sulfide concentrations can be successfully modeled with three variables: surface water sulfate, sediment TOC, and sediment iron measured as total extractable iron (TEFe). If this scientific understanding can be incorporated into an equation, then the equation can be adopted as the water quality standard, similar to EPA's approach to ammonia and copper standards. A standard that is an equation, rather than a uniform concentration that is applied to all waterbodies, is a reflection of the biogeochemical diversity of the environment. New approaches such as this are needed as environmental regulation progresses from protecting organisms from pollutants that are directly toxic, to protecting them from pollutants whose negative effects are both indirect and a function of environmental conditions that vary from site to site. In the case of sulfate, an equation-based standard would reflect the evidence (discussed below) that an equation will be more accurate than a fixed standard

To identify a protective sulfate concentration for a particular water, it would be logical to employ the relationships revealed by the structural equation model and to work backwards from the protective sulfide concentration (120 micrograms/liter, µg/L) to identify the particular concentration of sulfate that would protect wild rice in that waterbody. A direct way to accomplish this task would be to first arrange the structural equation model into a single equation that expresses porewater sulfide as a function of the variables in the model (sulfate, sediment iron, and sediment TOC). Substituting the protective sulfide concentration for that variable and rearranging the equation would then derive an equation for the protective sulfate concentration as a function of iron and TOC concentrations. Such an equation could be applied to any wild rice water for which TEFe and TOC are known. However, rearranging the equation in that way results in re-transformation bias, reducing the accuracy of the equation (MPCA, 2015; Pollman et al., in press). Therefore, the MPCA has taken a different approach.

The re-transformation bias seen using the structural equation model can be avoided by predicting the protective sulfate concentration using multiple binary logistic regression (MBLR) with the variables identified from the structural equation model (Pollman et al., in press). By first relying on the structural equation model development to identify the appropriate variables, an MBLR model can be developed using the same field data. MBLR directly predicts the probability of exceeding the protective sulfide concentration threshold as a function of sulfate, TEFe, and TOC.

MBLR is a predictive analysis; in this case the regression predicts the probability that sulfide is greater than 120 µg/L. The inputs to the regression are the field survey data from 108 different sites for the observed sediment iron, sediment TOC, surface water sulfate and porewater sulfide (the Class B data). All of the Class B is used—including low-transparency waters, waters with wild rice, and waters without wild rice—because the resulting equation is a model of chemical relationships, and does not, and should not, include information on the presence or absence of wild rice. To include only samples where wild rice was present would certainly bias the data toward lower sulfide concentrations. The model could not be expected to predict higher sulfide concentrations as accurately if a high proportion of high-sulfide sites are excluded (which would happen if only sites with wild rice were included in the regression).

When all 108 samples are used, the MBLR regression is:

logit(sulfide>120 μg/L) = 9.3176 + 1.8962*log10sulfate - 3.6443*log10 iron + 2.2698*log10TOC (equation 1)

An equation to predict a protective concentration of sulfate can be derived if a probability is inserted into the equation. A probability of 0.5 (that sulfide is greater than 120 μg/L) produces sulfate values that most accurately predict the sulfide concentrations that were observed during the field survey (see Appendix 8 for a discussion of why 0.5 is the most accurate probability). At a probability of 0.5, the likelihood that sulfide is greater than 120 μg/L is equal to the likelihood that sulfide is less than 120 μg/L—in other words, using a probability of 0.5 to develop the equation produces the sulfate concentration that best matches a porewater sulfide concentration of 120 μg/L. Probabilities greater than 0.5 would be under-protective, and probabilities less than 0.5 would be over-protective.

Using a simplified version of the formula, the equation becomes:

$$\text{Logit(Sulfide >120)} = \text{constant} + a \log_{10} \text{Sulfate} + b \log_{10} \text{Iron} + c \log_{10} \text{TOC} \quad \text{(equation 2)}$$

$$\text{Log}\left(\frac{\text{Probability Sulfide>120 μg/L}}{1-\text{Probability Sulfide>120 μg/L}}\right) = \text{constant} + a \log_{10} \text{Sulfate} + b \log_{10} \text{Iron} + c \log_{10} \text{TOC} \quad \text{(equation 3)}$$

When a probability is chosen, a constant is produced for the left side of the equation (constant2):

$$\text{constant2} = \text{constant1} + a \log_{10} \text{Sulfate} + b \log_{10} \text{Iron} + c \log_{10} \text{TOC} \quad \text{(equation 4)}$$

If Sulfate is moved to one side and everything else to the other side, the equation becomes:

$$\text{constant2} - \text{constant1} - b \log_{10} \text{Iron} - c \log_{10} \text{TOC} = a \log_{10} \text{Sulfate} \quad \text{(equation 5)}$$

$$\log_{10} \text{Sulfate} = \frac{\text{constant2} - \text{constant1}}{a} - \frac{b}{a} \log_{10} \text{Iron} - \frac{c}{a} \log_{10} \text{TOC} \quad \text{(equation 6)}$$

$$\log_{10} \text{Sulfate} = \text{new constant} - \text{new b} \log_{10} \text{Iron} - \text{new c} \log_{10} \text{TOC} \quad \text{(equation 7)}$$

$$\text{Sulfate} = 10^{\text{new constant}} \times \text{Iron}^{\text{new b}} \times \text{TOC}^{\text{new c}} \quad \text{(equation 8)}$$

Use of a probability of 0.5 produces a logit(sulfide >120)=0, which creates the proposed equation:

$$Calculated\ Sulfate\ Standard = 0.0000121 \times \frac{Iron^{1.923}}{organic\ carbon^{1.197}} \quad \text{(equation 9)}$$

Or, alternatively,

$$\text{MBLR120 Sulfate} = 0.0000121 \times \text{TOC}^{-1.197} \times \text{TEFe}^{1.923} \quad \text{(equation 10)}$$

where sulfate is expressed as mg/L, TOC as percent dry weight, and TEFe as mg/kg.

Operationally, this equation to determine the protective sulfate threshold can be applied to any waterbody for which sediment TOC and sediment TEFe data are available. Of course, the data need to be produced using methods that are consistent with the procedures used to produce the field data on which the MBLR-based equation was derived.

The effect of different sediments in different wild rice waterbodies is illustrated by calculating the protective sulfate concentrations for three wild rice lakes with contrasting sediment quality. All three lakes had low ambient sulfate concentrations—less than 0.5 mg/L—but because of differences in sediment chemistry, the three have widely different MBLR-calculated protective sulfate concentrations, ranging from 1.2 to 186 mg/L (Table 1-9).

Table 1-9. Calculated protective surface water sulfate concentrations for three wild rice lakes. Note that these examples are for illustrative purposes only.

Study Site	State ID	Sediment Total Organic Carbon (%)	Sediment Iron (mg/ kg)	MBLR120-Calculated Protective Sulfate Concentration (mg/L)
Little Round Lake	03-0302	27.5	3,069	1.2
Elk Lake	15-0010	10.2	8,480	27
Rice Lake	18-0053	35.6	50,389	186

In summary, SEM was used to understand and characterize the relationships between the important parameters in the system that relates sulfate and sulfide, and then MBLR was used to translate the understanding gleaned from SEM into a relationship that can be used to calculate a numeric sulfate standard for each wild rice water.

F. Comparison of an equation-based standard to fixed standards: error rates and concerns

In the development of numeric water quality standards, even when a statistically valid stressor-response relationship is developed there will be a proportion of the waterbodies for which any given standard will be either under-protective or over-protective (EPA, 2009b; McLaughlin, 2012a,b; Vermont DEC, 2014; Smeltzer et al., 2016). To explore this using the MPCA-sponsored field survey data, each waterbody can be compared against a potential sulfate standard to see if the standard would be consistent with its measured porewater sulfide concentration. In other words, does any given sulfate standard that is predicted to be protective of wild rice also result in a porewater sulfide concentration that is protective of wild rice? Conversely, does a sulfate level that is predicted to not be protective of wild rice also result in sulfide levels that are not protective of wild rice? When the sulfate standard is consistent with the measured sulfide, the standard has a correct, or true, classification. A true negative occurs when ambient sulfate is less than the standard and sulfide is less than the protective concentration of 120 µg/L. A true positive occurs when sulfate is greater than the standard and sulfide is greater than the protective concentration of 120 µg/L.

The MPCA field survey data can be examined to determine the proportion of misclassifications (false positive and false negative prediction errors). A false positive error (called a Type 1 error in statistics) occurs when the ambient sulfate concentration exceeds the standard, but porewater sulfide is actually below the protective concentration of 120 µg/L; in such a case, the standard is overly stringent. False positives are a concern because they potentially could cause unneeded investment in sulfate control to keep sulfide at non-toxic levels. A false negative prediction error (a Type 2 error in statistics) occurs when the ambient sulfate concentration is less than the standard, but the porewater sulfide is actually above the protective concentration; in such a case, the standard is insufficiently stringent and adverse impacts may occur where they were not expected. In the development of a water quality standard, while the primary goal is to protect beneficial uses, it is also desirable to minimize the sum of these errors, which is the overall proportion of misclassifications. The total misclassification rate can be calculated for each proposed water quality standard. It has been proposed that it may be optimal to choose a water quality standard that balances misclassifications between false positives and false negatives, so that when an error does occur it is equally likely to be over-protective as under-protective (Vermont DEC, 2014).

The misclassification rate can be calculated for all possible fixed standards using the Class B dataset. At low potential sulfate standards, below 5 mg/L, the misclassification rate is high. For instance at a potential sulfate standard of 1.0 mg/L the misclassification rate is 46% because of a high proportion of false positive errors, indicating that a standard set at 1.0 mg/L would be overly stringent (44% of the sites false positive; 2% false negative; Fig. 1-8). The misclassification rate declines to 32% as the potential sulfate standard rises to 5 mg/L, and then varies between 32% and 37% up to a standard of 40 mg/L. The analysis presented here is limited to potential fixed sulfate standards up to 40 mg/L, above which the proportion of false negatives rises (indicating that fixed standards set above this level would not be reasonable). The lowest misclassification rate, 32% is produced at three potential fixed sulfate standards, 5, 10, and 26 mg/L. At 5 mg/L 24% of the sites would be false positive, and 8% false negative. At 26 mg/L, 4% of the sites would be false positive, and 28% false negative. A fixed sulfate standard of 10 mg/L would be the most balanced between false positives and false negatives, since at 10 mg/L the proportions of the two types of error are equal, at 16%, summing to a total of 32%.

In March 2015 the MPCA proposed to use a SEM-based equation that incorporates sulfate, iron, and organic carbon to calculate sulfate standards for wild rice waters (MPCA, 2015). This approach would result in a misclassification rate of 26% (Fig. 1-8). The refined approach presented in section E of this TSD of calculating the sulfate standard using multiple binary logistic regression (MBLR) and the same three environmental variables produces a misclassification rate of 16% (9% false positive and 7% false negative). The MBLR equation was validated by applying it to an independent data set (dataset Class V, N=47), which produced a slightly higher misclassification rate of 19% (11% false positive and 8% false negative). The proportion of false negative errors is therefore at least twice as high for a fixed standard of 10 mg/L than for the MBLR-calculated equation-based standard (16%, compared to 8% from Class V, or 7% from Class B) (Fig. 1-8). A major question is whether or not the lower overall error rate of the MBLR equation when compared to a fixed standard (16-19%, compared to 32%) justifies the additional investment in collecting iron and organic carbon data at each wild rice water.

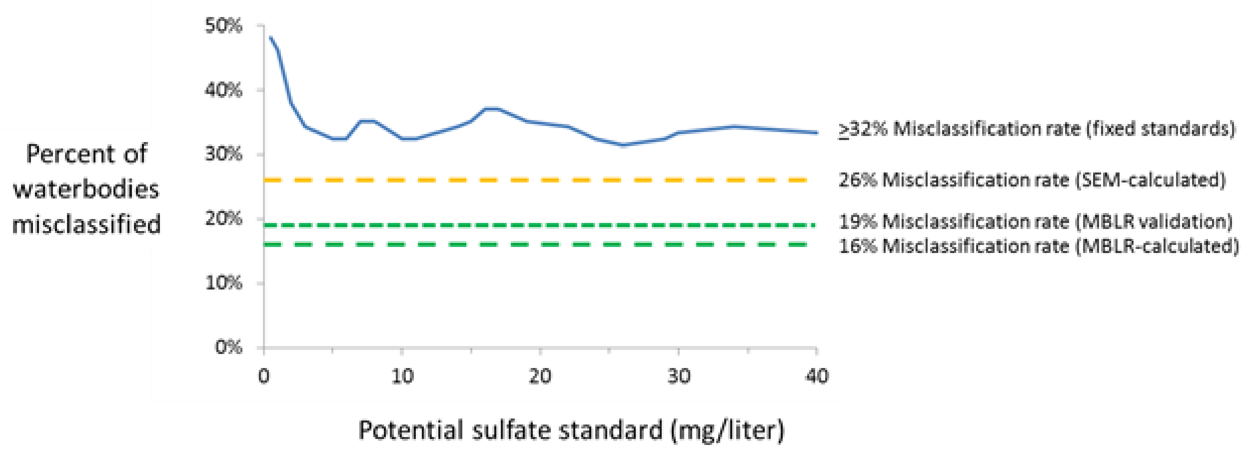


Figure 1-8. The misclassification rate compared across a range of potential sulfate standards. The misclassification rate is the sum of the percentage of false positive and false negative errors at a given potential sulfate standard.

Interplay between protective sulfide concentration and prediction errors

The analysis presented above shows that the MBLR-based equation produces sulfate standards that have fewer false positives and false negatives than any fixed sulfate standard. The equation produces about half the total misclassifications compared to the best fixed sulfate standards. Such comparisons are based on how well matched potential sulfate standards are to sulfide concentrations of 120 µg/L.

But what would the equation-based misclassification rate be if protective sulfide concentrations other than 120 µg/L were chosen? If errors were fewer for a different protective sulfide concentration, would it make sense to base the equation on that sulfide concentration? The interplay between protective sulfide concentrations and prediction errors can be confusing, because it may be tempting to recommend a sulfide concentration as being protective simply because it has relatively few prediction errors. However, it would not be reasonable to promote such a sulfide level unless it were in a range of sulfide concentrations that have a high probability of protecting the beneficial use.

It therefore would be a mistake to designate a sulfide concentration with a low misclassification rate as "protective" without evaluating how well it protects wild rice from that level of sulfide. A critical point to keep in mind is that misclassifications are not correlated with the degree of protection offered by a particular sulfide concentration. If a proposed protective sulfide concentration produces few errors, but the sulfide concentration is not actually protective of wild rice, then the enticement of low errors should be ignored.

Accuracy of calculated sulfate standards across potential protective sulfide concentrations

The potential consequences of designating sulfide concentrations other than 120 µg/L as protective can be investigated through analysis of the Class B dataset. First, the false positives and false negatives can be presented as a percentage of all 108 equation-based predictions across the spectrum of potential protective sulfide concentrations (Fig. 1-9). The sum of false positives and false negatives (the total misclassification rate) dips to 16% between 120 and 130 µg/L, and exceeds 16% at higher sulfide levels until a continuous decline to 9% that begins at 180 µg/L (Fig. 1-9).

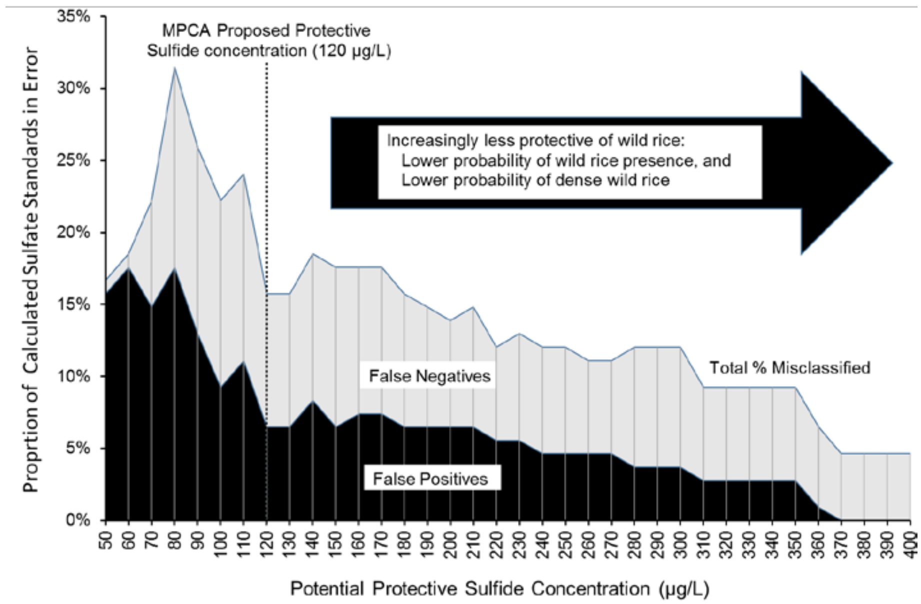


Figure 1-9. The proportion of false positive and false negative prediction errors calculated for potential protective sulfide concentrations ranging from 50 to 400 µg/L (in increments of 10 µg/L). The sum of false negatives and false positives is the total misclassification rate.

Although prediction errors decline when potential protective sulfide concentrations exceed 180 µg/L, such sulfide concentrations would not be as protective of wild rice as 120 µg/L. For instance, the probability that wild rice will be present declines as sulfide concentrations increase (Fig. 1-10), which was one of the lines of evidence included in the identification of 120 µg/L as an appropriate protective sulfide concentration (see Chapter 1, part C, above). In addition, the density of wild rice declines as sulfide concentrations increase; change-point analysis found a statistically significant decrease in density at 112 µg/L, which was another line of evidence examined. The probability that a wild rice water will exhibit dense wild rice (e.g., greater than 25 stem/m^2 or 40 stems/m^2) also declines as sulfide concentrations increase (Fig. 1-11).

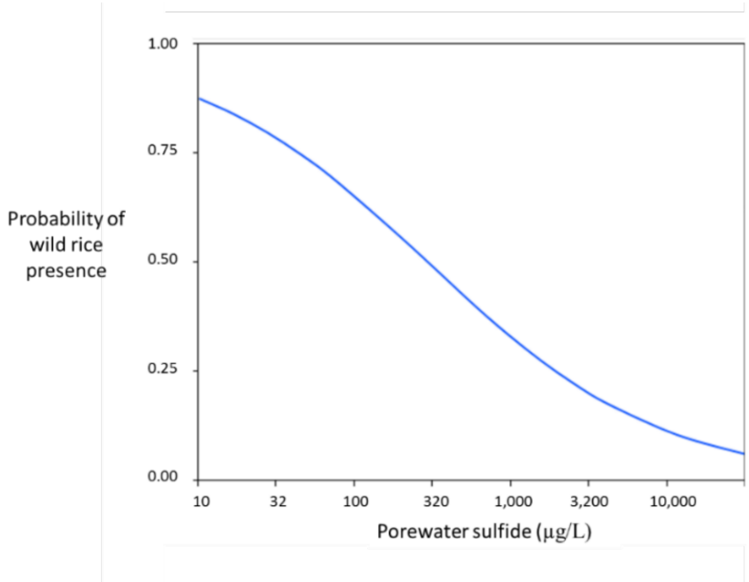


Figure 1-10. Probability of wild rice presence as a function of porewater sulfide (binary logistic regression; p=0.001; N=108).

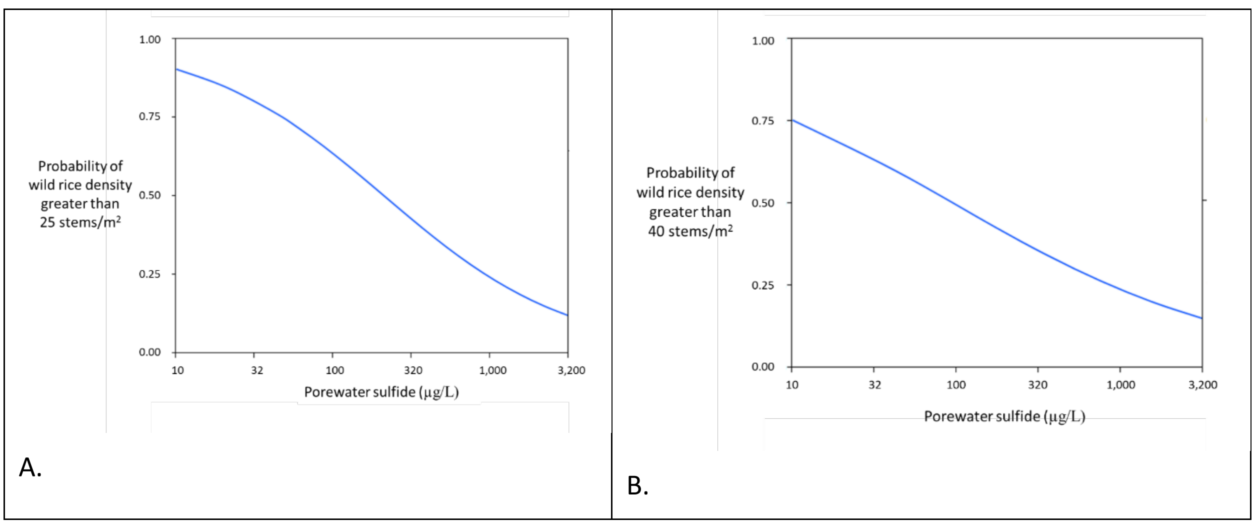


Figure 1-11. Probability of wild rice present at densities (A) greater than 25 stems/m^2 (binary logistic regression; p=0.013) and (B) 40 stems/m^2 (binary logistic regression; p=0.076). (Based on sites with wild rice in the Class B dataset, N=67.)

In contrast, the probability that a wild rice water will exhibit sparse wild rice (e.g., less than 10 stems/m^2) increases significantly as sulfide concentrations increase (Fig. 1-12). In other words, as sulfide increases and the probability of wild rice even being present declines (Fig. 1-10), it becomes more probable that the wild rice that is present has a low density (Fig. 1-13). For instance, at 120 µg/L, there is a 24% chance that wild rice density is less than 10 stems/m^2, but at 300 µg/L the probability more than doubles, to 52%. Simultaneously, the probability that wild rice density is greater than 25 stems/m^2 declines from 60% at a protective level of 120 µg/L to 44% at 300 µg/L.

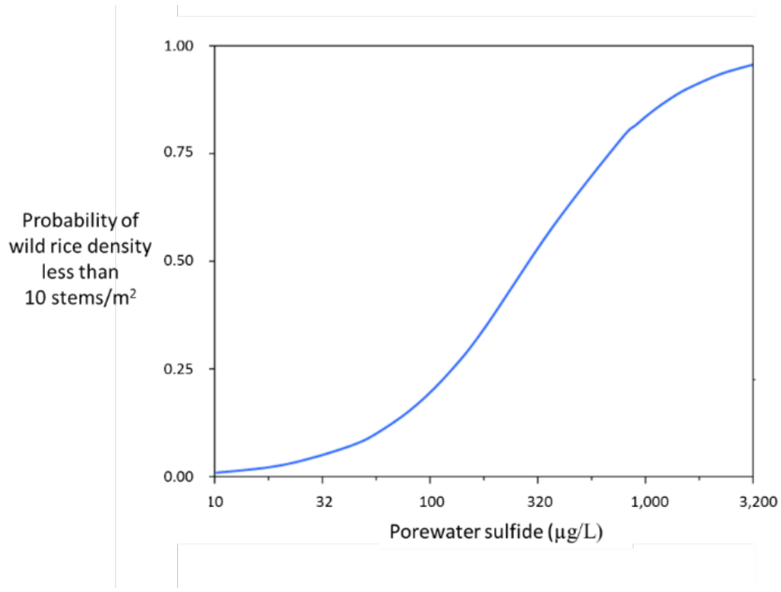


Figure 1-12. Probability of wild rice being present at a density of less than 10 stems/m² (binary logistic regression; p=0.0003). (Based on sites with wild rice in the Class B dataset, N=67.)

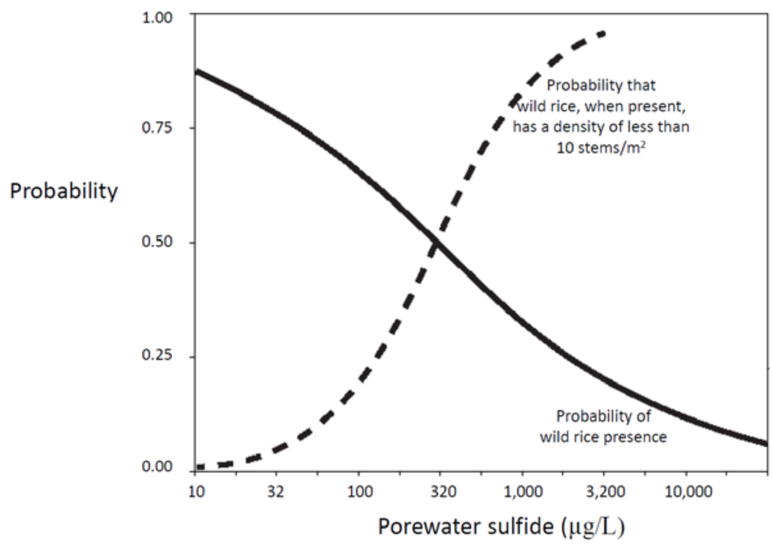


Figure 1-13. Probability of wild rice presence and the probability that the wild rice has a density of less than 10 stems/m², plotted against porewater sulfide concentrations.

Why not make the protective sulfide concentration zero?

It is evident that the highest probability of wild rice presence and a dense population occurs when porewater sulfide is lowest. However, it is unrealistic to have a goal of zero sulfide in the sediment porewater of wild rice waters. Sulfide is a natural chemical that is produced in the environment by naturally occurring bacteria from sulfate, which itself is a common natural chemical. Sulfate concentrations vary naturally across the landscape (Myrbo et al., in press-1), as do the other variables that control the production of sulfide, iron and total organic carbon (Pollman et al., in press). As a result, even under natural conditions there are waterbodies that are not hospitable to sulfide-sensitive species such as wild rice. In addition, there are likely areas within some wild rice waters that have lower iron or higher total organic carbon that naturally produce porewater sulfide that is incompatible with wild rice. For instance, an isolated bay of a wild rice water could plausibly have low sediment iron concentrations because the local watershed is poor in iron or there is no emergent groundwater rich in iron (Maranger et al., 2006). Similarly, a bay of a wild rice water could plausibly have higher sediment organic carbon because it lacks water movement to carry away decaying macrophyte plant material; it has been observed that natural wild rice generally grows best in waters that have some movement (Moyle, 1944; DNR, 2008; Table 1-6).

It is good that sulfate is present at least at minimal concentrations, since sulfate is an essential nutrient for plant growth. Zero sulfide and zero sulfate are not reasonable goals, so the question is, what is a reasonable goal for the protection of wild rice?

The field survey sponsored by the MPCA yields information about the range of sulfide in the porewater of wild rice waters. Of the 108 waterbodies in the Class B dataset, only two were less than the analytical lab's reporting limit of 11 µg/L. Sulfide was therefore likely present in the porewater of sediment as wild rice evolved over the millennia. It is also likely that wild rice, like other wetland plants, has adaptations that allow it to grow and reproduce in the presence of some concentration of sulfide in porewater. The multiple lines of evidence indicate that wild rice populations can thrive if porewater sulfide is less than 120 µg/L.

If it is true that wild rice populations can thrive at sulfide concentrations up to 120 µg/L, why do the graphs of presence and density (Figs. 1-10 and 1-11) imply that wild rice would benefit from every incremental decrease of sulfide below 120 µg/L? The graphs extend down to 10 µg/L, where the probability of wild rice presence is predicted to be 88%, and 75% of wild rice stands are predicted to have density greater than 40 stems/m^2. If lower sulfide is apparently associated with better wild rice growth, why not make the protective sulfide concentration as low as possible, such as the analytical limit of 11 µg/L?

There are multiple reasons why making the protective sulfide concentration as low as possible is not reasonable, or necessary to protect wild rice:

Firstly, cause and effect is likely backwards at very low concentrations of sulfide. The graphs relating sulfide to wild rice presence and density (Figs. 1-10 and 1-11), support the overall conclusion that wild rice presence and density can be controlled by exposure to sulfide, (Myrbo et al., in press-1; Fort et al., 2017; Pastor et al., 2017). However, when sulfide is low enough for wild rice to grow to dense levels, it is reasonable to assume that oxygen release by the wild rice would decrease sulfide to even lower concentrations, producing the continuous slope observed in the graphs. It is well established that wetland plants can release oxygen from their roots, which is thought to be an adaptation that decreases the toxicity of sulfide by converting it to sulfate (Lamers et al., 2013). Myrbo et al. (submitted-2) found that sulfide concentrations are significantly lower when wild rice plants are present, an observation that provides support for the idea that high densities of wild rice can drive porewater sulfide to very low concentrations. Myrbo et al. (submitted-2) go on to suggest that there may be a tipping point in the exposure of wild rice to sulfide, above which oxygen release is insufficient to detoxify the sulfide and a wild rice population cannot persist over the long term. In other words, the capacity of wild rice to detoxify sulfide is limited. The shape of the graphs in Figures 1-10 and 1-11 are explicable if sulfide concentrations above 120 µg/L control wild rice presence and density, but that at some concentration below 120 µg/L wild rice starts controlling the sulfide concentration.

Secondly, the accuracy of the equation that would calculate sulfate standards deteriorates for protective sulfide concentrations below 120 µg/L (Fig. 1-9, Table 1-10). The sum of false positives and false negatives is 16% at 120 and 130 µg/L, but from 70 to 110 µg/L ranges between 22% and 32%. Both false positives and false negatives are serious errors. False negative errors could result in ongoing use impairment. False positive errors could lead to inappropriate management interventions using resources that would be better directed elsewhere (Smeltzer et al., 2016). Below 70 µg/L the errors are essentially all false positives (Table 1-10)—where ambient sulfate is greater than the calculated standards, but porewater sulfide is less than the assumed protective sulfide concentration of 50 or 60 µg/L (MPCA did not calculate the misclassification rates below 50 µg/L).

Wild rice exhibits atypical dose-response curves

It was noted earlier (in "MPCA-sponsored field survey: estimates of protective sulfide concentrations," above) that the logistic curve relating wild rice presence to sulfide does not exhibit a flat area of "no effect" at low sulfide concentrations (Figs. 1-4 and 1-10; Appendix 7). Similarly, the probability of observing high wild rice density does not exhibit a flat area of no effect at low sulfide levels (Fig. 1-11). MPCA staff were initially surprised at the shape of these dose-response curves, since environmental toxicologists typically observe, and expect, a sigmoid-shaped relationship between the growth of an organism and the dose, or concentration, of a chemical (e.g., Landis and Yu, 2003, p. 32). The expectation of a sigmoid-shaped curve is based on the assumption that a chemical has no effect at very low concentrations, but increasingly greater effect as concentrations of the chemical increase. However, environmental toxicologists generally have no expectation that organisms have the ability to decrease the environmental concentration of the toxic chemical, an ability that dense populations of wild rice appear to have when growing in low concentrations of sulfide (through oxidation as described above). The expectation that chemicals affect organisms, and not the other way around, can be explained by the focus of environmental toxicologists on synthetic chemicals that are not natural in the environment, and the assumption that sensitive species do not possess adaptations to reduce the environmental concentration of a toxic chemical. In fact, in their book *Introduction to Environmental Toxicology*, Landis and Yu characterize the sigmoid shape as the typical response of organisms to a "xenobiotic"—xenobiotic being their term for a toxic chemical. The EPA defines a xenobiotic as a chemical "…that does not occur naturally in the environment. Xenobiotics occur as a result of anthropogenic activities such as the application of pesticides and the discharge of industrial chemicals to air, land, or water." (EPA, 1992, p. 38). Environmental toxicologists have generally not evaluated the effect of a natural toxin such as sulfide on organisms, although there is increasing interest in the effect of sulfide on plants (Lamers et al., 2013). Because high densities of wild rice can further decrease low concentrations of porewater sulfide, as seen by Myrbo et al. (submitted-2), atypical dose-response curves are produced.

Alternative metrics for evaluation of false positives and false negatives

There are multiple metrics of the accuracy of predictions that can be calculated when false positives (FP), false negatives (FN), true positives (TP), and true negatives (TN) are known (Fielding and Bell, 1997). In the discussion above, the false predictions are calculated as the proportion of the total predictions, which Fielding and Bell call the misclassification rate (misclassification rate = (FP +FN)/(FP+FN+TP+TN). The overall misclassification rate for potential fixed sulfate standards is presented in Fig. 1-8, and the components (false positives and false negatives) are presented in Fig. 1-14a.

A different way to examine the accuracy of predictions is to treat predictions as though they were medical diagnoses, and then to calculate the rate that the diagnosis is incorrect. For instance, a false negative is actually a positive; the “false negative rate” (FNR, as defined by Fielding and Bell) is the proportion of all positives that are false negatives: FNR=FN/(FN+TP). From a medical point of view, the FNR is the rate at which people with a disease are incorrectly diagnosed as not having the disease. Similarly, the false positive rate (FPR) is the rate at which healthy people are incorrectly diagnosed as having a disease. In the world of sulfate water quality standards, the false positive rate is the rate at which the ambient sulfate concentrations in waterbodies exceed the standard, but porewater sulfide is actually below the protective concentration of 120 µg/L.

The State of Vermont identified phosphorus standards to protect against eutrophication by finding the phosphorus concentration where FPR and FNR are equal, so that the standard was equally likely to be over-protective and under-protective (Smeltzer et al., 2016). It is possible to perform this type of analysis for fixed sulfate standards (Fig. 1-14b), but not for equation-based standards, where the error rates are not functions of potential fixed numeric sulfate standards. (Although it is possible to calculate the misclassification rate for the identified protective sulfide concentration of 120 µg/L.)

For potential fixed sulfate standards, the two accuracy metrics (misclassification rate and error rate) produce similarly shaped curves characterizing false positives and false negatives (Fig. 1-14 a,b). In addition, the curves cross at similar sulfate concentrations (10 mg/L and 7 mg/L, respectively), the concentrations where over-protection and under-protection would be balanced.

Early in this section (F) of the TSD it is noted that the overall misclassification rate for the best fixed sulfate standard (32%) is much greater than the misclassification rate for the proposed equation (16% for the dataset it was developed on, and 19% for an independent dataset).

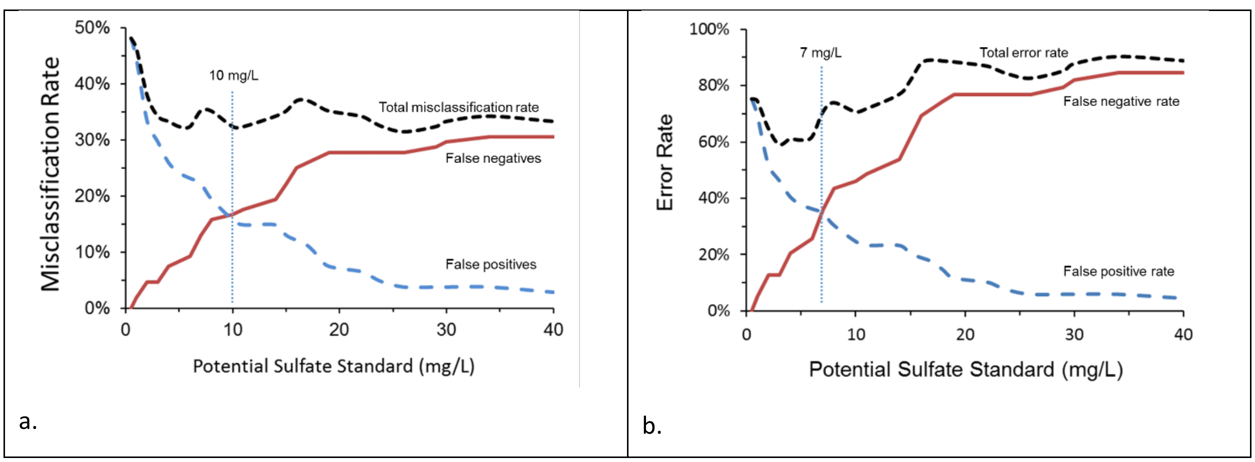


Figure 1-14. Two different ways (as described by Fielding and Bell, 1997) of interpreting the false negatives and false positives associated with a spectrum of potential sulfate criteria (potential standards) and their classification accuracy associated with a protective sulfide concentration of 120 µg/L: a) The total misclassification rate, showing that false negatives and false positives percentages are equal at 10 mg/L, summing to 32%. The total also sums to 32% at 5 mg/L and 26 mg/L, but the former is dominated by false positives (24%) and the latter is dominated by false negatives (28%). b) The total error rate, showing that the false negative rate and false positive rate are equal at 7 mg/L.

Table 1-10. Calculated false classification percentages for potential protective sulfide concentrations from 50 to 400 µg/L (Class B dataset, which approximates a probabilistic sample of waterbodies that could potentially host wild rice; N=108).

					False Predictions		
Potential Protective Sulfide (µg/L)	True positives	False positives	False negatives	True negatives	Percent false positive	Percent false negative	Total percent misclassified
50	89	17	1	1	15.7%	0.9%	16.7%
60	85	19	1	3	17.6%	0.9%	18.5%
70	68	16	8	16	14.8%	7.4%	22.2%
80	51	19	15	23	17.6%	13.9%	31.5%
90	47	14	14	33	13.0%	13.0%	25.9%
100	40	10	14	44	9.3%	13.0%	22.2%
110	35	12	14	47	11.1%	13.0%	24.1%
120	29	7	10	62	6.5%	9.3%	15.7%
130	26	7	10	65	6.5%	9.3%	15.7%
140	22	9	11	66	8.3%	10.2%	18.5%
150	17	7	12	72	6.5%	11.1%	17.6%
160	17	8	11	72	7.4%	10.2%	17.6%
170	17	8	11	72	7.4%	10.2%	17.6%
180	17	7	10	74	6.5%	9.3%	15.7%
190	16	7	9	76	6.5%	8.3%	14.8%
200	16	7	8	77	6.5%	7.4%	13.9%
210	14	7	9	78	6.5%	8.3%	14.8%
220	14	6	7	81	5.6%	6.5%	12.0%
230	12	6	8	82	5.6%	7.4%	13.0%
240	11	5	8	84	4.6%	7.4%	12.0%
250	11	5	8	84	4.6%	7.4%	12.0%
260	11	5	7	85	4.6%	6.5%	11.1%
270	11	5	7	85	4.6%	6.5%	11.1%
280	8	4	9	87	3.7%	8.3%	12.0%
290	8	4	9	87	3.7%	8.3%	12.0%
300	8	4	9	87	3.7%	8.3%	12.0%
310	9	3	7	89	2.8%	6.5%	9.3%
320	9	3	7	89	2.8%	6.5%	9.3%
330	9	3	7	89	2.8%	6.5%	9.3%
340	9	3	7	89	2.8%	6.5%	9.3%
350	9	3	7	89	2.8%	6.5%	9.3%
360	9	1	6	92	0.9%	5.6%	6.5%
370	9	0	5	94	0.0%	4.6%	4.6%
380	9	0	5	94	0.0%	4.6%	4.6%
390	9	0	5	94	0.0%	4.6%	4.6%
400	9	0	5	94	0.0%	4.6%	4.6%

Table 1-11. Calculated false classification percentages and diagnosis error rates for potential sulfate standard concentrations from 0.5 to 40 mg/L (Class B dataset; N=108).

					False predictions			Diagnosis Error Rates	
Potential Sulfate Standard (mg/L)	True positives	False positives	False negatives	True negatives	Percent false positive	Percent false negative	Misclass-ification rate	False Positive Rate	False Negative Rate
0.5	39	52	0	17	48%	0%	48.1%	75%	0%
1	37	48	2	21	44%	2%	46.3%	70%	5%
2	34	36	5	33	33%	5%	38.0%	52%	13%
3	34	32	5	37	30%	5%	34.3%	46%	13%
4	31	28	8	41	26%	7%	33.3%	41%	21%
5	30	26	9	43	24%	8%	32.4%	38%	23%
6	29	25	10	44	23%	9%	32.4%	36%	26%
7	25	24	14	45	22%	13%	35.2%	35%	36%
8	22	21	17	48	19%	16%	35.2%	30%	44%
10	21	17	18	52	16%	17%	32.4%	25%	46%
11	20	16	19	53	15%	18%	32.4%	23%	49%
14	18	16	21	53	15%	19%	34.3%	23%	54%
15	15	14	24	55	13%	22%	35.2%	20%	62%
16	12	13	27	56	12%	25%	37.0%	19%	69%
17	11	12	28	57	11%	26%	37.0%	17%	72%
18	10	10	29	59	9%	27%	36.1%	14%	74%
19	9	8	30	61	7%	28%	35.2%	12%	77%
22	9	7	30	62	6%	28%	34.3%	10%	77%
23	9	6	30	63	6%	28%	33.3%	9%	77%
24	9	5	30	64	5%	28%	32.4%	7%	77%
26	9	4	30	65	4%	28%	31.5%	6%	77%
29	8	4	31	65	4%	29%	32.4%	6%	79%
30	7	4	32	65	4%	30%	33.3%	6%	82%
34	6	4	33	65	4%	31%	34.3%	6%	85%
40	6	3	33	66	3%	31%	33.3%	4%	85%

False negative sites under the current 10 mg/L standard (but correctly classified by the MBLR-based equation)

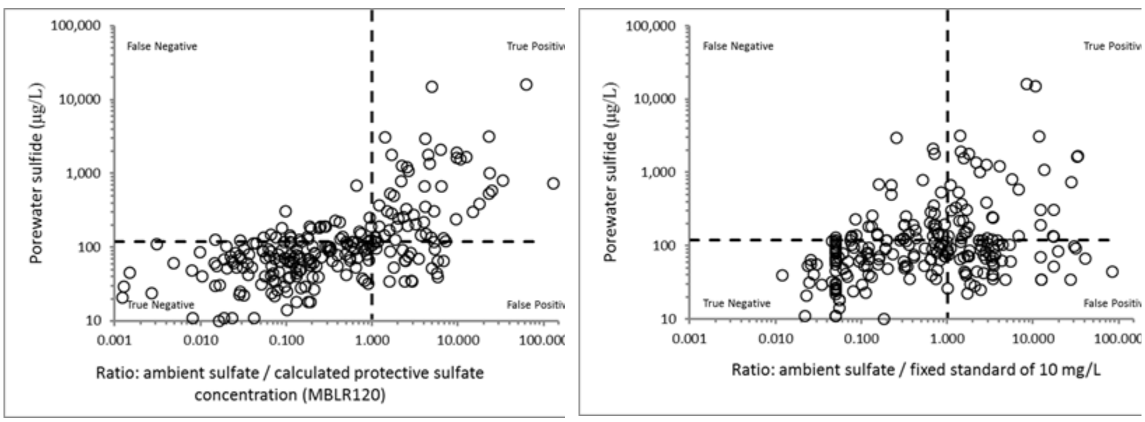
Some sites have sedimentary concentrations of iron and organic carbon that allow relatively efficient conversion of sulfate to porewater sulfide. If surface water carried sulfate into the sediment, 100% conversion of only 0.4 mg/L would exceed a sulfide concentration of 120 µg/L, an indication of why regulation of sulfate concentrations less than 10 mg/L would be appropriate when iron availability is low. Highly efficient conversion to sulfide was observed in some sites in the MPCA field survey data set. Among the sites in the MPCA field survey, there are nine sites where a fixed standard of 10 mg/L would not be protective, but the MBLR equation would be protective (Table 1-12). The ambient sulfate concentrations at these sites range from 1.3 to 7.8 mg/L, and observed porewater sulfide concentrations range from 145 to 2,525 µg/L, above the protective concentration of 120 µg/L sulfide. At these sites, wild rice density is generally low (zero to 10.4 stems/m^2) with an exception of 69.7 stems/m^2 observed in the single visit to Bowstring River.

Table 1-12. Examples of false negatives relative to a fixed numeric standard of 10 mg/L: sites with sulfate less than 10 mg/L, but with greater than the calculated protective sulfate concentration, as calculated by the multiple binary logistic regression (MBLR120). As predicted by the MBLR equation, sulfide concentrations are greater than 120 µg/L, the protective sulfide concentration. (Values are average when the site was sampled more than once.)

Site	State ID	Ambient sulfate (mg/L)	MBLR120 (mg/L)	Wild Rice density stems/m^2	Porewater Sulfide (µg/L)	Trans-parency (cm)	Number of Field Samples
Anka Lake	21-0353-00-201	4.3	0.7	10.4	565	89	3
Big Sucker Lake	31-0124-00-203	7.8	2.1	3.8	145	101	1
Bowstring River	S007-219	1.3	0.6	69.7	256	101	1
Gilchrist Lake	86-0064-00-201	7.0	1.7	0.0	355	101	1
Rice Lake	02-0008-00-206	3.6	2.6	0.0	145	31	1
Rice Lake	66-0048-00-203	5.2	2.4	0.0	777	20	1
Rice Lake	73-0196-00-216	4.7	0.9	0.0	2,525	101	2
Rice Lake	74-0001-00-201	3.8	3.2	0.0	217	3	1
Westport Lake	61-0029-00-204	6.7	3.1	3.3	998	86	2

It is useful to examine the implications of the data from the Bowstring River in some detail, because the calculated protective sulfate concentration was extremely low. The Bowstring River was sampled at only one location during the field survey, so it was uncertain how representative the single analyses of TOC and TEFe were. The following discussion should therefore not be taken as a thorough description of the waterbody, but rather as an opportunity to discuss the effect of sulfide on the probability of wild rice occurrence in a waterbody. This site on the Bowstring River was later sampled in detail as part of an implementation pilot project, described in Chapter 3, *Implementation of the Wild Rice Standard.*

Based on the single sample from the field survey, Bowstring River would have an extremely low calculated sulfate standard, 0.6 mg/L sulfate, based on the MBLR equation (TOC is high, and TEFe is low). The ambient sulfate concentration was just 1.3 mg/L (1.0 mg/L when sampled in the implementation pilot project 6/23/2015), but produced a porewater sulfide concentration of 256 µg/L, appreciably higher than the protection goal of 120 µg/L sulfide. Despite exceeding the protective porewater sulfide level of 120 µg/L, Bowstring River supported a dense population of wild rice, which is a reminder that 120 µg/L is not a stark threshold below which wild rice can exist and above which wild rice dies. Rather, above 120 µg/L the *probability* of observing wild rice declines progressively as sulfide concentrations increase. According to the logistic regression, the probability of observing wild rice is 69% at 120 µg/L, and declines to a probability of 59% at 256 µg/L (Fig. 1-4). The probability curve suggests that the wild rice population on the Bowstring River is at risk if even slight increases in sulfate occur above the measured ambient concentration of 1.3 mg/L, given that the MBLR-calculated protective sulfate concentration was 0.7 mg/L. If ambient sulfate were allowed to approach 10 mg/L, it is likely that porewater sulfide would become much higher and that the wild rice population would decline in this waterbody. If sulfide reached 500 µg/L, the probability of wild rice occurrence would decline to 50%. As the ambient sulfate concentration increases above the calculated protective concentration for that waterbody, the likelihood of elevated porewater sulfide increases dramatically (Fig. 1-15 a).



a b

Figure 1-15. Observed accuracy observed when the MPCA survey data are assessed against (A) standards calculated with the proposed equation, and (B) a fixed sulfate standard of 10 mg/L. Sites to the right of the vertical dashed line exceed the potential sulfate standard, the goal of which is to keep porewater sulfide below the protective concentration of 120 µg/L. Sites above the horizontal dashed line actually had porewater sulfide greater than 120 µg/L. The sites in the upper right quadrants (above and to the right of the dashed lines) are correctly classified as exceeding the standard (true positives), whereas the sites in the lower right quadrant are false positives. Sites in the upper left quadrant are false negatives—sites where the ambient sulfate concentration was falsely identified as protective of wild rice, but the porewater sulfide was greater than 120 µg/L. (All survey data are graphed, so that some waterbodies are represented by multiple points; N=222.)

Note that four of the nine sensitive sites noted above that are negatively affected by ambient concentrations of sulfate below 10 mg/L are called “Rice Lake” (Table 1-12), which some assume means that the early settlers had observed obvious wild rice populations. No wild rice plants were observed in these lakes during the field survey. These sites are not notably enriched with sulfate – ambient sulfate ranges from 3.6 to 5.2 mg/L – yet porewater sulfide is elevated above the protective sulfide concentration of 120 µg/L.

If wild rice used to grow in these four lakes, porewater sulfide may have been below the protective sulfide concentration, which implies that these lakes experienced an increase in sulfate or organic matter, or, less likely, the loading rate of iron has decreased. These four lakes lie in areas where there is significant anthropogenic land use, including agriculture. Agricultural activity could increase sulfate loading, either through the use of groundwater for irrigation (since groundwater often has higher sulfate concentrations than surface water) or by the application of sulfur-containing fertilizers. Tile drainage in a watershed may also increase the export of sulfate to receiving waters, because of increased aerobic oxidation of sulfide minerals in the soil (Lamers et al., 2013).

In addition, anthropogenic activity almost always increases loading of phosphorus to surface waters, which likely would decrease transparency. As discussed in section A of this TSD, reduced transparency reduces the probability of wild occurrence independent of the porewater sulfide concentration in that waterbody. Wild rice can be excluded from a site if the water transparency is less than 30 cm (Part B of Chapter 1, above). Three of the four Rice Lakes had low observed transparency (3, 20, and 31 cm), in addition to exceeding the protective sulfide concentration.

False positive sites under the current 10 mg/L standard (but correctly classified by the MBLR-based equation)

Some sites have sediment concentrations of iron and organic carbon that do not result in relatively efficient conversion of sulfate to porewater sulfide. Among the wild rice sites in the MPCA field survey there are six sites where the observed sulfate is greater than 10 mg/L but sulfide concentrations are less than 120 µg/L—sites that under a 10 mg/L fixed sulfate standard would falsely be classified as areas where wild rice is not sufficiently protected. The MBLR equation correctly predicted that these sites would have sulfide below 120 µg/L (Table 1-13), thereby protecting wild rice.

At these six sites, average wild rice densities range from 31 to 141 stems/m^2. Ambient sulfate concentrations range from 18 to 32 mg/L, well below the calculated protective sulfate concentrations, which range from 93 to 546 mg/L. Observed sulfide concentrations range from 53 to 112 µg/L.

Table 1-13. Examples of false positives relative to a numeric sulfate standard of 10 mg/L: sites with sulfate greater than 10 mg/L, but with sulfate concentrations lower than the calculated protective sulfate concentration. As predicted by the MBLR equation, sulfide concentrations do not exceed 120 µg/L, the protective sulfide concentration. (Values are average when the site was sampled more than once.)

Site	State ID	Ambient sulfate (mg/L)	MBLR120 (mg/L)	Wild Rice density stems/m^2	Porewater Sulfide (µg/L	Trans-parency (cm	Number of Field Samples
Hay Lake	31-0037-00-202	26.9	218	141	59	86	2
Mississippi Pool 4 / Robinson Lake	79-0005-02-201	29.6	262.6	46.5	67	90	3
Mississippi Pool 5 / Spring Lake	S007-660	32.5	546.1	39	53	88	5
Mississippi Pool 8 at Genoa	S007-222	31.2	93	31.2	112	86	4
Mississippi Pool 8 at Reno Bottoms	S007-556	18.1	187.6	72.3	71	57	1
Partridge River	S007-443	24.1	302	42.5	80	79	6

Practical implications of false positive and false negative prediction errors

If the ambient sulfate concentration is greater than the standard, the state of Minnesota is required to take action, pursuing either a) completion of a Total Maximum Daily Load (TMDL) study to determine how to reduce sulfate concentrations below the standard, or b) an EPA-approved site-specific standard for the site. The latter would be pursued if there is evidence that the exceedance of the sulfate standard is a *false positive error*. The false positive rate is greater for fixed standards, so a fixed standard would require the pursuit of more TMDLs or site-specific standards when, in fact, neither are needed to protect wild rice.

Because any fixed standard would be less accurate than an equation-based standard, under a fixed standard there would be more cases in which a wild rice water has a rice population judged to be healthy, but where the ambient sulfate concentration exceeds the standard. In such situations, it would be necessary to develop a site-specific standard to protect the beneficial use, which involves significant staff time and resources. This effort would occur less often under the implementation of an equation-based sulfate standard.

When a false positive is calculated for a sulfate discharge, the determination may result in unneeded investment in water treatment—which is why the false positive rate should be minimized.

False negative errors—where it is thought that sulfide will not accumulate to levels that harm the wild rice population when, in fact, it does—will not be recognized for a number of years, because it takes multiple years for sulfide to accumulate in the sediment and harm the rice (Pastor et al., 2017). False negative errors, therefore, potentially cause environmental harm—harm that may be difficult to reverse, because there is little experience for intentionally oxidizing and detoxifying sulfide once it accumulates in sediment (Ning et al., 2011).

The prediction error rate, the need for site-specific standards, and the occurrence of harm due to false-negative classification can all be reduced by adopting the MBLR equation as the sulfate standard to protect wild rice.

The Mississippi River below the Twin Cities is a good example of the ramifications of retaining a fixed sulfate standard. The MPCA field survey sampled four pools of the Mississippi River below the Minneapolis-Saint Paul Metropolitan Area that have had large populations of wild rice for many years. Ambient sulfate concentrations (18 to 32 mg/L) were well above 10 mg/L. The observed sulfate concentrations are well below the protective sulfate values calculated from the MBLR equation (93 to 546 mg/L). If the wild rice sections of the Mississippi River listed in Table 1-13 were evaluated against a fixed sulfate standard of anything less than 18 mg/L, either a site-specific standard would need to be developed or, under section 303(d) of the federal Clean Water Act, Minnesota would be required to develop a TMDL plan to reduce sulfate concentrations to below the standard. A TMDL plan would entail the calculation of the maximum amount of sulfate that could be discharged to the Mississippi and its tributaries, which would lead to the allocation of the necessary reductions to achieve compliance with the sulfate standard. Development and implementation of such a TMDL would be costly in terms of staffing resources and the potential for additional treatment requirements, and would not appreciably benefit the wild rice populations in these pools of the Mississippi since porewater sulfide concentrations are already less than the protective sulfide concentration of 120 µg/L. However, if the wild rice sulfate water quality standard were based on calculated values generated using the MBLR model, then a TMDL would not have to be developed, Minnesota would not have to determine how the sulfate concentration in the Mississippi could be reduced by as much as 70%, and wild rice would remain sufficiently protected from sulfate impacts.

Comparison of error rates to Vermont's phosphorus standards

The state of Vermont recently adopted, and EPA approved, fixed phosphorus standards to protect aesthetic use in lakes and aquatic biology in streams. Numeric standards were derived in a way to minimize false positive and false negative rates (Vermont DEC, 2014; Smeltzer et al., 2016). Eleven different phosphorus standards were developed, depending on the applicable tiered water use objective. The misclassification rates varied from 17 to 40% (Table 1-14), with a median of 35% - about the same as the best misclassification rate for possible fixed sulfate standards for wild rice (32%).

Table 1-14. Phosphorus standards developed by the state of Vermont (Vermont DEC, 2014) and associated misclassification rates.

Use Objective	Tier*	Phosphorus Criterion (µg/L)	Misclassification rate
Lake Aesthetics	Excellent aesthetic value	17	24%
	Good aesthetic value	18	17%
Aquatic Life	1	10	39%
(Small, high-gradient streams)	2	10	35%
	3	12	36%
Aquatic Life	1	9	40%
(Medium high-gradient streams)	2	9	39%
	3	15	22%
Aquatic Life	1	18	32%
(Warm-water, moderate gradient	2	21	31%
streams)	3	27	39%

*Tier Level of Aquatic Life Use Support

Analysis of Suggested Alternatives to the Protective Sulfide Level and Equation

During the process of developing the proposed revisions, the MPCA received a great deal of comment and advice from stakeholders and interested parties, many of which contained suggested alternate proposals for the sulfate standard. The MPCA considered a number of possible alternatives, including possible fixed standards and that a higher protective sulfide level (and related changes to the equation) might be appropriate.

With the release of the Draft TSD in July 2016 and in discussions of subsequent analyses, primarily with the Wild Rice Advisory Committee, MPCA staff frequently discussed the error rates of the equation. Commenters suggested that there were alternatives to the MPCA's identified protective sulfide level and equation that would result in a lower error rate (4% compared to 16%) but a similar level of wild rice protection.

Accordingly, MPCA staff have carefully reviewed the suggested changes in the derivation of an equation to calculate protective levels of sulfate. Ramboll (2017) suggested developing an equation with two changes to the work undertaken by the MPCA. The first change is adjusting the dataset used to perform the multiple binary logistic regression (MBLR), using only the 67 waterbodies where wild rice was observed. The second change is to use a protective porewater sulfide concentration of 300 µg/L, and developing the equation to relate sulfide to sulfate from there. Both of these changes would affect the resulting equation to calculate a numeric sulfate standard for a wild rice water.

Dataset used to perform the MBLR

Ramboll (2017) asserted that the chemical relationship between sulfate (in surface water) and sulfide (in sediment porewater) should be developed using regression analysis on a dataset that includes only waterbodies that have wild rice, because such a dataset "is most relevant to the receptor of concern which is a longstanding approach used by EPA in determining criteria." In support of this position, Ramboll (2017) asserted:

> This is similar to the longstanding EPA policy and practice of data use in development of criteria (USEPA 1994; Stephan et al., 1985; USEPA 2010). For example, when developing aquatic life criteria, EPA uses toxicity data from freshwater species to derive freshwater criteria and saltwater species are used to derive saltwater criteria. Likewise, criteria for warmwater fisheries are derived without toxicity data for coldwater species. [p. 3-1]

and

> In keeping with EPA policy and practice, only sites on the proposed wild rice list and with wild rice present should be included. [p. 4-1]

MPCA staff inspected the EPA documents cited by Ramboll (2017) and found no guidance directly pertinent to the question of what datasets should be analyzed when establishing a protective sulfide level and translating a protective sulfide level to a numeric standard to protect wild rice. The primary EPA guidance for the development of a water quality standard is that a state needs to demonstrate that its development procedure is fully protective of designated uses—and that EPA will review proposed standards by looking for a sound scientific rationale (EPA, 1994. p. 3-21, Water Quality Standards Handbook).

As described throughout this TSD, MPCA staff used the field survey data for two purposes: (1) to identify a porewater sulfide concentration that would be protective of wild rice growth and reproduction, and (2) to develop an equation that calculates a protective sulfate concentration that corresponds to the protective sulfide concentration identified in (1). Different subsets of the field data were used in support of each of the two purposes:

(1) Identification of a protective sulfide concentration: As MPCA staff reviewed the multiple lines of evidence for the identification a sulfide concentration to protect wild rice, different subsets of the field dataset were used, depending on the question being asked. For instance, when asking how porewater sulfide affects the probability that wild rice (of any density) will be observed in a waterbody, it was necessary to include waterbodies where no wild rice was observed. When addressing the probability of wild rice being present, two different datasets were analyzed, all 108 waterbodies (yielding an EC10 of 58 μg/L), and a subset that consisted only of sites with sufficient transparency to support wild rice (yielding an EC10 of 91 μg/L). MPCA staff regard the latter estimate as more defensible, since elevated sulfide is not responsible for the lack of wild rice when transparency is inadequate to support wild rice. In contrast, when the question was how sulfide affects the density of wild rice, only waterbodies with wild rice were included in the change-point analysis, which revealed a statistically significant decline in wild rice density at 112 μg/L. (Including waterbodies with no wild rice in this analysis would not have clearly addressed the question of how sulfide affects wild rice density.)

(2) Development of a protective sulfate concentration: MPCA staff developed a mathematical relationship that characterizes the chemical relationship between sulfate and the protective level of sulfide (120 μg/L) by including all 108 waterbodies. MPCA used all available data because the goal was to statistically describe a chemical relationship in the environment, not the effect of sulfide on wild rice.

Using only the 67 wild rice waterbodies has the effect of calculating higher sulfate levels than if all 108 waterbodies are used. This is perhaps because excluding waterbodies without wild rice also excludes many waterbodies with high sulfide, skewing the data used to calibrate the equation.

One way to see the effect of calibrating the equation with different waterbody datasets (and protective sulfide concentrations) is to compare the median potential sulfate standard that each equation produces when applied to the 67 waterbodies within the Class B dataset that had wild rice. The MPCA proposal (protective sulfide of 120 μg/L, equation developed with all Class B data) yields a median sulfate concentration 14 mg/L (Table 1-15). When an equation is developed only with data from waterbodies with wild rice, the median potential sulfate standard increases to 61 mg/L, which would allow much more porewater sulfide to develop. The effect is magnified if an equation is developed with a protective sulfide concentration of 300 μg/L. If developed with all 108 sites, the median potential sulfate standard would be 20 mg/L. But, if the equation is developed with only with data from sites with wild rice, the median potential sulfate standard would be 209 mg/L (Table 1-15). Calculated sulfate standards are clearly influenced by the dataset used to develop the equation.

MPCA staff concludes that it is most defensible to perform the regression that relates sulfate and sulfide with the entire 108-waterbody data set, rather than the data set that only includes sites with wild rice. First, the point of the regression is to develop a mathematical description of the chemical relationship between the three variables that have been demonstrated to control porewater sulfide: sulfate, TOC, and sediment iron (Pollman et al., in press). Second, since it has been shown that elevated sulfide is one of the primary controllers of wild rice presence in a waterbody (Myrbo et al., in press-1), it is evident that excluding waterbodies without wild rice would likely also exclude waterbodies that have high sulfide, which could skew the results of the regression. In fact, excluding sites without wild rice excludes 77% of the highest sulfide concentrations (10 of the 13 waterbodies with the highest sulfide). It is essential to the goal of the analysis to perform a robust regression that accurately predicts elevated sulfide, and not including data with elevated sulfide is counterproductive to that goal.

Table 1-15. Effect on median protective sulfate concentrations (for waters with wild rice) of developing equations with different datasets, and different protective sulfide concentrations.

	Median calculated protective sulfate concentration in waters with wild rice (N=67)	
Protective sulfide concentration used to develop equation	Equation developed with all Class B Waterbodies (N=108)	Equation developed with only Class B Waterbodies with wild rice (N=67)
120 μg/L	14 mg/L*	61 mg/L
300 μg/L	20 mg/L	209 mg/L**

*MPCA proposal **Ramboll (2017) proposal

Protective level of sulfide

Ramboll (2017) asserted that a protective sulfide concentration of 300 μg/L provides a similar level of protection for the wild rice beneficial use as 120 μg/L. The evidence given for this assertion is that there is no statistical difference in average wild rice stem densities below the 120 μg/L and below 300 μg/L (55 and 52 stems/m^2, respectively, p. 3-3) (MPCA's calculations are slightly different, 57 and 53 stems/m^2, a difference that is not important in this discussion).

The appropriate way to determine if 300 μg/L provides a similar level of protection as 120 μg/L is different than the test performed by Ramboll (2017). Rather than compare overlapping ranges of porewater sulfide, which violates the fundamental statistical principle that requires independence between two compared groups, it is more appropriate to compare the under 120 μg/L group to the 120-300 μg/L group. If 300 μg/L is similarly protective, there would not be a significant difference between these two groups.

As shown in Table 1-16, the average and median stem densities of the less-than-120 µg/L group are greater than the 120-300 µg/L group (average density of 57 vs 38, and median density of 47 vs 21 stems/m^2). A nonparametric statistical test (Wilcoxon-Mann-Whitney) finds that the two groups are significantly different at the p= 0.06 level. A more in-depth analysis shows that waterbodies with porewater sulfide less than 120 µg/L are more likely to have dense (> 40 stems/m^2) wild rice than stands with sulfide between 120 µg/L and 300 µg/L (Appendix 9). Wild rice waters with sulfide less than 120 µg/L are 5.6 times as likely as sites with sulfide between 120 and 300 µg/L to have dense wild rice (> 40 stems/m^2) than sparse wild rice (< 10 stems/m^2) ($p<0.5$). This is consistent with the change-point analysis, which found that wild rice density is significantly lower at sulfide concentrations greater than 112 µg/L (Appendix 7).

Table 1-16. Comparison of wild rice occurrence and density between two groups: waterbodies with porewater less than 120 µg/L and waterbodies with sulfide between 120 µg/L 300 µg/L.

Group	Number if waterbodies	Number of waterbodies with wild rice	Proportion with wild rice	Average density of wild rice (stems/m^2)	Median density of wild rice (stems/m^2)
less than 120 µg/L	69	49	71%	57	47
120 to 300 µg/L	22	13	59%	38	21

Therefore, wild rice density is significantly less robust between 120 and 300 µg/L than below 120 µg/L. Because density of wild rice in a waterbody is likely related to persistence of the population and to maintaining the beneficial use of wild rice, MPCA concludes that a porewater sulfide concentration of 300 µg/L is not protective of the wild rice beneficial use.

The MPCA did not make any changes to the equation based on the information provided. The proposal does have a lower error rate than the MPCA-proposed approach; however, it is important to remember that while it is desirable to minimize error rates as much as possible, doing so is a secondary consideration. The primary goal and requirement of the standard is to protect the wild rice beneficial use from the impacts of elevated sulfide. The MPCA's review of the proposal shows that the changes would result in a standard that is not sufficiently protective.

Chapter 2. Evidence that a different standard is needed for some wild rice waters

The basis of the proposed equation to calculate a numeric sulfate standard for wild rice waters is founded upon interrelationships of sulfate, organic carbon, and iron that produces sulfide, which is the toxic agent. With this understanding, there are two probability-based relationships involved in the determination of a sulfate concentration that will protect wild rice from elevated sulfide in the sediment: (1) the choice of a particular sulfide concentration that would be protective of wild rice, and (2) the translation of that sulfide concentration to the corresponding sulfate concentration for that particular waterbody (based on the iron and organic carbon in that waterbody's sediment). As a result, there will be false predictions associated with any sulfate standard, but there will be fewer false predictions when sulfate standards are equation-based, compared to the number of false predictions associated with a fixed standard (as described in part F of Chapter 1).

The first part of this Chapter 2 addresses wild rice waters with false positives and the need for an alternate sulfate standard when sulfide is predicted to be above 120 µg/L but is actually below 120 µg/L. The second part of this Chapter 2 addresses wild rice waters with true positives—sulfide is predicted to be above 120 µg/L and sulfide is actually above that level but the beneficial use is still protected.

Alternate numeric sulfate standard for false positive wild rice waters

A small proportion of wild rice waters in the MPCA-sponsored field study consistently exhibit a porewater sulfide concentration less than 120 µg/L when their ambient sulfate concentrations are greater than their calculated sulfate standards—they are false positives. Such waterbodies are not conforming to the conceptual model on which the equation-based sulfate standard is based, and therefore an appropriate sulfate standard must be determined through an alternative method. Application of an alternate standard could be based on empirical observations.

In the MPCA-sponsored surveys (2011-2013), the dataset that includes all samples in which false negatives and false positives can be identified consists of 222 samples from 115 different natural waterbodies (the dataset termed Class G). In this dataset, at least one false positive was observed in 14 different waterbodies (Fig. 2-1). Thirteen of the 14 waterbodies were sampled more than once, allowing an examination of the consistency of the sulfide predictions. False positives were consistently observed in four of the waterbodies. These four waterbodies consistently had porewater sulfide below 120 µg/L, despite predicted sulfide concentrations above that threshold (Table 2-1). Wild rice was growing in all four of the waterbodies. The most reasonable explanation for unexpectedly low porewater sulfide in these waterbodies is that surface water sulfate was not penetrating downward into the sediment because of upwelling groundwater.

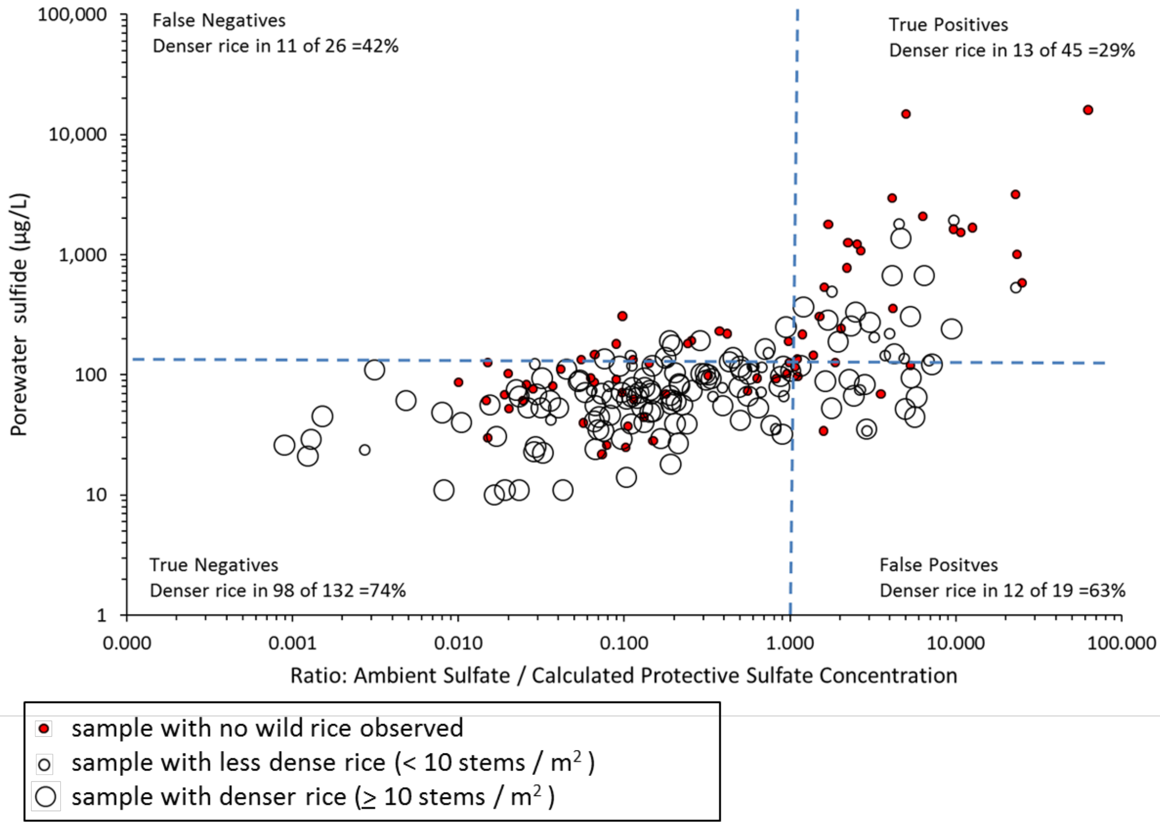


Figure 2-1. Prediction accuracy of the proposed equation for 222 site visits to 115 different waterbodies (data set Class G), plus density of wild rice occurrence, at two levels of density. Of the 222 samples, 19 false positives were found from 14 different waterbodies, of which 12 had wild rice. In 46 site visits to these 14 different waterbodies there were 19 false positives, 10 true negatives, 5 false negatives, and 12 true positives Table 2-1).

False positives (where elevated sulfate does not elevate sulfide) are a concern because they potentially could cause unneeded investment in sulfate control. False positives may merely be the result of random error, especially when ambient sulfate is close to the calculated numeric sulfate standard. Random error is likely the cause of a false positive observed in Second Lake. Second Lake was sampled once in 2011 and once in 2012, and wild rice density was at about the median density of the Class B sites (41 stems per square meter) in both years (37 and 48 stems/m^2, respectively). In 2012, a false positive was observed when the ambient sulfate concentration in Second Lake was 0.7 mg/L, which was slightly greater than the calculated protective level of 0.6 mg/L, and the measured porewater sulfide, 119 µg/L, was slightly lower than the protective threshold of 120 µg/L (Table 2-1). In 2011, a false negative determination for Second Lake was perhaps an example of random error in the other direction. The ambient sulfate concentration was 0.9 mg/L, lower than the calculated protective level of 1.9 mg/L, and the measured porewater sulfide of 139 µg/L was greater than the protective threshold of 120 µg/L (Table 2-1). Four of the ten sites likely exhibit false positives as a result of random error associated with ambient sulfate levels similar to the calculated protective sulfate concentration (Table 2-1).

More importantly, false positives may also be the result of the failure of a waterbody to conform to the conceptual model upon which the equation is based. As described in Chapter 1 of this TSD, the conceptual model is supported by significant statistical relationships (Pollman et al., in press), so that most of the waterbodies in the field survey act as described by the model. The model is based on the assumption that porewater sulfide is produced by bacteria in the sediment that are utilizing sulfate transported from the surface water downwards into the sediment. However, there may be wild rice waters where groundwater actively moves upward through the sediment, in which case sulfate in surface water would not play a major role in the production of sulfide. In such cases, ambient sulfate in surface water in comparison to the calculated sulfate standard can produce false positives, depending on the sediment concentrations of organic carbon and extractable iron. Wild rice waters with upwelling groundwater might be most often encountered in gaining streams, which receive water from groundwater, and some lakes that receive groundwater. The interaction of groundwater and surface waters is complicated, and is a function of multiple variables such as the texture and depth of soils, topography, and even seasonal growth of plants that transpire large amounts of groundwater, such as willows (Fetter, 2001).

In a study of 46 Wisconsin lakes, Nichols and Shaw (2002) found that wild rice is statistically associated with shallow areas where groundwater was emerging into the lake. The researchers were not sure why there would be such an association, but it is possible that they happened to sample waterbodies where upwelling groundwater allowed porewater sulfide concentrations to be low enough for wild rice to grow. Nichols and Shaw did not discuss the issue of sulfate and sulfide.

Of the 14 waterbodies in the MPCA study with at least one false positive, upwelling groundwater at four waterbodies seems the likely explanation for unexpectedly low porewater sulfide concentrations (Table 2-1). Three of the four waterbodies are small streams that could be receiving base groundwater flows that keep sulfate in the surface water from moving into the sediment.

For instance, Second Creek (not related to Second Lake, discussed above), was sampled five times and porewater sulfide was less than 120 µg/L in each case despite relatively high sulfate concentrations (303 to 838 mg/L; sulfate was not measured for one of the samplings). Only two of the samples were false positives, because calculated protective concentrations are also relatively high (148 to 947 mg/L) as a result of low sediment TOC and high extractable iron (Table 2-1). Because of interest in this site that combined high sulfate, low sulfide, and robust wild rice density, in 2015 researchers from the University of Minnesota conducted an investigation that measured and modeled groundwater and geochemistry at the site (Yourd, 2017). Yourd found that the model of the geochemical relationships corroborated the findings of Pollman et al. (in press) that sulfide accumulation in porewater depends on the levels of iron and organic carbon—but that hydrologic flux can also play a significant role in the geochemistry of porewater. Yourd concluded that porewater sulfide concentrations in an iron-rich environment like Second Creek may only become elevated when high concentrations of sulfate are able to move into the sediment. Yourd only observed sulfate movement into the sediment when stream water levels were unusually high—which occurred because of a temporary obstruction directly downstream of the study area.

Implementation of an alternate sulfate standard to protect wild rice

When porewater sulfide concentrations are consistently below the protective concentration of 120 µg/L, but ambient sulfate concentrations exceed the equation-based standard (false positives), it is apparent that ambient sulfate concentrations are not being efficiently converted into sulfide. The alternate sulfate standard proposal is based on the idea that when porewater sulfide concentrations are protective of wild rice, the ambient sulfate concentration must also be at a protective concentration.

However, even given these satisfactory conditions, it is not immediately obvious what the applicable sulfate standard should be for a wild rice water that consistently exhibits false positives. An obvious candidate numerical sulfate standard would be the average ambient sulfate concentration that had been observed for a few years, since that concentration had not caused an exceedance of the protective sulfide concentration of 120 µg/L. But the problem with adopting the average ambient sulfate concentration as the standard is that it is likely, given hydrologic variability, that annual average sulfate concentrations will sometimes be higher in coming years (unless the few years of data were unusual and resulted in the highest possible sulfate concentrations).

Therefore, a reasonable alternate sulfate standard would be higher than the average sulfate concentration observed over just two years of monitoring. But how much higher? One approach is to relate the measured porewater sulfide concentration to 120 µg/L, and to calculate how much higher sulfate could be to maintain porewater sulfide at or below 120 µg/L. Such an approach would need to assume (1) that some surface water sulfate might make its way into the sediment and be converted to sulfide, and (2) that waterbodies have differing empirical efficiencies of converting sulfate to sulfide (the molar ratio of sulfide to sulfate, expressed as a percentage). In the MPCA-sponsored field survey, only 17 of the 115 different natural waterbodies had a sample with efficiency exceeding 50%. The median conversion efficiency of the natural waterbodies was 7.7%. The sulfate-addition experiment of Pastor et al. (2017) offers an opportunity to calculate the efficiency of conversion with different sulfate concentrations interacting with a given sediment (and consistent concentrations of TOC and extractable iron). As the sulfate concentrations increased, the efficiency of conversion declined significantly from a maximum of 4% at the lowest sulfate concentration to a maximum of about 2% (Fig. 2-2).

Therefore, it is likely that the maximum increase in porewater sulfide concentrations as a result of increased sulfate would be proportional to the increase in sulfate. The experimental sulfate additions of Pastor et al. (2017), showing a declining efficiency, suggest that the sulfide increase would be less than proportional. With this understanding, a conservative alternate standard would be an increase in the observed ambient sulfate that is proportional to the degree that 120 µg/L is greater than the observed maximum porewater sulfide concentration. For instance, if the observed porewater sulfide were 80 µg/L and observed ambient sulfate were 110 mg/L, a conservative sulfate standard would be 165 mg/L sulfate (120/80 * 110 mg/L).

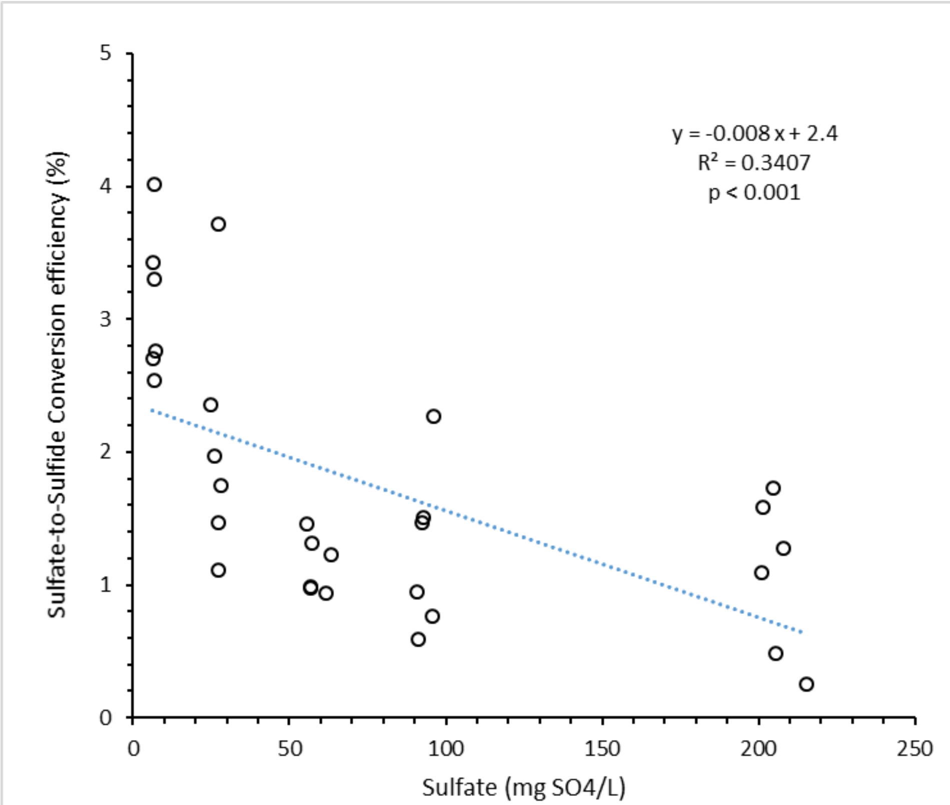


Figure 2-2. Trend in the efficiency of conversion of sulfate in surface water to sulfide in porewater (molar ratio of sulfide to sulfate, as a percentage), after three growing seasons of sulfate additions. The experiment is described in Pastor et al. (2017).

Summary: An alternate sulfate standard to protect wild rice

Implementation of an alternate sulfate standard in a wild rice water would be appropriate when a) ambient sulfate concentrations exceed the equation-based standard and b) porewater sulfide concentrations are demonstrably below the protective concentration of 120 µg/L. The most likely explanation for such observations is the upwelling of groundwater that is lower in sulfate than the surface water. However, sulfate in the surface water may contribute to the production of porewater sulfide if, for instance, groundwater reverses direction seasonally. It might be problematic to set the sulfate standard at the ambient concentration observed over just a few years of monitoring, since natural hydrologic fluctuation may produce an exceedance of the standard. A protective approach to calculating an alternate sulfate standard would be to adjust the observed ambient sulfate concentration by the factor that the protective sulfide concentration of 120 µg/L exceeds the observed ambient porewater sulfide concentration.

Table 2-1. All waterbodies in the field survey that exhibited at least one false positive (Class G dataset) Waterbodies are clustered into three categories in an effort to understand why false positives were produced: 1) Four waterbodies for which the likely explanation is that groundwater was upwelling through the sediment, so that the sites were not accurately modeled by the proposed equation; 2) Four waterbodies for which the likely explanation is random error because sulfate level is only slightly greater than the calculated protective concentration; and 3) Six waterbodies, each of which were sampled at least three times, that exhibited inconsistent behavior, which might be resolved with more extensive sampling. (CPSC120 = Calculated Protective Sulfate Concentration associated with a protective sulfide concentration of 120 µg/L).

Porewater sulfide relative to 120 µg/L	Accuracy Class-ification (FP, TP, FN, TN)	Ratio: Surface water SO4 / CPSC120	Ratio: porewater sulfide / 120	Wild Rice (stems/m2)	Waterbody Name, State ID	Field ID	Sample Date	Surface water SO4 (mg/L)	Pore water sulfide (µg/L)	Sediment Extractable Fe (µg/g)	Sediment Total Organic Carbon, TOC (%)	CPSC 120 SO4 (mg/L)
Waterbodies for which the likely explanation for false positive(s) is upwelling groundwater. Even when sulfate is high relative to CPSC, porewater sulfide is low.												
↓	TN	0.78	0.8	N/A	Second Creek	FS-303	5/30/2013	303	99	13,086	2.20	388.6
↓	TN	0.33	0.8	57.6	S007-220	FS-310	6/14/2013	316	93	31,190	4.22	946.8
↓	FP	2.43	0.6	76.4		FS-323	7/11/2013	405	67	10,036	2.91	166.9
↓	FP	5.66	0.4	66.8		FS-351	8/15/2013	838	45	7,088	1.84	148.0
	N/A	N/A	0.9	27.7		FS-384	9/19/2013	N/A	104	22,634	3.42	657.3
↓	FP	2.64	0.6	0.6	Ox Hide Creek	FS-198	9/7/2012	26.4	75	8,743	24.51	10.0
↓	TN	0.50	0.4	10.5	31-0106-00-203	FS-132	9/7/2012	26.4	42	14,936	14.43	52.7
↓	**FP**	5.30	1.0	0.0		FS-350	8/14/2013	25.9	119	3,889	12.12	4.9
↓	**FP**	2.83	0.7	121.0	Turtle River, ND S007-662	FS-358	8/19/2013	198	83	4,262	1.52	70.0
↓	**FP**	1.78	0.4	56.3	Big Swan Lake	FS-205	8/10/2012	5.47	53	1,719	4.81	3.1
↓	**FP**	2.27	0.8	133.7	77-0023-00-207	FS-204	8/10/2012	5.49	91	1,731	5.94	2.4

(continued)

Porewater sulfide relative to 120 µg/L	Accuracy Class-ification (FP, TP, FN, TN)	Ratio: Surface water SO4 / CPSC120	Ratio: porewater sulfide / 120	Wild Rice (stems/m2)	Waterbody Name, State ID	Field ID	Sample Date	Surface water SO4 (mg/L)	Pore water sulfide (µg/L)	Sediment Extractable Fe (µg/g)	Sediment Total Organic Carbon, TOC (%)	CPSC 120 SO4 (mg/L)
Waterbodies for which the likely explanation for false positive(s) is random error because the sulfate level was only slightly greater than the calculated protective concentration.												
↑	FN	0.45	1.2	37.3	Second Lake	P-24	9/7/2011	0.87	139	3,813	25.67	1.92
↓	**FP**	**1.16**	1.0	48.4	15-0091-00	FS-105	6/27/2012	0.74	119	2,527	33.3	0.64
↓	TN	0.64	0.8	0.0	Snowball Lake	FS-197	9/4/2012	8.4	94	4,213	6.00	13.2
↓	**FP**	**1.11**	0.8	0.0	31-0108-00-202	FS-347	8/12/2013	8.2	97	1,136	1.19	7.4
↓	**FP**	**1.07**	1.0	0.0	Trout Lake	FS-219	9/13/2012	38.6	117	12,535	15.00	35.9
↓	TN	0.96	0.9	0.0	31-0216-00-212	FS-356	8/14/2013	39.1	103	11,992	12.59	40.7
↑	FN	0.19	1.5	41.4	Mississippi R.	FS-208	8/14/2012	18.0	176	2,178	0.41	92.3
↓	**FP**	**1.01**	0.9	12.7	Pool 8 at Genoa	FS-311	6/20/2013	29.3	107	1,544	0.62	29.0
↓	TN	0.56	0.9	52.8	S007-222	FS-334	7/29/2013	44.2	102	1,969	0.40	78.3
↓	TN	0.19	0.5	17.8		FS-370	9/9/2013	33.3	62	6,558	1.43	172.4

(continued)

Porewater sulfide relative to 120 µg/L	Accuracy Class-ification (FP, TP, FN, TN)	Ratio: Surface water SO4 / CPSC120	Ratio: porewater sulfide / 120	Wild Rice (stems/m2)	Waterbody Name, State ID	Field ID	Sample Date	Surface water SO4 (mg/L)	Pore water sulfide (µg/L)	Sediment Extractable Fe (µg/g)	Sediment Total Organic Carbon, TOC (%)	CPSC 120 SO4 (mg/L)
The behavior of the six waterbodies below is inconsistent												
↑	FN	0.03	1.03	3.8	Sandy Lake	FS-251	9/21/2012	3.1	123	35,905	33.08	105.5
↓	TN	0.09	0.8	0.0	69-0730-00	FS-306	6/11/2013	11.0	91.8	35,357	28.53	122.3
↑	FN	0.98	1.6	0.0		FS-321	7/9/2013	122	189	36,502	29.51	124.9
↑	TP	1.11	1.1	0.0		FS-382	9/17/2013	67.9	135	26,645	32.28	61.2
↑	TP	2.68	9.0	0.0		FS-305	6/11/2013	135	1080	19,094	22.23	50.4
↑	TP	1.51	2.5	0.0		FS-348	8/13/2013	123	305	13,216	8.23	81.6
↓	**FP**	2.91	0.3	0.6		FS-380	9/17/2013	126	34	17,868	22.7	43.3
↓	**FP**	3.53	0.6	0.0		FS-349	8/13/2013	122	70	14,897	20.46	34.6
↓	**FP**	5.81	0.5	74.4	Unnamed Lake	P-57	9/23/2011	6.42	65	1,946	13.80	1.1
↑	TP	1.69	2.4	74.4	34-0611-00-201	P-57	9/23/2011	6.42	286	2,311	6.48	3.8
↑	TP	4.25	1.3	64.9		FS-183	7/30/2012	16.8	150	2,157	5.61	4.0
↑	TP	4.67	11.4	121.3	Monongalia	FS-77	7/26/2012	21.7	1,370	4,953	18.66	4.6
↓	**FP**	5.38	0.8	50.0	Lake	FS-313	6/23/2013	34.7	94	6,028	19.44	6.4
↑	TP	7.17	1.0	87.9	34-0158-01	FS-340	7/31/2013	33.6	122	5,530	22.10	4.7
↑	TP	9.45	2.0	154.4		FS-379	9/13/2013	34.6	242	5,436	26.42	3.7
↓	TN	0.86	0.7	31.6	Stella Lake	P-30	9/14/2011	7.59	80	2,159	2.88	8.8
↑	TP	4.54	14.9	0.3	47-0068-00	FS-188	8/27/2012	18.1	1,790	1,257	2.34	4.0
↓	**FP**	1.63	0.7	57.6		FS-341	8/1/2013	24.7	88	1,786	1.35	15.1

(continued)

Porewater sulfide relative to 120 µg/L	Accuracy Class-ification (FP, TP, FN, TN)	Ratio: Surface water SO4 / CPSC120	Ratio: porewater sulfide / 120	Wild Rice (stems/m2)	Waterbody Name, State ID	Field ID	Sample Date	Surface water SO4 (mg/L)	Pore water sulfide (µg/L)	Sediment Extractable Fe (µg/g)	Sediment Total Organic Carbon, TOC (%)	CPSC 120 SO4 (mg/L)
↑	TP	6.86	1.1	3.2	Dark Lake	FS-322	7/10/2013	175	131	2,480	1.48	25.5
↑	TP	4.89	1.1	2.9	69-0790-00-202	FS-352	8/15/2013	173	136	5,120	3.61	35.3
↑	TP	5.31	2.5	11.1		FS-368	9/5/2013	175	305	3,354	1.94	33.0
↓	**FP**	4.97	0.4	11.8		FS-369	9/5/2013	176	52	2,037	0.82	35.4
↓	TN	0.15	0.4	25.9	Little Birch Lake	P-47	9/21/2011	3.2	50	4,503	4.46	21.4
↑	FN	0.19	1.6	25.9	77-0089-00	P-47	9/21/2011	3.2	191	2,236	1.75	17.1
↓	**FP**	2.90	0.3	70.0		FS-54	8/3/2012	7.4	35	1,794	6.02	2.6

Evidence that site-specific standards may be needed for false positive wild rice waters

Some waterbodies will have wild rice when sulfide is greater than 120 µg/L

In the MPCA-sponsored field study, 29 waterbodies out of 115 surveyed (Class G dataset, N=222) had at least one true positive (at least one site visit found sulfide to be above 120 µg/L, consistent with the prediction of the proposed equation). Of the 29, 14 waterbodies had at least some wild rice present (48%), compared to 76% (62 out of 82) of the true negative samples (true negatives are samples conforming with predicted sulfide below 120 µg/L).

In some waterbodies where sulfide exceeds 120 µg/L the wild rice is dense and appears to be thriving. However, when sulfide exceeds 120 µg/L fewer samples have denser rice (for instance, greater than 10 stems/m^2). In the Class G dataset (N=222), only 34% of all samples from natural waterbodies have dense wild rice when sulfide exceeds 120 µg/L, whereas 73% of samples have dense wild rice when sulfide is less than 120 µg/L (calculated form Fig. 2-1). In dataset Class B (N=108), which approximates a probabilistic data set of natural waterbodies (Myrbo et al., in press-1), the proportion of samples with denser wild rice is significantly greater when sulfide is less than 120 µg/L (Chi square test; $p< 0.02$). Only 23% of Class B sites have dense wild rice when sulfide exceeds 120 µg/L, whereas 62% of sites have dense wild rice when sulfide is less than 120 µg/L (Fig. 2-3).

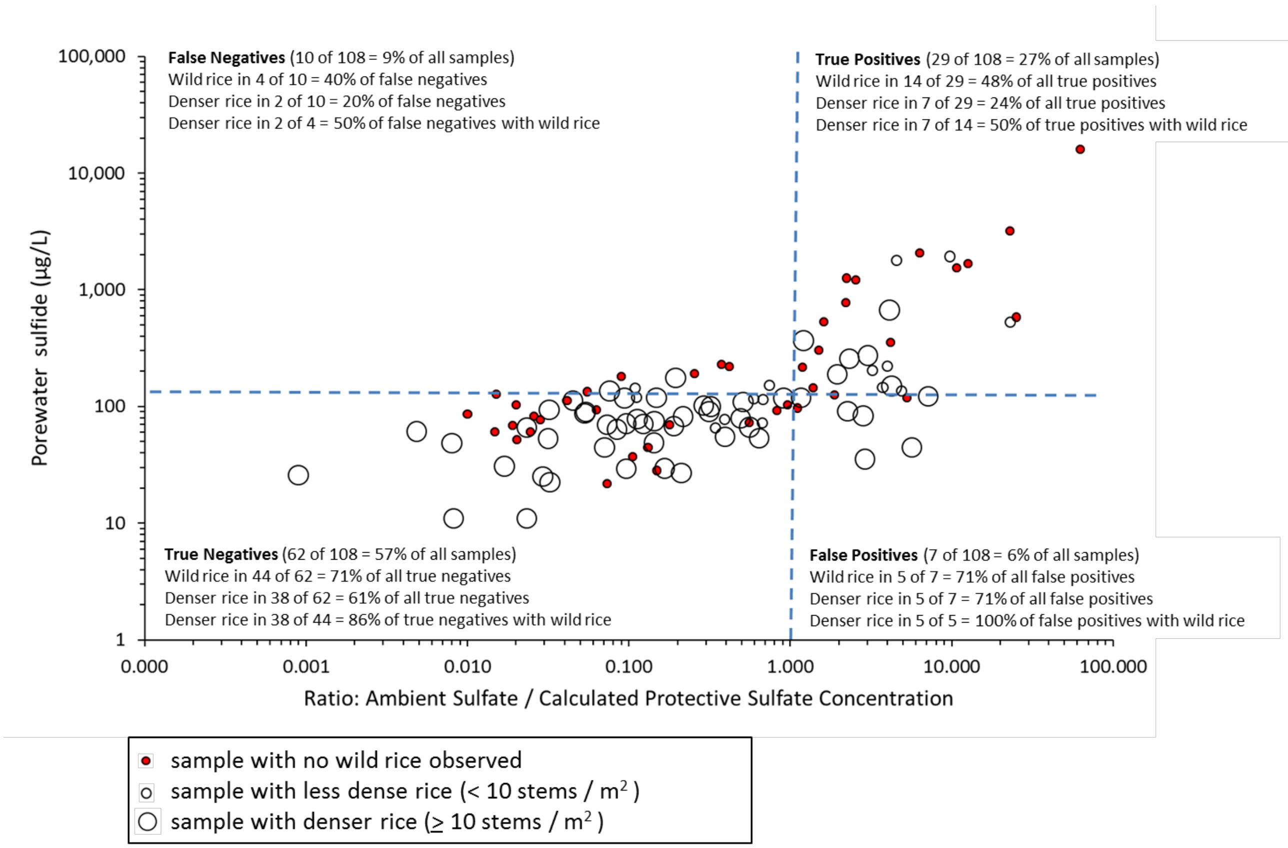


Figure 2-3. Prediction accuracy of the proposed equation for dataset Class B (a subset of 108 different waterbodies in Class G), plus density of wild rice occurrence, at two levels of density.

Possible explanations for wild rice in waterbodies with elevated porewater sulfide

There are several different possible explanations for the observation of wild rice in waterbodies with porewater sulfide in excess of 120 µg/L.

First, 120 µg/L was chosen to be a protective concentration along a gradient of declining probability of wild rice density and occurrence. There is no bright line below which sulfide is not toxic to wild rice and above which sulfide is toxic. As a result, wild rice is sometimes found in waters above the protective concentration, and sometimes in high density (above 40 stems per square meter); however, this occurs much less frequently than at levels of sulfide below the protective concentration. Because no water quality standard is perfect, it is inevitable that there will be some waterbodies where a standard is exceeded even while the beneficial use that the standard is designed to protect is maintained.

Second, it may be that the MPCA survey took too few samples to accurately characterize the specific waterbody. Six of the 14 true positive waterbodies with wild rice are represented by a single sampling (Table 2-2). Additional sampling might reveal that sulfide actually averaged below 120 µg/L. For instance, Stella Lake was sampled three times, and only in one of the three samplings did sulfide exceed 120 µg/L (Table 2-2).

A third possible explanation is that the sampling caught the wild rice population in the process of being extirpated from a waterbody that had sulfide in excess of what could be tolerated by wild rice. Four waterbodies had low densities of wild rice at the time of sampling (Christina, Big Sucker, Dark, and

Sandy, all below 4 stems/m^2; Table 2-2). Pastor et al. (2017) concluded that elevated porewater sulfide concentrations cause wild rice populations to decline by adversely affecting the seed production. Perhaps these sites had reproducing wild rice populations in the past that built up a store of seeds in the sediment that can remain viable for multiple years—a so-called seed bank. Not all viable wild rice seeds germinate in a given year. If sulfate has increased in these sites, increasing porewater sulfide, a possible explanation is that the few plants observed are the remnants of the seed bank produced in lower-sulfide years, and that the waterbody's wild rice population is likely to disappear in coming years.

A fourth possible explanation is that other variables that can control wild rice growth and reproduction, such as water depth, transparency, and nutrients such as nitrogen, are sufficiently optimal so as to offset the negative effects of elevated sulfide. For instance, seven cultivated wild rice paddies were sampled during the MPCA-wild rice study, and sulfide exceeded 120 µg/L at five of the seven sites. Wild rice density is very high in these cultivated operations, and growers have learned to optimize variables such as water depth, transparency, and nitrogen so that wild rice grows and produces seed successfully. Growers keep water depth relatively shallow during early seedling growth, which allows wild rice seedlings to quickly reach the water surface, simultaneously affording the plant more light for photosynthesis and access to the atmosphere. High rates of photosynthesis and emergence from the water into the atmosphere both allow more oxygen to be sent to the developing roots, potentially detoxifying sulfide (as discussed in *How access to oxygen may allow wild rice to detoxify sulfide* in Chapter 1, Part A). Wild rice growers also work to maintain high water transparency for seedlings, sometimes treating the water with copper sulfate to reduce the density of suspended algae. The productivity of wild rice is primarily limited by nitrogen; increased nitrogen availability increases the mean seed weight and number of seeds produced per stem (Pastor et al., 2017). Wild rice growers fertilize the paddies with nitrogen (as urea), which also allows wild rice to grow quickly, accelerating stem length and leaf development, and thereby increasing access to oxygen. There is evidence that wetland plants fertilized with nitrogen can better oxidize sulfide around the roots, reducing the potential toxicity (Howes et al., 1986).

Monongalia Lake is an outlier: dense wild rice despite elevated porewater sulfide

Among the 14 true positive waterbodies with at least some wild rice, Monongalia Lake stands out as having multiple samples that document dense wild rice that occurs simultaneously with elevated porewater sulfide (Table 2-2). Three of four samples were true positives, with porewater sulfide of 122, 242, and an unusually high 1,370 µg/L. Wild rice density was very high in all three samples (88, 154, and 121 stems/m^2, respectively, compared to a Class B median of 41 stems/m^2). Observed surface water sulfate concentrations of 22 to 35 mg/L were much higher than the calculated protective sulfate concentrations of 3.7 to 6.4 mg/L. This large (2,255 acres) but shallow (maximum depth 14 feet) lake lies in the Middle Fork Crow River watershed (Fig. 2-4), which is 46% agricultural, 26% wetland, and 10% developed/urban land use upstream of Monongalia Lake (calculated from MFCRWD, 2007). The Middle Fork Crow River flows through Monongalia Lake. Aside from the occurrence of dense wild rice in the presence of elevated porewater sulfide, the only field study parameters that are slightly atypical, compared to the Class B data set, are that in three of four sediment samples TOC, total sulfur, and total nitrogen are all in the upper quartile of Class B sites. Wild rice may be able to grow and reproduce in Monongalia Lake because environmental variables other than sulfide are sufficiently optimal so as to offset the negative effects of elevated sulfide (the fourth explanation, above), although extensive additional study would be required to evaluate that hypothesis. Monongalia Lake stands out as the least-well understood waterbody in the MPCA-sponsored field study in regards to factors that control wild rice growth and reproduction. The unique nature of this lake points towards the need for site-specific research and standard development.

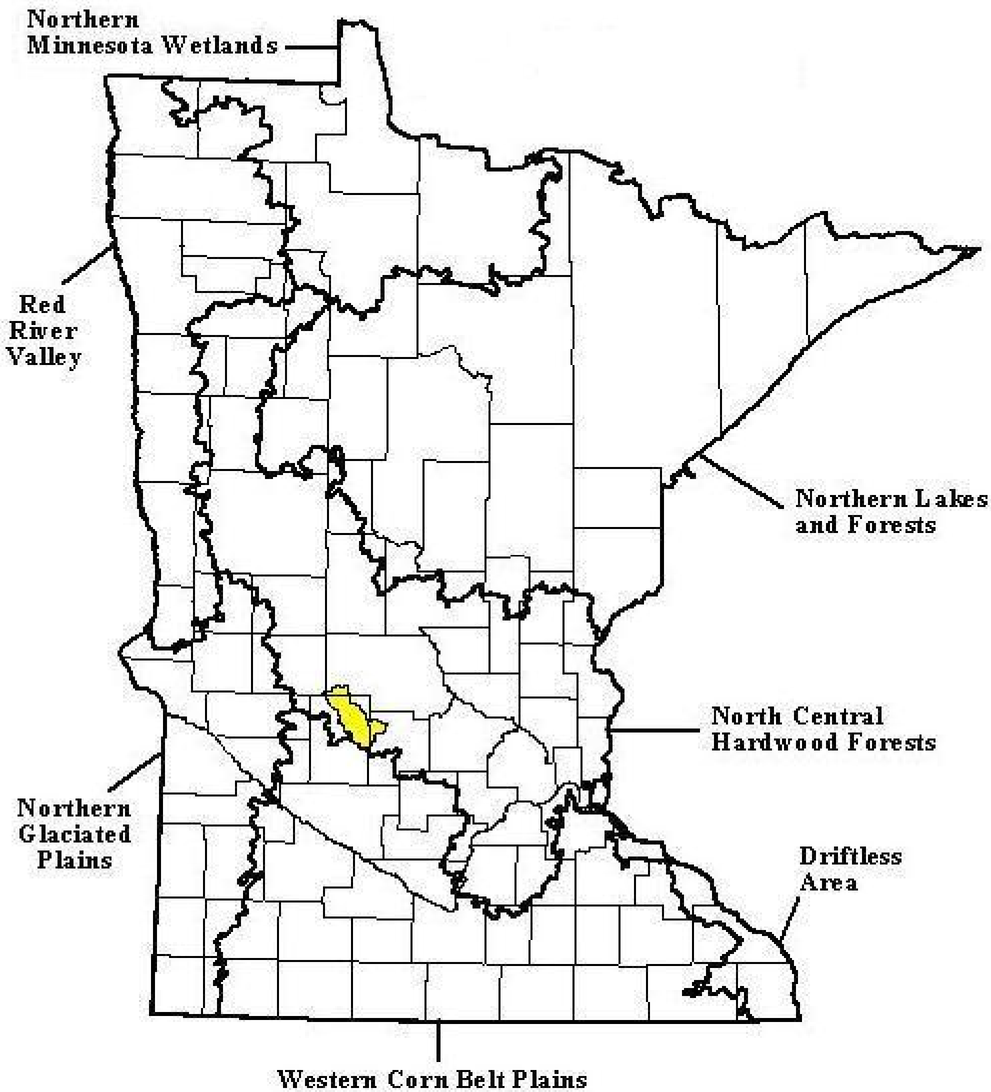


Figure 2-4. Location of the watershed that includes Monongalia Lake (yellow shaded area) (from MFCRWD, 2007).

Table 2-2. All waterbodies in the field survey that exhibited at least one true positive (dataset Class G)

Porewater sulfide relative to 120 µg/L	Accuracy Classification (FP, TP, FN, TN)	Ratio: Surface water SO4 / CPSC120	Ratio: porewater sulfide / 120	Wild Rice (stems/m2)	Waterbody Name, State ID	Field ID	Sample Date	Surface water SO4 (mg/L)	Pore water sulfide (µg/L)	Sediment Extractable Fe (µg/g)	Sediment Total Organic Carbon, TOC (%)	CPSC 120 SO4 (mg/L)
14 waterbodies with at least one true positive sampling that had wild rice present in at least one survey.												
↑	TP	1.2	3.1	114.9	Pine Lake 15-0149-00-205	FS-190	8/28/2012	14.7	368	4,477	7.08	12.2
↑	TP	1.8	4.1	3.0	Anka lake	P-35	9/16/2011	2.23	493	2,170	14.84	1.2
↑	TP	6.4	5.6	25.9	21-0353-00	P-34	9/16/2011	2.23	671	1,485	23.57	0.3
↑	TP	23.1	4.4	2.3		FS-192	8/29/2012	8.44	530	1,498	22.85	0.4
↑	TP	3.0	2.3	30.2	Ina Lake 21-0355-00-202	FS-191	8/29/2012	7.08	274	2,216	9.09	2.3
↑	TP	9.8	16.1	0.6	Christina Lake 21-0375-00-315	FS-339	7/31/2013	14.6	1,930	1,741	8.96	1.5
↑	TP	2.5	2.8	12.4	Swan Lake (W Bay)	FS-61	8/30/2012	12.5	332	5,827	22.71	5.0
↑	TP	4.0	1.8	3.8	31-0067-01	FS-62	8/30/2012	14	221	4,821	22.53	3.5
↑	TP	3.7	1.2	3.8	Big Sucker L. 31-0124-00-203	FS-216	9/12/2012	7.78	145	3,559	21.45	2.1
↑	TP	4.7	11.4	121.3	Monongalia	FS-77	7/26/2012	21.7	1,370	4,953	18.66	4.6
↓	FP	5.4	0.8	50.0	Lake	FS-313	6/23/2013	34.7	94	6,028	19.44	6.4
↑	TP	7.2	1.0	87.9	34-0158-02	FS-340	7/31/2013	33.6	122	5,530	22.10	4.7
↑	TP	9.4	2.0	154.4		FS-379	9/13/2013	34.6	242	5,436	26.42	3.7
↓	FP	5.8	0.5	74.4	Unnamed Lake	P-57	9/23/2011	6.42	65	1,946	13.80	1.1
↑	TP	1.7	2.4	74.4	34-0611-00-201	P-57	9/23/2011	6.42	286	2,311	6.48	3.8
↑	TP	4.2	1.3	64.9		FS-183	7/30/2012	16.8	150	2,157	5.61	4.0

(continued)

Porewater sulfide relative to 120 µg/L	Accuracy Classification (FP, TP, FN, TN)	Ratio: Surface water SO4 / CPSC120	Ratio: porewater sulfide / 120	Wild Rice (stems/m2)	Waterbody Name, State ID	Field ID	Sample Date	Surface water SO4 (mg/L)	Pore water sulfide (µg/L)	Sediment Extractable Fe (µg/g)	Sediment Total Organic Carbon, TOC (%)	CPSC 120 SO4 (mg/L)
↓	TN	0.9	0.7	31.6	Stella Lake	P-30	9/14/2011	7.59	80	2,159	2.88	8.8
↑	TP	4.5	14.9	0.3	47-0068-00	FS-188	8/27/2012	18.1	1,790	1,257	2.34	4.0
↓	FP	1.6	0.7	57.6		FS-341	8/1/2013	24.7	88	1,786	1.35	15.1
↑	TP	2.0	1.6	144.8	West Battle L. 56-0239-00-204	FS-228	8/15/2012	4.03	189	3,108	17.37	2.1
↑	TP	4.1	5.6	39.8	Bee Lake 60-0192-00-202	FS-87	8/23/2012	11	670	3,054	13.62	2.7
↑	TP	6.9	1.1	3.2	Dark Lake	FS-322	7/10/2013	175	131	2,480	1.48	25.5
↑	TP	4.9	1.1	2.9	69-0790-00-202	FS-352	8/15/2013	173	136	5,120	3.61	35.3
↑	TP	5.3	2.5	11.1		FS-368	9/5/2013	175	305	3,354	1.94	33.0
↓	FP	5.0	0.4	11.8		FS-369	9/5/2013	176	52	2,037	0.82	35.4
↑	FN	0.0	1.0	3.8	Sandy Lake	FS-251	9/21/2012	3.05	123	35,905	33.08	105.5
↓	TN	0.1	0.8	0.0	69-0730-00	FS-306	6/11/2013	11	92	35,357	28.53	122.3
↑	TP	2.7	9.0	0.0		FS-305	6/11/2013	135	1,080	19,094	22.23	50.4
↑	FN	1.0	1.6	0.0		FS-321	7/9/2013	122	189	36,502	29.51	124.9
↓	FP	3.5	0.6	0.0		FS-349	8/13/2013	122	70	14,897	20.46	34.6
↑	TP	1.5	2.5	0.0		FS-348	8/13/2013	123	305	13,216	8.23	81.6
↑	TP	1.1	1.1	0.0		FS-382	9/17/2013	67.9	135	26,645	32.28	61.2
↓	FP	1.6	0.3	0.0		FS-381	9/17/2013	126	34	16,172	11.67	79.2
↑	TP	2.3	2.1	69.7	Bowstring River S007-219	FS-214	9/11/2012	1.34	256	1,974	24.34	0.6

(continued)

Porewater sulfide relative to 120 µg/L	Accuracy Classification (FP, TP, FN, TN)	Ratio: Surface water SO4 / CPSC120	Ratio: porewater sulfide / 120	Wild Rice (stems/m2)	Waterbody Name, State ID	Field ID	Sample Date	Surface water SO4 (mg/L)	Pore water sulfide (µg/L)	Sediment Extractable Fe (µg/g)	Sediment Total Organic Carbon, TOC (%)	CPSC 120 SO4 (mg/L)
15 waterbodies with at least one true positive sampling for which wild rice was not observed in any site visit.												
↑	TP	1.4	1.2	0.0	Rice Lake 02-0008-00-206	FS-231	8/17/2012	3.6	145	2,159	7.98	2.6
↑	TP	62.8	133.3	0.0	Bean Lake 03-0411-00-201	FS-85	8/21/2012	85	16,000	1,967	11.85	1.4
↑	TP	2.5	10.2	0.0	Cromwell Lake 14-0103-00-201	FS-128	8/22/2012	41.2	1,220	2,948	2.85	16.2
↑	TP	10.7	12.8	0.0	North Geneva L. 24-0015-00-209	FS-176	7/24/2012	15.6	1,540	2,212	13.45	1.5
↑	TP	22.9	26.6	0.0	South Geneva L. 24-0015-02-208	FS-177	7/24/2012	14.1	3,190	1,618	16.71	0.6
↑	TP	1.9	1.1	0.0	Upper Panasa L.	FS-59	8/29/2012	29.6	126	895	0.43	15.8
↓	TN	0.1	0.3	0.0	31-0111-00-202	FS-383	9/18/2013	33.6	40	19,148	2.86	590.3
↑	TP	2.0	2.0	0.0	Lower Panasa L.	FS-60	8/29/2012	33.6	243	8,048	14.12	16.5
↑	TP	2.2	10.5	0.0	31-0112-00	FS-357	8/15/2013	28.5	1,260	2,347	2.42	12.7
↑	TP	1.6	4.5	0.0	Little Sucker L. 31-0126-00-202	FS-223	9/14/2012	13.7	534	6,297	16.56	8.5
↑	TP	23.4	8.4	0.0	Holman L.	FS-218	9/13/2012	24.2	1,010	3,035	29.74	1.0
↑	TP	25.1	4.9	0.0	31-0227-00-202	FS-353	8/12/2013	68	583	5,094	30.60	2.7
↑	TP	5.0	123.7	0.0	Lady Slipper L.	P-55	9/22/2011	107.71	14,840	2,814	2.09	21.5
↑	TP	9.7	13.6	0.0	42-0020-00	FS-79	7/27/2012	330	1,630	3,314	1.85	34.1
↑	TP	12.6	14.0	0.0		FS-78	7/27/2012	335	1,680	2,719	1.66	26.5

(continued)

Porewater sulfide relative to 120 µg/L	Accuracy Classification (FP, TP, FN, TN)	Ratio: Surface water SO4 / CPSC120	Ratio: porewater sulfide / 120	Wild Rice (stems/m2)	Waterbody Name, State ID	Field ID	Sample Date	Surface water SO4 (mg/L)	Pore water sulfide (µg/L)	Sediment Extractable Fe (µg/g)	Sediment Total Organic Carbon, TOC (%)	CPSC 120 SO4 (mg/L)
↑	TP	1.7	14.9	0.0	Westport 61-0029-00-204	FS-186	8/1/2012	7.11	1,790	4,917	20.15	4.2
↑	TP	2.2	6.5	0.0	Rice Lake 66-0048-00-203	FS-181	7/27/2012	5.22	777	3,829	21.67	2.4
↑	TP	4.1	24.8	0.0	Rice Lake	FS-184	7/30/2012	2.58	2,970	1,523	15.03	0.6
↑	TP	6.3	17.3	0.0	73-0196-00-216	FS-345	8/7/2013	6.85	2,080	2,012	14.83	1.1
↑	TP	1.2	1.8	0.0	Rice Lake 74-0001-00-201	FS-179	7/25/2012	3.84	217	4,152	19.07	3.2
↑	TP	4.2	3.0	0.0	Gilchrist L. 86-0064-00-201	FS-194	8/31/2012	6.98	355	3,117	20.81	1.7
↑	TP	3.2	1.7	6.7	Westport L. 61-0029-00-205	FS-346	8/8/2013	6.3	205	3,262	19.66	2.0

Chapter 3. Implementation of the wild rice sulfate standard

Sediment Sampling and Analysis

Sediment sampling is conducted to provide the data needed to calculate the numeric sulfate standard for a wild rice water. Sediment total extractable iron (TEFe) and sediment total organic carbon (TOC) concentrations are the two measured variables used in the proposed equation to calculate the numeric sulfate standard. When MPCA developed the draft proposed approach, released in March 2015 (MPCA, 2015), both MPCA and commenters noted that there was spatial variability in the TOC and TEFe measured in the sediment of a wild rice bed. These two parameters are measured in homogenized 10-cm long sediment cores, which represent many years of sediment accumulation. It is not expected that TOC and TEFe change significantly over the near term unless unusual hydrologic events occur. No statistically significant seasonal trend was observed in the field data (Myrbo et al., in press-1). To produce data that are pertinent to the protection of wild rice, sediment sampling must be conducted in the places where wild rice grows. Growth patterns of wild rice vary annually as exemplified in Fig. 3-1. It is important to establish how and where sediment samples will be collected in efforts to be representative of the wild rice water.

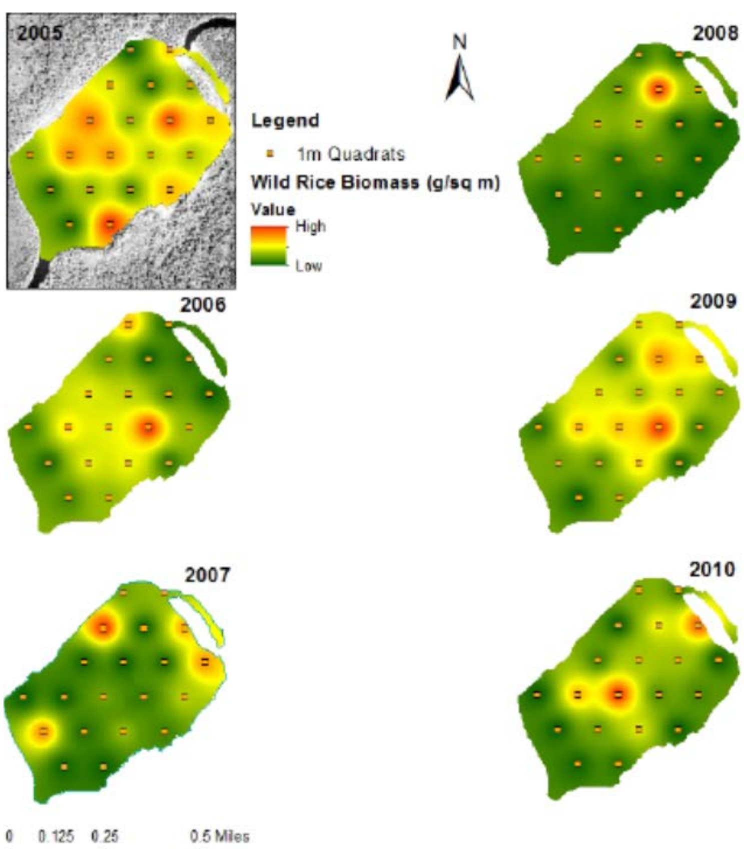


Figure 3-1. Example of variable growth patterns of wild rice biomass across years. Reprinted with permission: Wild Rice Monitoring Handbook by Tonya Kjerland (2015), published by the University of Minnesota Sea Grant College Program; from MN Sea Grant.

To effectively implement an equation-based standard, MPCA must specify how many samples are needed to characterize the sediment of a wild rice water, and how to consider those samples in the calculation of the numeric standard. To inform this approach, in June 2015 a pilot study was conducted to examine spatial variability in sediment TOC and TEFe found in six wild rice waters. In addition, collecting and analyzing a large sample size from different waterbodies is useful for informing decisions about an appropriate sample size for implementation of the water quality standard. The study sampled six different wild rice waters (four rivers and two lakes) identified on the MPCA draft list of wild rice waters, at areas that were sampled during 2011-2013 as part of the MPCA-sponsored field sampling. Within each wild rice water, 25 individual sediment samples (sediment cores) were collected and analyzed for TOC and TEFe.

The 25 sediment sampling locations at each waterbody were selected using the following guidelines:

- The coordinates for each wild rice bed were those used for the wild rice field study. The coordinates all corresponded to an access point adjacent to the waterbody. From that point, a representative bed of wild rice was located and a location was identified to begin sampling. This location was at least fifty meters away from the access point. On streams, the starting point was always upstream of the road crossing, if present. From that point, a transect perpendicular to the shoreline (and to water flow) was followed for collecting samples.
- The first sample was retrieved along the transect line where rice was found growing nearest the shoreline.
- The distance between each sample point was approximately 2 meters.
- Sampling stopped at the point along the transect where wild rice growth was not observed or water depth was too great (approximately 4 feet of water; Kjerland, 2015). In cases where wild rice growth was observed all the way to the opposite shore (e.g., a shallow lake or stream), professional judgment was used to determine a reasonable transect length.
- Additional transects were laid out in the same manner as described, parallel to the first transect, as needed to complete collection of the 25 samples.

All sediment samples were collected in the following manner:

- Sediment was collected using 70 mm diameter polycarbonate core tubes.
- The top ten centimeters of the substrate sampled in each core was collected and placed into a plastic bag. Samples were kept on ice in the field.
- In the lab, each bagged sample was gently mixed by hand. A subsample from each bagged sample was placed into a jar for analysis of TOC and TEFe. These samples were refrigerated until analysis.

Methods for TOC analysis followed EPA method 9060 (EPA, 2004) and analysis of TEFe followed Balogh et al. (2009) as modified by the Minnesota Department of Health (MDH, 2016).

Table 3-1. Summary results from 2015 pilot study, consisting of 25 sediment cores collected and analyzed from each of six wild rice waters. Total organic carbon (TOC) and total extractable iron (TEFe) were quantified in each core. All data is reported in Appendix 3.

Waterbody (abbreviation)	Mean TOC (%)	SD	CV(%)	Minimum	Maximum
Bowstring River (BRT)	16.0	1.9	12	12.6	19.7
Clearwater River (CLRT)	20.3	2.5	12	16.2	25.4
Hesitation Wildlife Management Area (HWMAT)	21.8	2.8	13	16.1	25.9
Mission Creek (MCT)	3.8	0.9	24	1.5	5.3
Monongalia Lake (MLT)	16.9	7.1	42	2.4	27.2
Mississippi River (MRT)	15.2	4.0	26	6.1	22.0

Waterbody (abbreviation)	Mean TEFe (mg/kg)	SD	CV(%)	Minimum	Maximum
Bowstring River	3,827	640	17	2,169	4,680
Clearwater River	13,439	2,652	20	8,370	19,800
Hesitation Wildlife Management Area	38,088	13,850	36	24,300	74,700
Mission Creek	15,707	3,882	25	7,470	22,500
Monongalia Lake	6,041	1,792	30	2,610	9,000
Mississippi River	5,432	436	8	4,680	6,300

As expected, the measured sediment TOC and TEFe concentrations were variable (Table 3-1). Paired values of TOC and TEFe reported from each sediment core analysis were used to calculate a sulfate concentration using the equation being proposed for the water quality standard for sulfate. Analysis of Variance performed on this data set showed significant differences ($p<0.05$) between wild rice waters, which infers that the variability of sulfate values calculated within a waterbody varied less than the variability between wild rice waters. Given this information, it is important to know how sample size affects variability.

One way to examine this is to compare the variability of the data around the mean to increasing sample size. Graphing this for both TOC and TEFe shows that as sample size increases, the variability decreases (Figs. 3-2 and 3-3). Variability is displayed as the width of the confidence interval along the y-axis. The rate of narrowing of the confidence interval levels off at a sample size of about 20 to 25. This suggests that a large amount of the sample variability has been accounted for with a sample size of 25 and that further samples would not greatly improve the estimate of either sediment TEFe or TOC.

Based on this information, the MPCA examined whether this same conclusion could be drawn using composite samples. A composite sample is collected by using the same sampling equipment as described above (core samples), but instead of collecting and analyzing individual samples, a set of samples collected from an area are pooled into a single sample for analysis. MPCA proposes that instead of collecting and analyzing 25 separate core samples from each wild rice water, composites of samples be collected and analyzed from five separate areas within the wild rice water. These five composite samples, each comprised of five individual core samples, would then be analyzed for TOC and TEFe.

An important question to answer is whether the variability of sulfate values calculated from composite samples is similar to the variability seen in values calculated from single core samples. To investigate this, calculated sulfate values from theoretical composite samples were compared to calculated concentrations from individual cores using data from the 2015 pilot study. Cores from the 2015 pilot study were placed into groups of five and average TOC and TEFe values were calculated to simulate a composite sample. The groups were determined by the order that the samples were retrieved from the sample area (i.e. first five samples in first composite group, second five samples in second composite group, etc.) to simulate composite sampling in the field. Using the proposed equation, the protective sulfate value was calculated for each TOC and TEFe pair from individual and composite samples (Appendix 3). Percentile ranks were determined using the full set of individual calculated sulfate values; 10^{th} to 90^{th} percentiles are shown in Table 3-2. The percentiles of each composite calculated sulfate value range from 11% to 93% among the wild rice waters (Appendix 3), showing that the composite samples capture the majority of the variability of the single samples.

To effectively implement an equation-based approach to determining the sulfate standard, a single numeric sulfate standard needs to be determined for each wild rice water. The purpose of sampling sediments in the wild rice bed is to capture the variability of the sediment concentrations of TEFe and TOC to ensure that the single sulfate standard selected from the group of five representative sulfate values calculated is protective of the wild rice beneficial use throughout the wild rice water. The MPCA compared the lowest composite value from each site to the percentile ranks (Table 3-2; Appendix 3), and observed that they all fall within the 10^{th} and 30^{th} percentiles for the six sites. Selecting the lowest value as the sulfate standard for the wild rice water addresses the need to protect for sensitive conditions where sulfide may accumulate, protecting the wild rice.

There are two reasons that it is not reasonable to use the average calculated sulfate concentration rather than the lowest calculated sulfate concentration. First, the goal of developing a sulfate standard is to allow wild rice to grow throughout the suitable locations in a wild rice water, not just in a subset. Use of an average would protect only a portion of the wild rice, given that use of an average implies that about half of the wild rice would need a lower numeric sulfate standard to avoid high porewater sulfide concentrations. Second, while “average” might sound like it would protect half of the wild rice, in fact, protection might be far less than half. The reason that “average” does not necessarily protect half of the wild rice is that calculation of averages is vulnerable to extreme values. For example, if one of the five calculated potential sulfate standards were extremely high, the average could actually be higher than four of the five values. In such a case, the use of an average as the numeric sulfate standard could conceivably protect only a very small proportion of the wild rice in a wild rice water. For the above reasons, use of the lowest calculated sulfate concentration is much more defensible and reasonable than use of a calculated average concentration.

Table 3-2. Lowest calculated sulfate value of composite samples compared to sulfate values at various percentiles calculated from the 25 individual samples analyzed from each waterbody of the pilot study.

Waterbody	Lowest calculated sulfate value from composites (mg/L)	Calculated sulfate values at various percentiles calculated from 25 individual samples (mg/L)				
		10th	30th	50th	70th	90th
Bowstring River	2.1	2.0	3.3	3.6	3.9	5.3
Clearwater River	22.3	19.7	23.5	24.4	32.3	50.1
Hesitation WMA	104.3	85.7	112.7	142.2	217.2	469.4
Mission Creek	240.1	203.1	247.6	294	312.8	397.1
Monongalia Lake	6.6	5.1	6.8	8.6	10.7	13.8
Mississippi River	5.6	4.6	6.0	6.9	9.3	12.8

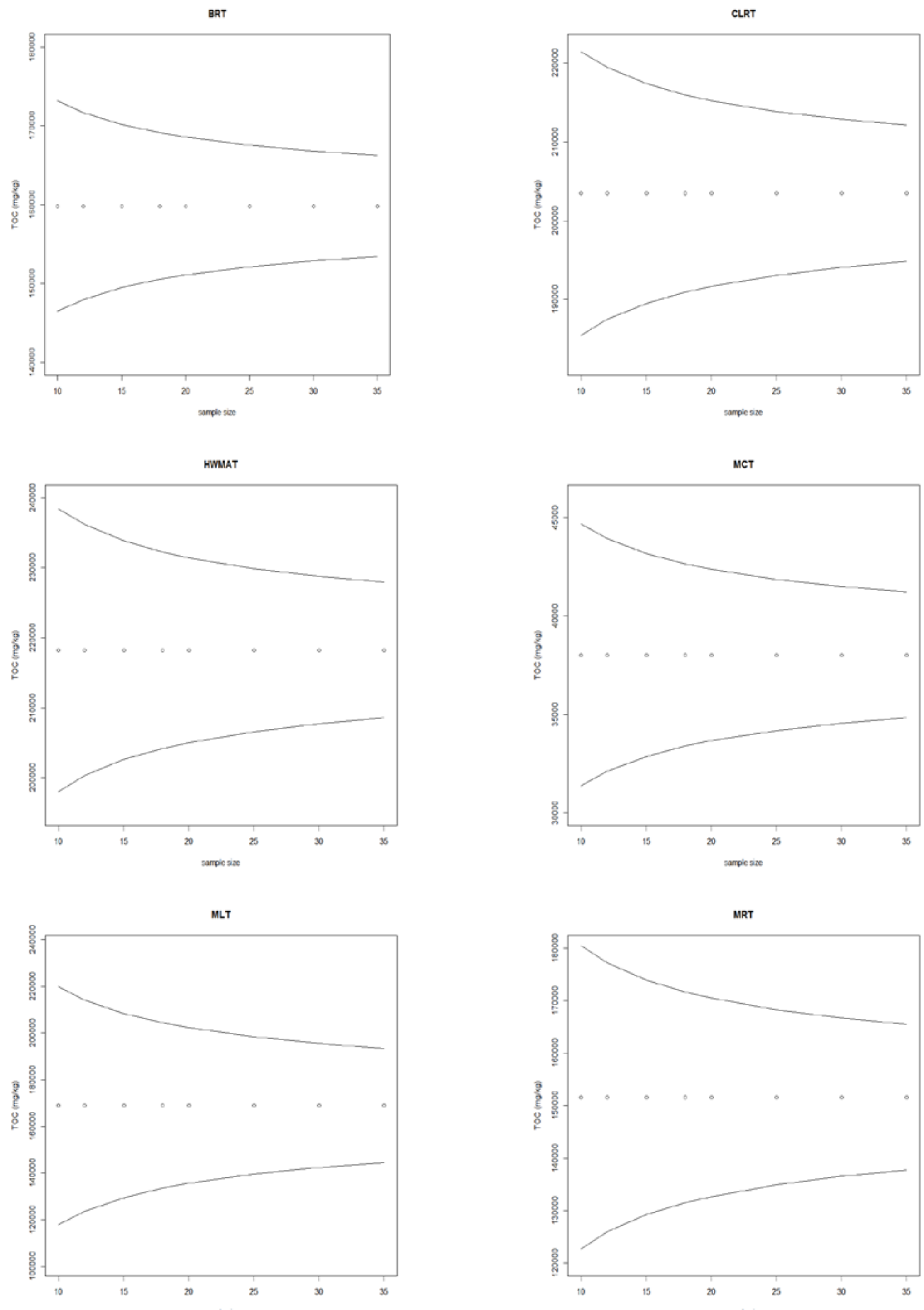


Figure 3-2. Graph of confidence interval widths compared to sample size for sediment TOC for each of the waterbodies sampled. See Table 3-1 for an explanation of the waterbody acronyms.

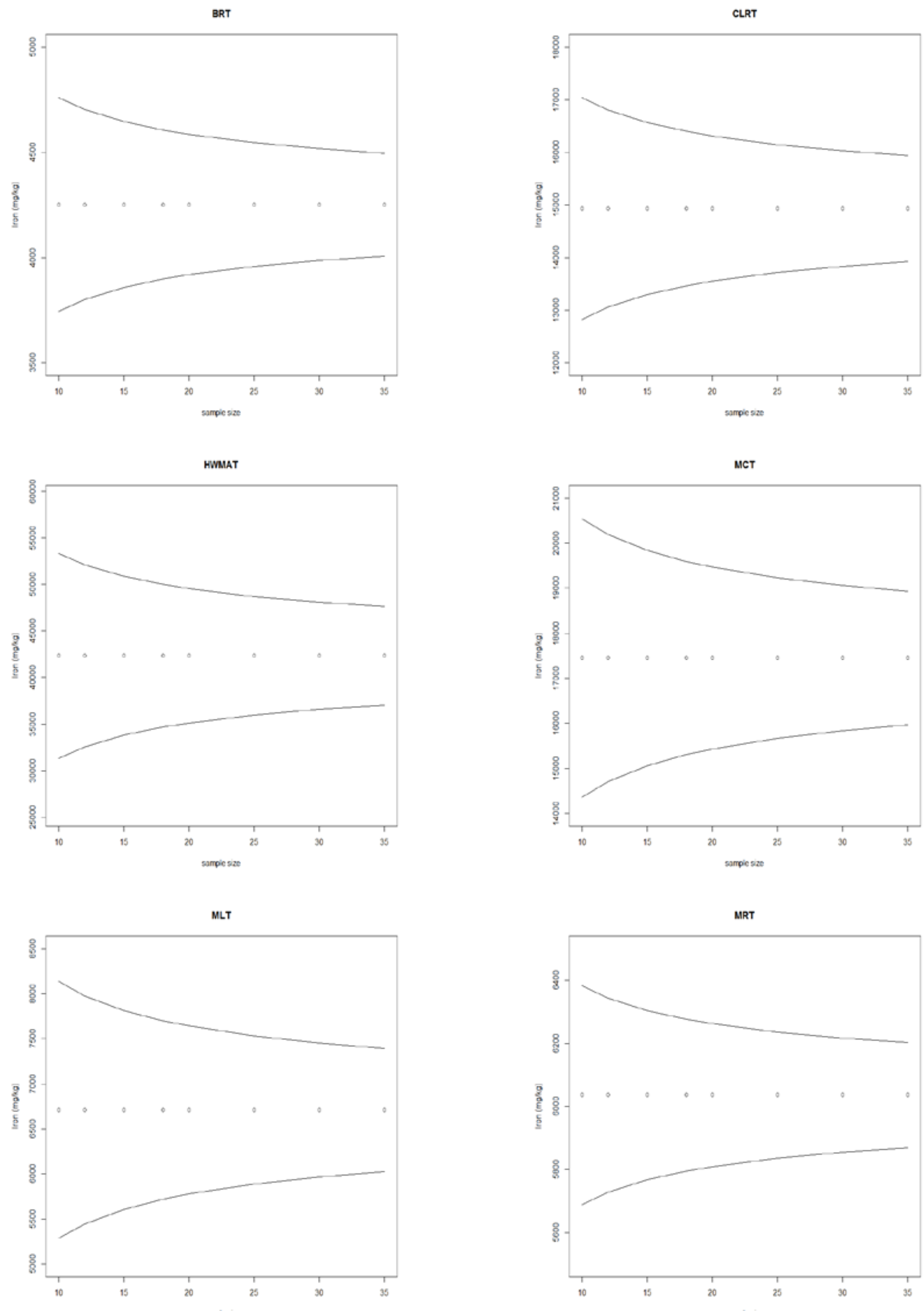


Figure 3-3. Graph of confidence interval widths compared to sample size for sediment iron for each of the waterbodies sampled. See Table 3-1 for an explanation of the waterbody acronyms.

Conforming with the Sulfate Standard

An important part of implementing any water quality standard is determining whether any given waterbody meets the standard. The magnitude, duration, and frequency of a standard not only are the bases for determining how waterbodies are assessed against the standard, but also inform permit requirements.

The magnitude is the level of the standard – in this case the amount of sulfate allowable in the wild rice water to maintain the protective sulfide level. The magnitude will usually be the numeric standard calculated with the equation, using sediment samples collected as described above. It may also be a sulfate concentration derived using the procedures for an alternate standard, or a site-specific standard.

The averaging time of the standard is the duration, and the frequency is how often the magnitude may be exceeded before the standard is considered to be violated. The analysis in Chapter 1 speaks to the magnitude of the standard, while this section discusses the technical information supporting the MPCA's proposed duration and frequency of the standard.

Appropriate duration and frequency are most easily determined for chemicals that are directly toxic to aquatic organisms. Determining duration and frequency for a chemical that has indirect negative effects, such as sulfate, is more challenging.

For this standard, duration is defined as the averaging period for sulfate that was found to be related to observed porewater sulfide concentrations, and frequency is defined as the interval between poor wild rice growth years from which wild rice has the undoubted ability to recover.

Duration (Averaging Time)

Defining duration for a pollutant should reflect the available information about the timeline of impact to the beneficial use. For example, a standard to protect against acutely toxic conditions may be expressed as a "never to exceed" duration, whereas one that protects against impacts over the longer term may be expressed as an annual or even multi-year average.

The MPCA is proposing to apply the standard as an annual average. This means that throughout a year, surface water sulfate concentrations could fluctuate above and below the standard so long as the annual average concentration is below the numeric sulfate standard for that wild rice water.

There are two main factors supporting the use of the annual average. First, sulfate is not directly harmful to wild rice and the conversion of sulfate to sulfide is not instantaneous. Second, the use of an annual average of sulfate concentrations is consistent with the empirical statistical relationships upon which the equation is based.

1. Sulfate is not directly toxic and takes time to convert to sulfide

Expression of the numeric standard as an annual average accounts for the fact that sulfate is not a direct toxicant upon wild rice, but rather that elevated sulfate concentration can lead to elevated sulfide in the sediment porewater, which is the toxicant of concern.

Porewater sulfide is produced biologically under anaerobic conditions throughout the year in the sediment where wild rice grows; accumulation of sulfide in the sediment depends on the sulfate concentration as well as the concentrations of total organic carbon and total extractable iron present in the sediment. Sulfide can be produced at any time throughout the year (DeRocher and Johnson, 2013). From this understanding, it is reasonable to conclude that the concentration of sulfate in surface water is important throughout the year, not just when wild rice is actively growing.

One possible approach is to implement the standard as a concentration that should never be exceeded. This would be reasonable if sulfate were directly toxic to wild rice. But several studies (Fort et al., 2014; Pastor et al., 2017) demonstrate that sulfate is not directly toxic to wild rice at concentrations encountered in Minnesota. However, over time sulfate can contribute to the buildup of sulfide in the porewater of sediments in which wild rice grows, so it is still important to regulate the concentration of sulfate in surface water.

The effect of elevated sulfate is (a) indirect, and (b) relatively slow. For instance, in a multi-year sulfate addition experiment (treatment sulfate concentrations of 0, 50, 100, 150, and 300-mg/L additions), it was not until the third year of the experiment that wild rice growth and reproduction was significantly affected in the 100 mg/L treatment (Pastor et al., 2017). In this case, the calculated protective sulfate concentration for the sediment used in the experiment was 34 mg/L. Even after five years of sulfate additions the 50 mg/L treatment (which had produced an actual average surface water sulfate concentration of 41 mg/L, less than the target of 50 mg/L because sulfate kept being converted to sulfide in the sediment) had no statistically significant effect on the most sensitive endpoints, seedling survival, seedling germination, and final plant biomass (Pastor et al., 2017). The 41 mg/L average sulfate concentration had not harmed wild rice after five years, which may be because (a) the equation-calculated sulfate concentration of 34 mg/L is sufficiently conservative to be protective of a concentration 20% higher than the calculated standard, or (b) not enough time had passed for the negative impact of elevated sulfate to manifest. It should be noted that the experiment was not a true mimic of likely impacts in the real environment, because the experiment was conducted in plastic tubs that cut off the iron supply from the watershed. Therefore, negative impacts might be observed in the experiment that would not occur in nature, where there is re-supply of iron to the sediment. After five years of sulfate additions, the highest sulfate treatment (300 mg/L) depleted the iron in the experimental tubs, allowing porewater sulfide to increase dramatically (Pastor et al., 2017).

The conversion of sulfate to sulfide is slow because it is a multi-step process. First, sulfate needs to enter the sediment from the overlying water, which in most wild rice sites occurs by diffusion. Diffusion is essentially a consequence of Brownian motion, the vibration of molecules proportional to temperature. While the speed of diffusion is driven by temperature, the direction of diffusion is from areas of high concentrations to areas of low concentration. Diffusion is a slow process, particularly under colder conditions. Second, once sulfate has entered anoxic sediment, the conversion to sulfide is a consequence of the growth of bacteria that respire sulfate instead of oxygen. If the growth of these bacteria is limited by sulfate (they can also be limited by the availability of organic matter), over the long term sulfide production is proportional to the sulfate concentration (Herlihy and Mills, 1985; Urban et al., 1994; Holmer and Storkholm, 2001). Microbial growth is also strongly affected by temperature. Bacteria grow slower under colder conditions.

Not only is the conversion of elevated sulfate to sulfide relatively slow, but the process of sulfate diffusion into the sediment is reversed if there is a decline in the concentration of sulfate in the surface water (DeRocher and Johnson, 2013). After a decline in sulfate concentration, the diffusion gradient is reversed, and unreacted sulfate will diffuse back into the overlying water (until concentrations are equal).

There is limited available information to support the determination of an alternative to a one-year averaging time. A key example is the limited potential to model the effect of varying sulfate concentrations on porewater sulfide, in order to determine how long sulfate concentrations would need to be elevated to affect sulfide concentrations.

Modeling is one of the most powerful analytical tools available to environmental science. Scientists use models as a way to develop hypotheses, explain complex interrelated processes, and to present their understanding of a particular subject matter. ”Modeling” has a broad definition within environmental science; a model can range from a conceptual diagram to a complex computer model involving days of super-computing processing time.

There are no official rules of “modeling” but there are some best practices, including:

1) Start simple and add complexity later.
2) Add complexity to your model only as necessary.
3) A model is only as good as the quality of the data used to develop and implement the model (a phenomenon often communicated as “GIGO”, or “Garbage In Garbage Out” – a reminder to not put undue faith in the output of an unvalidated model).

The effect of short-term fluctuations in sulfate concentrations on porewater sulfide concentrations is difficult to model mathematically, and therefore difficult to predict. Among other reasons, modeling is difficult because both diffusion and bacterial growth are affected by temperature, and temperature changes rapidly in the spring and fall. For instance, if sulfate concentrations are temporarily high for a time in the winter, less sulfate will diffuse into the sediment than under warmer conditions, and bacterial conversion to sulfide will be slow because of the cold. If the sulfate concentration then declines, spring comes, and the sediment warms, the sulfate will simultaneously begin to diffuse up into the overlying water and conversion to sulfide will accelerate even as the sulfate concentration declines. The MPCA commissioned a study to examine these interactions (DeRocher and Johnson, 2013) that compared the effect of varying sulfate concentrations at two temperatures. The study confirmed many of the expected relationships between temperature, sulfate, sulfide, and iron, but also produced some unexpected results associated with one of the two sediment sources. The unexpected result (continued release of sulfate from the sediment throughout the experiment) was most likely an artifact of exposing the sediment to oxygen while mixing the sediment during the experimental set up. A major lesson of the study is that the development of a general model that predicts porewater sulfide from varying sulfate concentrations and varying temperature would be a major effort.

No published model tries to address the net effect of fluctuating sulfate concentrations and temperature. Rather, modelling efforts to date either assume constant sulfate concentration (for instance, in the marine environment (e.g., Eldridge and Morse, 2000) or step changes from one concentration to either a higher or lower sulfate concentration (for instance, increases or decreases in the atmospheric deposition of sulfate; Nikolaidis et al., 1989). Moreover, there are no published experimental studies in which sulfate concentrations were purposefully varied and compared to the effect of holding the sulfate concentration constant at the average concentration of the varying system. Thus, there is limited information on the effects of short-term fluctuations in sulfate concentrations in order to inform the MPCA’s decision of an averaging time for the standard, beyond the conclusion that sulfate increases act over the longer term—a year or more—rather than days or months.

2. An annual average is consistent with the data and empirical statistical relationships

MPCA developed the equation by using the ambient surface water sulfate concentrations observed in the field survey, which is not significantly different from the annual average concentration (see below). Therefore, the proposed equation is relating the annual average sulfate concentration to porewater sulfide. Myrbo et al. (in press-1) showed that in 14 wild rice waters there is no significant seasonal trend in porewater sulfide over the wild rice growing season, even though there was a slight increase in surface water sulfate over the summer. If there is an annual cycle in porewater sulfide, it is likely that sulfide is lower in the winter, as studies found (Leonard et al., 1993; Urban et al., 1994), which was attributed to greater winter oxygen penetration, lower sulfate diffusion rates, and decreased bacterial growth rates. The MPCA's equation, which is based on summer porewater sulfide concentrations, is therefore predicting the highest sulfide likely to be encountered in a waterbody.

In addition, Myrbo et al. (submitted-2) found that in experimental mesocosms porewater sulfide was linearly related to annual average sulfate concentration (which varied because the sulfate concentration was readjusted to target concentrations periodically and between adjustments sulfate diffused into the sediment; see Fig. 3-4 in the discussion below).

Implementing the average as an *annual* average is reasonable because of the strong annual temperature and organic matter production cycle in Minnesota, which strongly affect sulfide production. Bacteria only produce sulfide because bacteria are metabolizing decaying plants, which are produced on a strong annual cycle. All wild rice plants die in the fall, producing an abundance of organic matter that drives the production of sulfide, if sulfate is available.

An analysis of repeated samples from 14 different natural wild rice sites showed no significant time trends in sediment total organic carbon or sediment total extractable iron. A slight seasonal increase in sulfate (statistically significant at the p=0.05 level; Myrbo et al., in press-1) was observed, which is likely due to temporary dilution after spring snowmelt (Myrbo et al., in press-1). Because it takes many years to accumulate 10 cm of sediment, it makes sense that the iron and total organic carbon measured in the 10-cm long sediment samples show no change over time. Ten-cm long cores represent about 20 years of sediment accumulation (lead-210 dated age at 9-cm depth of cores from eight wild rice lakes average 21 years, with a median of 19 years; unpublished data from A. Myrbo, University of Minnesota).

For the 14 field study sites for which at least 3 samples were taken in one growing season, the sample used in the development of the equation is not significantly different from the average of the samples (p=0.94, Wilcoxon signed-rank nonparametric test). Conversely, regression analysis shows that the samples used to develop the equation are good estimates of the average of the samples. Regression analysis of log-transformed data (to approximate a normal distribution) with and without Second Creek yields slopes near 1.0 (0.944 to 0.971) and very high R^2 values (both 0.988). Second Creek had relatively high sulfate concentrations, which averaged 466 mg/L in 2013, in contrast to the 13 other sites, which ranged from 0.74 to 174 mg/L.

The equation therefore relates porewater sulfide to average surface water sulfate concentrations, not to maximum sulfate concentrations. Consequently, it is logical to implement the calculated sulfate standard as an annual average. If the calculated sulfate standard were implemented as a maximum value, the associated porewater sulfide concentration would be lower than the protective value of 120 µg/L, which would be over-protective.

Data collected during the sulfate-addition mesocosm experiment of Pastor et al. (2017) provides further evidence that the annual average surface water sulfate concentration is related to the porewater sulfide concentration. In this experiment, sulfate concentrations varied significantly over the year because of conversion to sulfide in the sediment. For instance, in 2013 the highest experimental sulfate treatment averaged 257 mg/L (Fig. 3-4), but ranged from 49 to 308 mg/L. Similarly, the second-highest sulfate treatment averaged 121 mg/L, but ranged from 14 to 151 mg/L. Yet, there is a highly statistically significant relationship between annual average sulfate concentration and porewater sulfide ($p < 0.001$, Fig. 3-4).

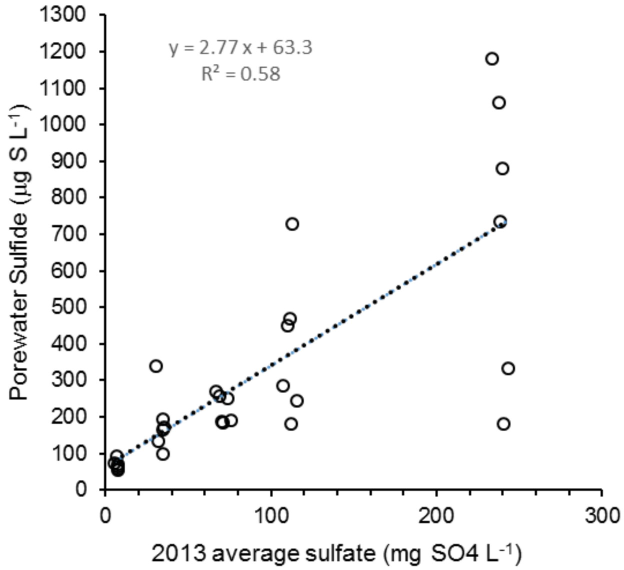


Figure 3-4. Relationship between average sulfate concentration from 2013 (8 measurement dates) and porewater sulfide measured at the end of the 2013 growing season. The regression between average sulfate concentration and porewater sulfide is highly significant ($p < 0.001$).

Frequency (how often the magnitude may be exceeded)

Given natural environmental variability, there is some probability that a water quality standard will be exceeded on occasion, due to factors other than human impacts. For instance, a dry summer can greatly decrease the expected dilution capacity of a receiving water. The question, then, is how frequently the sulfate standard can be exceeded without adversely impacting the beneficial use.

Porewater sulfide concentrations will decrease after an exceedance of a sulfate standard

The level of porewater sulfide is the long-term balance between production and loss of sulfide. If elevated sulfate in one year is followed by a year of lower sulfate, it is expected that porewater sulfide would re-equilibrate to the long-term average. The return to the long-term average sulfide concentration occurs because of a) the un-converted sulfate would diffuse back to the surface water and b) porewater sulfide would be oxidized by oxygen, ferric iron, and other oxidants. The concentration of porewater sulfide in a particular waterbody is, then, the net result of multiple dynamic processes involving sulfide production, sulfide oxidation, and reactions with both ferric (oxidation of sulfide) and ferrous iron (precipitation of sulfide). If sulfate concentrations are temporarily relatively high, producing higher sulfide concentrations, the system will tend to revert to a long-term average porewater sulfide concentration once sulfate is lowered, due to all the processes that affect sulfide—a phenomenon known as “sulfide buffering” (Giordani et al., 2008).

Several studies and reviews have concluded that observed sulfide concentrations are the balance between dynamic sulfide formation and sulfide degradation. Holmer & Storkholm (2001) found that up to 90% of sulfide production is oxidized to sulfate. Leonard et al. (1993) found seasonal variation in sediment sulfide in three lakes in northeastern Minnesota, where there is net loss of sulfide in the winter. Urban et al. (1994), working in Little Rock Lake in Wisconsin, found that winter oxygen penetration oxidized sulfide in lake sediment, sometimes resulting in sulfate diffusion back into the surface water. The initial spring measurements in the sulfate-addition mesocosms of Pastor et al. (2017) also showed release of sulfate from the sediment into the overlying water (Myrbo et al., submitted-2).

Oxidation of sulfide can occur when sulfide encounters oxygen in the sediment, either through release from plant roots or bioturbation (mixing by benthic animals). Sulfide is also oxidized by the introduction of ferric iron to sediment from the watershed that is mixed downward by bioturbation (sulfide reduces ferric iron, a process that oxidizes the sulfide (Hansel et al., 2015).

As a result of the diffusion of sulfate that never was converted to sulfide back into the surface water, and the multiple processes that oxidize sulfide, temporary high concentrations of sulfate in surface water are not permanently preserved in the sediment as high sulfide. Porewater sulfide concentrations will return to the long-term average after a temporary exceedance of the sulfate standard.

Wild rice populations will recover even if porewater sulfide is temporarily elevated

A waterbody's wild rice population will be able to persist at a high average stem density if the annual average sulfate concentration does not exceed the calculated standard very often. The MPCA had to define what "very often" means in order to define the allowable excursion frequency. Because of the limitations of available environmental knowledge, the severity of an excursion cannot be rigorously related to the impact on a wild rice population. Nevertheless, MPCA expects that a wild rice population will not be significantly harmed by an exceedance that occurs only once in ten years, because that frequency will allow the environmental chemistry and wild rice population to recover between exceedances, thereby providing a high degree of protection.

New findings from the mesocosm experiment described by Pastor et al. (2017) provide some information on potential for wild rice to recover after a decrease in sulfate that had been elevated above the calculated protective concentration. The outdoor experiment grew wild rice in natural sediment at five different levels of sulfate (six replicates of each: control, 50, 100, 150, and 300 mg/L). If a numeric sulfate standard were calculated based on the sediment used in the experiment, it would be 34 mg/L (TOC=8.1%; TEFe=8,300 µg/g). In the fifth year of treatment at the 300 mg/L level, in 2015, no wild rice plants grew in five of the six replicates, and the sixth replicate had just one plant (the control averaged 22 plants/replicate) (Pastor et al., 2017). As an experiment within the experiment, starting in 2016 no sulfate was added to five of the six replicates. In 2016, two of the mesocosms had three plants germinate and produce abundant seeds. Recovery was more widespread in the spring of 2017 (Pastor, 2017a, b). It is informative that wild rice could begin to recover within two years after four years of sulfate concentrations markedly greater than the calculated protective concentration of 34 mg/L. Through 2013, the 300 mg/L sulfate treatment actually averaged 207 mg/L because of ongoing conversion of sulfate to sulfide (Myrbo et al., submitted-2). These observations support the idea that porewater sulfide and wild rice can recover after occasional one-year exceedances in sulfate concentrations above the standard.

Therefore, it is unlikely that one year of elevated sulfate will have a long-term negative effect on wild rice growth and reproduction, so long as sulfate concentrations do not remain elevated above the allowable annual average for multiple years in a row.

Furthermore, the available scientific evidence supports that even a one-year elevation in sulfide levels in the sediment porewater above 120 µg/L would not have a long-term negative effect on wild rice growth and reproduction, so long as sulfide concentrations do not remain elevated above 120 µg/L for multiple sequential years. Relatively poor reproduction in one year out of five or ten years is extremely unlikely to have a long-term negative effect on the persistence of a wild rice population, because wild rice populations build up a seed bank in the sediment so that only a portion of dormant seeds germinate in any given year. In fact, wild rice is infamous for oscillating between low and high populations under natural conditions on a 3- to 5-year cycle (Pastor and Walker, 2006). The existence of the seed bank allows wild rice to recolonize a waterbody even if all growing plants are eliminated by an environmental disturbance in a given year (MDNR, 2008). For example, a June 2012 precipitation event completely eliminated wild rice in Kettle Lake (Carlton County), but the following year the density of wild rice was above average (55 stems per square meter, compared to a 10-year average of 41 stems per square meter (Vogt, 2017), (not counting two years of zero density, 2012 and 2016).

Based on the foregoing, MPCA is proposing a one in ten year exceedance frequency as reasonable and protective of the beneficial use.

Appendix 1. Other potential consequences of increasing sulfate concentrations

This TSD largely restricts the discussion of negative effects of increased sulfate concentrations to the accumulation of toxic concentrations of sulfide in the sediment porewater of wild rice beds.

There are two other potential pathways of concern regarding elevated sulfate: potential direct toxicity of sulfate to aquatic organisms (e.g. Wang et al., 2016), and negative consequences of sulfide production even if porewater sulfide remains at low levels. These should be kept in mind even if sulfate concentrations could be increased at a site without harming wild rice due to impacts on porewater sulfide. These considerations, while not directly relevant to the refinement of the wild rice sulfate standard, represent additional insight gained from the MPCA-sponsored study that can be used to inform water quality management decision-making.

The scientific literature includes evidence for multiple hypothesized effects associated with the conversion of sulfate to sulfide in sediment. The outdoor mesocosm experiment conducted by Pastor et al. (2) presented an opportunity to evaluate multiple hypotheses simultaneously. Data from the mesocosms were obtained in August 2013 and 2015, the results of which are reported in Myrbo et al. (submitted-2). In addition, the correlations observed in the MPCA-sponsored field survey are consistent with the science summarized below.

Stoichiometric releases associated with sulfate-enhanced decomposition of organic matter

The shallow-water aquatic ecosystems in which wild rice grows usually accumulate significant concentrations of organic matter; in the MPCA field survey the median concentration of organic matter is 25% on a dry weight basis. The organic matter, which is plant litter that has not fully decomposed, accumulates because decomposition by the microbial community is greatly slowed by limited availability of the principal terminal electron acceptors (TEAs) – oxygen, nitrate, oxidized manganese, oxidized iron, sulfate, and carbon dioxide – which are thermodynamically favored in that order (Froelich et al., 1979). A major reason wetlands accumulate organic matter is that oxygen availability, and therefore decomposition, is significantly reduced in water-saturated sediments; oxygen is consumed by bacteria within a few millimeters into sediment, and is supplied at a very slow rate because of its low solubility in water (10 ppm, compared to 210,000 ppm in the atmosphere). The next thermodynamically-favored TEA, nitrate, is not elevated in most wild rice waters, and therefore is not generally available to support decomposition. Manganese concentrations in sediment are usually minor compared to iron, and will not be discussed here. Ferric iron, the next thermodynamically favored TEA, is mostly present as a solid, and therefore of limited availability to bacteria. Even small increases in sulfate availability can increase bacterial activity, increasing decomposition in rough proportion to sulfate concentrations (Perry et al., 1986; Cook et al., 1986). The production of methane, which occurs when carbon dioxide is utilized as a TEA, is the least thermodynamically favorable and generally occurs when the other TEAs are depleted.

Plants have a relatively constant ratio among the important building blocks of carbon (C), nitrogen (N), and phosphorus (P), which are therefore released proportionally during decomposition of sedimentary organic matter. When sulfate is available, release of C, N, and P can be proportional to sulfide production (Froelich et al., 1979; Weston et al., 2006; Myrbo et al., submitted-2). Other plant components, including potassium (Lamers et al., 1998) and silica (Weston et al., 2006), are also released into solution during decomposition of plants. In the controlled outdoor mesocosm experiment, Myrbo et al. (submitted-2) found that porewater sulfide concentrations are significantly related to increases in products of decomposition in the surface water: total phosphorus, total nitrogen, dissolved organic carbon, and alkalinity. In addition, enhanced decomposition also increased the concentration of total mercury in the overlying water—mercury that presumably had been associated with the solid organic matter that decomposed. Mercury would have been delivered to the sediment from the atmosphere, either directly in precipitation or dry deposition to the emergent plant material, or indirectly from the watershed (Wiener et al., 2006). In the surface water of the mesocosms, total mercury was highly correlated with dissolved organic carbon, which is known to have a high affinity for mercury (Ravichandran, 2004).

It is not surprising that sulfide production is statistically correlated with predicted changes in the controlled mesocosm experiment, where the only change was the sulfate concentration, and sediment and overlying water were initially the same among treatments. That statistically significant correlations with porewater sulfide are observed in the MPCA-sponsored field survey, given the great heterogeneity in landscapes across Minnesota (Moyle, 1956; Heiskary et al., 1987), reinforces the conclusion that sulfide production is an important process that can control the occurrence of wild rice. Although the importance of sulfide is clear to many wetland scientists, this knowledge is not yet widespread among environmental scientists in general. It is pertinent to repeat a quote from Chapter 1 of this TSD from a study in central New York State of the factors that control plant species distribution in a wetland: "…it is puzzling that there has not been more work to investigate the possible role of sulfide as a master variable controlling plant community composition within inland wetland ecosystems." (Simkin et al., 2013).

Among the 108 field sites sampled in the MPCA survey, sulfide production (measured as acid-volatile sulfide or porewater sulfide) is significantly correlated with porewater total phosphorus, ammonia, and silica, and surface water total nitrogen, total phosphorus, potassium, and alkalinity (Myrbo et al., in press-1). These correlations support the hypothesis that production of sulfide is associated with enhanced decomposition of sedimentary organic matter, releasing the nutrients, alkalinity, and mercury to porewater and surface water.

Sulfate-enhanced release of phosphorus from sediment iron through sulfide production

There are two processes through which increased sulfide production is associated with the release of phosphorus from solid phases in the sediment, thereby increasing concentrations in porewater and surface water: 1) enhanced decomposition of organic matter, releasing phosphorus as discussed above, and 2) the release of phosphorus as a result of the interaction of sulfide and iron in the sediment. The addition of sulfate can produce more sulfide, which is thought to interact with iron in several ways that solubilize phosphorus (Caraco et al., 1989; Smolders and Roelofs, 1993; Maynard et al., 2011). When surface water sulfate and sedimentary sulfide concentrations are low, phosphorus is associated with several different phases of iron (Smolders and Roelofs, 1993; Maynard et al., 2011). When sulfate concentrations increase, sulfide production increases in sediment porewater, which reacts with ferrous iron, precipitating as iron-sulfide compounds, which do not sorb phosphate effectively (Roden and Edmonds, 1997).

Potential for sulfate-enhanced increased production of methylmercury

Increased sulfide production, which can result from an increase in sulfate loading or concentration under certain conditions, has long been known to increase the conversion of inorganic mercury to methylmercury (Gilmour et al., 1992), a phenomenon confirmed in an ecosystem-level sulfate addition experiment in Minnesota (Jeremiason et al., 2006). Methylmercury is the form of mercury that bioaccumulates in fish. Increased production of methylmercury is a significant concern, given that bioaccumulation of methylmercury in fish is a major cause of water quality impairments in Minnesota, resulting in a state-wide effort to reduce mercury contamination in fish (MPCA, 2007). Increased sulfide production not only has been shown to mobilize inorganic mercury from sediment, but also to increase the proportion of that mercury that is converted to methylmercury (Myrbo et al., submitted-2).

Other changes associated with conversion of sulfate to sulfide

The calculated numeric sulfate standard to protect wild rice should not be taken to mean that it is automatically defensible to increase average ambient sulfate concentrations to that level, even if wild rice would not be harmed. Indeed, even if the calculated sulfate concentration is not thought to be directly harmful to aquatic biota, and even if none of the three classes of chemical changes that are associated with increased sulfide production, described above, there may be other concerns about increasing sulfate concentrations and sulfide production.

The produced sulfide has a number of non-exclusive potential fates. The sulfide could 1) remain in the sediment porewater as free sulfide, 2) diffuse into the surface water, to be oxidized to sulfate, 3) be oxidized in the sediment, 4) volatilize to the atmosphere, or 5) react with metals (usually forming iron-sulfide compounds), forming insoluble precipitates in the sediment. The net concentration of sulfide remaining in the sediment can be quantified as acid-volatile sulfide (AVS), which can be a useful indicator of cumulative sulfide production.

Some of the consequences of sulfide production are not necessarily negative, and some have as yet poorly understood ramifications. For instance, one stoichiometric consequence of the conversion of sulfate to sulfide is the production of alkalinity. While it is not clear that additional alkalinity is negative, it is a change in the aquatic ecosystem, and some organisms seem to have different alkalinity optima (e.g., Moyle, 1945; Vestergaard and Sand-Jensen, 2000).

The production of alkalinity is not necessarily permanent, because the conversion of sulfate to sulfide is reversible. In many of the field survey sites most of the sulfide was precipitated as a solid when it reacted with iron, forming iron-sulfide compounds. If the waterbody dries and the sediment is exposed to oxygen in the atmosphere, the sulfide can be oxidized, and upon rewetting release sulfate as sulfuric acid, negating the alkalinity that had been produced earlier when the sulfide was produced. This has been documented in eastern North America (Kerr et al., 2012) and Australia, where the issue of restoration of wetlands with sulfidic sediment has been addressed (Ning et al., 2011). If the alkalinity had been produced gradually and washed downstream, the production of acid might not be buffered. Thus, even though the production of iron-sulfide solids detoxifies the porewater sulfide by removing it from solution, the accumulation of sulfidic sediment, which can be quantified as AVS, also represents the potential for episodic release of sulfate, which could be acidic.

Appendix 2. Wild Rice Seeds and Food Value

Part of the beneficial use established is the use of wild rice as a food source for wildlife. Information on the amount of wild rice needed to support wildlife, especially waterfowl, may be helpful in considering the beneficial use, and is provided here.

Literature estimates of wild rice seed weights and number of seeds per stem

Ranges for wild rice seed weights found in the scientific literature, other reports, and personal communications are shown in the Table A2-1. Similarly, Table A2-2 shows some literature ranges for the values for number of seeds per seed head in wild rice populations in Minnesota and Wisconsin. Although the ranges are quite large, means and medians of number of seeds per stem in natural wild rice waters are about 50 seeds per stem.

Table A2-1. Wild rice seed weight estimates found in the literature.

Seed weight estimates (dry weight in mg)	Description of paper or research	Reference
17.1 mg-42.3 mg (range of lakes and rivers) 35.39-37.81 mg (range in lakes) 20.63-23.77 mg (range in rivers) Seeds in lakes were 11.9 to 18.2 mg larger than their paired riverine populations. Mean seed mass in lake populations was 41 percent larger than in river populations.	Lacustrine and riverine populations of wild rice in northern Minnesota and Wisconsin, four river and four lake pairs	Eule-Nashoba, 2010; Eule-Nashoba et al., 2012
2011 24.6 (1.24) 2012 27.8 (0.9) 2013 29.7 (1.1)	Means of samples from six control tanks with standard errors in parentheses	Pastor, 2013
20-30 mg (dry) River rice may average somewhat lower than lake rice	Personal communication of literature values from natural stands and weighing of hand-harvested rice	David Schimpf, retired associate professor of biology at University of Minnesota Duluth and technical advisor to MPCA wild rice advisory committee

Table A2-2. Literature ranges of number of seeds per head.

# of grains per head	Description of research, study	Source
Range 19-115 grains per head on 14 stands of wild rice (all are lakes)	Survey of 14 stands of wild rice-Table 1 from 1941	Moyle, 1942, Fisheries Research Investigational Report # 40
Seed scars/panicle Range =23.9-132.8	Lacustrine and riverine populations of wild rice in northern MN and WI, four river and four lake pairs	Eule-Nashoba, 2010; Eule-Nashoba, 2012
12.75-102.35 number of seed scars/panicle Mean of seed scars/panicle 46.39 standard deviation of 29.7	17 wild rice populations in northern Wisconsin	Lu et al., 2005

The MPCA is using an estimate of 25 mg for wild rice seed weight and an estimate of 50 seeds per wild rice stem in the calculations to put into context the food value of wild rice. Table A2-3 shows the number of seeds and stems to support the daily energy needs for a dabbling duck.

Table A2-3. Seeds and stem values to support daily energy needs of a dabbling duck.

Mass of wild rice required to meet the daily energy expenditure of a dabbling duck	Daily Intake of seeds corresponding to 85 grams	Number of stems corresponding to 3,400 seeds (assuming 50 seeds per stem)
85 grams	3,400 seeds	68 stems

The MPCA initially considered criteria for identifying a wild rice water of ¼ acre of wild rice with an average density of 8 stems per square meter, or ½ acre of wild rice with 4 stems per square meter would meet at a minimum the food energy needs of a pair of ducks for two months. Although these criteria were not carried forward into the proposed rule, they support the MPCA's proposal that a single stem of wild rice (or other small amount) is insufficient to demonstrate the beneficial use and support identifying a water as a wild rice water.

Food value of wild rice

The nutritional value that the wild rice grain affords to waterfowl is equivalent to or exceeds the caloric energy values provided by many other wetland plants and agricultural grains (Sherfy, 1999; Gray et al., 2013). Wildlife researchers use these food energy values in determining species-specific daily energy expenditures for waterfowl supported by a given amount of food over a given management area. These calculations are often expressed as duck-energy days (or duck days) and represent the number of days a given amount of food will support a duck or group of ducks. These types of calculations have been used to build complex models to estimate the carrying capacity of large regions for a variety of species.

In its simplest form, duck-energy days can be determined by the following equation:

Duck-energy days = Food available (grams dry weight) x True Metabolizable Energy (kcal/gram dry weight)

Daily Energy Expenditure (kilocalories/day)

This can be simplified to solve for the amount of wild rice needed to meet the daily energy requirements of a single duck.

Daily Energy Expenditure average dabbling duck (kcal/day) = g of wild rice needed by a duck for a day

True Metabolizable Energy (kcal/g dry weight)

The MPCA is using a value of 294.35 kcal/day as the daily energy expenditure for an average dabbling duck (Reinecke and Kaminski, 2006) and a value of 3.47 kcal/g (Sherfy, 1999) for the True Metabolizable Energy of wild rice.

294.35 kcal/day divided by 3.47 kcal/g = 84.82 g wild rice needed to feed an average dabbling duck for one day.

While it is recognized that ducks do not only eat wild rice, the approximate 85 gram per day can be used to estimate the number of ducks that can theoretically feed on a given amount of wild rice. See below for details and discussion of values used for estimates of daily energy expenditure and true metabolizable energy and calculation of grams of wild rice needed to feed a dabbling duck for a day.

Daily Energy Expenditures

Daily Energy Expenditures (DEE) for waterfowl are calculated based on the strong relationship between body mass and basal metabolic rate (BMR) or resting metabolic rate (RMR) within and among species of birds (King, 1974; Prince, 1979; Miller and Eadie, 2006).

The Mississippi Alluvial Valley (MAV) is a waterfowl management area in the Lower Mississippi that is important to migrating and wintering waterfowl. Resource managers of the Mississippi Alluvial Valley Joint Venture have developed a DEE of 294.35 that is based on: 1) the daily energy requirements of an dabbling ducks during fall and winter and 2) the population goals in the MAV for seven dabbling ducks and the wood duck (Reinecke and Kaminski, 2006). Previously, the daily energy expenditures of the mallard were used as a surrogate for all the species found in the joint venture. This value is a reasonable estimate for daily energy expenditure for ducks eating wild rice as the dabbling ducks found in the Mississippi Alluvial Valley include many of the same species found in Minnesota and include species that consume wild rice such as the mallard and blue-winged teal.

True Metabolizable Energy (energy value of waterfowl foods)

True metabolizable energy (TME) is recognized as a valid expression of dietary quality that can be measured rapidly and reliably (Miller and Reinecke, 1984). The TME of waterfowl foods is an important component for accurate assessments of waterfowl energetics. It can be calculated indirectly using a regression model, or measured experimentally by feeding birds a controlled diet and measuring excretory energy.

There is a lack of TME values for common waterfowl food and species. The species studied most frequently include the Mallard, American Black Duck, Northern Pintail, Blue-Wing Teal, Carolina Wood Duck and Canada Goose. Eadie et al., cite values of true metabolizable energy (TME) of white rice as ranging from 3.34 to 3.76 kcal/gram. (Eadie et al., 2008). One study reports a mean value of 3.47 kilocalories/gram (3.07 to 3.92 range) for the TME of wild rice (*Zizania aquatica*)(Sherfy, 1999) and was based on blue-winged teal. Mallard values were not available for wild rice.

The MPCA is planning to use the mean TME of 3.47 kilocalories per gram for wild rice reported in 1999 by Sherfy as the TME for wild rice.

Calculation of amount of wild rice needed to an average dabbling duck for a day

> 294.35 kcal/day divided by 3.47 kcal/g = 84.82 g wild rice needed to feed an average dabbling duck for one day.

Although ducks do not only eat wild rice, this value can be used to estimate the number of ducks that can obtain food from a given amount of wild rice. A wild rice water of 0.25 acres of wild rice with a stem density of eight stems per square meter or 0.50 acres with a stem density of four stems per square meter would meet at a minimum the food energy needs of a pair of ducks for two months.

Appendix 3. Results for the 2015 sediment pilot study

Raw sediment analytical data, selected statistics and calculated values of sulfate for sites sampled during the 2015 sediment pilot study. Individual ID = individual sediment core sample; % TOC = percent sediment Total Organic Carbon; TEFe = sediment Total Extractable Iron; Composite = Average of 5 individual samples composited as one sample; Calculated sulfate = sulfate value calculated using the equation: Sulfate = 0.0000121 x ($Iron^{1.923}$/$Organic\ Carbon^{1.197}$); Organic Carbon = TOC and Iron = TEFe.

Table A3-1. Results for sediments collected from Bowstring River.

Individual ID	TOC (% Dry)	TEFe (mg/kg)	TOC Composite (% Dry)	TEFe Composite (mg/kg)	Calculated Sulfate Composite (mg/L)	Calculated Sulfate Individual (mg/L)
1-1	16.8	4230				3.9
1-2	16.9	4050				3.5
1-3	19.1	4230				3.3
1-4	17.2	4140				3.6
1-5	16.3	3600	17.3	4050	3.5	3.0
1-6	15.0	2520				1.6
1-7	14.4	3330				3.0
1-8	13.5	4500				5.7
2-10	13.5	3870				4.3
2-11	16.0	4140	14.5	3672	3.5	4.0
2-12	15.1	4590				5.2
2-13	17.0	4320				4.0
2-14	15.7	4320				4.4
2-15	14.0	3510				3.4
2-16	14.8	3690	15.3	4086	4.1	3.5
2-9	15.6	3870				3.6
3-17	14.2	3780				3.8
3-18	12.6	4320				5.7
3-19	15.6	3870				3.6
3-20	15.1	4680	14.6	4104	4.3	5.4
3-21	19.0	3060				1.8
3-22	16.4	3150				2.3
4-23	17.7	3240				2.2
4-24	18.4	2160				1.0
4-25	19.7	4500	18.2	3222	2.1	3.6
Mean=	16.0	3827				3.6
Std. Dev=	1.9	640				1.2
CV (%)=	12%	17%				34%
min=	12.6	2160				1.0
max=	19.7	4680				5.7

Percentiles for individual calculated sulfate values

10th	30th	50th	70th	90th
2.0	3.3	3.6	3.9	5.3

Table A3-2. Results for sediments collected from Clearwater River.

Individual ID	TOC (% Dry)	TEFe (mg/kg)	TOC Composite (% Dry)	TEFe Composite (mg/kg)	Calculated Sulfate Composite (mg/L)	Calculated Sulfate Individual (mg/L)
1-1	19.2	11700				23.4
1-2	21.0	15300				35.3
1-3	16.6	8370				14.6
1-4	21.0	12600				24.3
1-5	16.2	13500	18.8	12294	26.4	37.8
1-6	20.3	18900				55.1
1-7	25.4	13500				22.1
2-10	19.9	14400				33.5
2-11	16.5	10800				24.1
2-12	17.5	11700	19.9	13860	31.1	26.2
2-13	25.3	12600				19.4
2-14	18.9	18000				54.7
2-15	24.5	12600				20.2
2-8	21.2	12600				24.0
2-9	17.7	15300	21.5	14220	29.7	43.3
3-16	21.8	9900				14.6
3-17	21.5	12600				23.6
3-18	21.0	13500				27.7
3-19	22.5	12600				22.3
3-20	18.4	11700	21.0	12060	22.3	24.7
3-21	22.2	13500				25.9
3-22	19.0	19800				65.3
3-23	20.9	12600				24.4
3-24	19.9	11700				22.4
3-25	20.2	16200	20.4	14760	34.0	41.2
Mean=	20.3	13439				30.0
Std. Dev=	2.5	2652				13.0
CV (%)=	12%	20%				43%
min=	16.2	8370				14.6
max=	25.4	19800				65.3

Percentiles for individual calculated sulfate values

10th	30th	50th	70th	90th
19.7	23.5	24.4	32.3	50.1

Table A3-3. Results for sediments collected from Hesitation Wildlife Management Area.

Individual ID	TOC (% Dry)	TEFe (mg/kg)	TOC Composite (% Dry)	TEFe Composite (mg/kg)	Calculated Sulfate Composite (mg/L)	Calculated Sulfate Individual (mg/L)
T1	22.7	45000				255.7
T10	25.6	27000				82.9
T11	23.9	36000				156.5
T12	23.4	29700				110.9
T13	24.7	26100	24.1	32760	129.5	81.1
T14	25.9	36000				142.2
T15	23.0	29700				113.2
T16	25.4	31500				112.6
T17	23.6	39600				190.9
T18	22.9	39600	24.2	35280	148.6	197.9
T19	21.4	25200				90.0
T2	19.8	48600				349.2
T20	19.3	37800				222.1
T21	22.1	30600				125.8
T22	22.1	34200	20.9	35280	176.4	155.8
T23	19.0	74700				838.5
T24	20.7	58500				472.9
T25	20.0	56700				464.1
T3	18.3	69300				759.2
T4	16.1	41400	18.8	60120	558.6	328.6
T5	17.4	27000				131.6
T6	17.6	24300				106.0
T7	20.9	26100				99.0
T8	24.7	25200				75.8
T9	25.1	32400	21.1	27000	104.3	120.5
Mean=	21.8	38088				231.3
Std. Dev=	2.8	13850				204.5
CV (%)=	13%	36%				88%
min=	16.1	24300				75.8
max=	25.9	74700				838.5

Percentiles for individual calculated sulfate values

10th	30th	50th	70th	90th
85.7	112.7	142.2	217.2	469.4

Table A3-4. Results for sediments collected from Mission Creek.

Individual ID	TOC (% Dry)	TEFe (mg/kg)	TOC Composite (% Dry)	TEFe Composite (mg/kg)	Calculated Sulfate Composite (mg/L)	Calculated Sulfate Individual (mg/L)
1-1	3.1	11700				207.0
1-2	3.6	15300				294.0
1-3	5.1	16200				213.7
1-4	4.5	18900				333.7
1-5	3.7	11700	4.0	14760	240.1	170.4
1-6	2.8	10800				203.9
1-7	3.3	13500				255.8
1-8	4.0	12600				175.1
2-10	3.3	17100				400.1
2-11	3.6	18000	3.4	14400	277.0	392.7
2-12	4.2	17100				303.2
2-13	1.5	7470				202.6
2-14	3.2	14400				302.8
2-15	2.6	11700				251.9
2-16	4.5	16200	3.2	13374	259.2	250.1
2-9	4.4	14400				205.4
3-17	4.0	17100				314.0
3-18	3.9	18000				359.3
3-19	5.3	19800				298.1
3-20	5.2	19800	4.6	17820	293.0	307.8
3-21	4.6	20700				391.3
3-22	5.0	22500				413.4
3-23	3.8	22500				582.0
3-24	2.4	10800				247.0
3-25	3.6	14400	3.8	18180	375.0	263.4
Mean=	3.8	15707				293.6
Std. Dev=	0.9	3882				93.6
CV (%)=	24%	25%				32%
min=	1.5	7470				170.4
max=	5.3	22500				582.0

Percentiles for individual calculated sulfate values

10th	30th	50th	70th	90th
203.1	247.6	294.0	312.8	397.1

Table A3-5. Results for sediments collected from Monongalia Lake.

Individual ID	TOC (% Dry)	TEFe (mg/kg)	TOC Composite (% Dry)	TEFe Composite (mg/kg)	Calculated Sulfate Composite (mg/L)	Calculated Sulfate Individual (mg/L)
1-1	4.3	3330				12.4
1-2	9.9	5310				11.3
1-3	19.2	6930				8.6
1-4	2.4	2610				15.7
1-5	23.1	8910	11.8	5418	9.6	11.1
2-6	2.5	2610				14.8
2-7	19.1	6750				8.2
2-8	10.6	4950				9.1
3-10	18.7	6210				7.2
3-11	12.5	9000	12.7	5904	10.3	23.6
3-9	17.4	7740				11.9
4-12	14.7	5760				8.3
4-13	20.1	6300				6.7
4-14	24.1	4410				2.7
4-15	24.7	7110	20.2	6264	6.6	6.7
5-16	19.3	7830				10.8
5-17	23.6	8820				10.6
5-18	22.6	6300				5.9
6-19	27.2	6570				5.1
6-20	25.1	4950	23.6	6894	6.6	3.3
7-21	21.6	5760				5.2
7-22	8.5	4050				8.1
8-23	14.8	4950				6.1
8-24	18.3	6750				8.6
8-25	17.9	7110	16.2	5724	7.3	9.8
Mean=	16.9	6041				9.3
Std. Dev=	7.1	1792				4.4
CV (%)=	42%	30%				47%
min=	2.4	2610				2.7
max=	27.2	9000				23.6

Percentiles for individual calculated sulfate values

10th	30th	50th	70th	90th
5.1	6.8	8.6	10.7	13.8

Table A3-6. Results for sediments collected from Mississippi River.

Individual ID	TOC (% Dry)	TEFe (mg/kg)	TOC Composite (% Dry)	TEFe Composite (mg/kg)	Calculated Sulfate Composite (mg/L)	Calculated Sulfate Individual (mg/L)
1-1	19.3	4680				4.0
1-10	22.0	4770				3.5
1-11	15.1	5310				6.8
1-12	12.4	6120				11.4
1-13	16.6	5940	17.1	5364	6.0	7.6
1-14	11.8	5760				10.7
1-15	14.1	6030				9.5
1-16	12.3	5670				9.9
1-17	9.7	5220				11.3
1-18	9.2	5580	11.4	5652	10.8	13.7
1-19	6.1	4860				17.2
1-2	16.0	5130				6.0
1-3	19.4	5130				4.7
1-4	14.0	5400				7.7
1-5	16.9	5220	14.5	5148	6.8	5.8
1-6	20.8	5220				4.5
1-7	17.5	5130				5.4
1-8	17.6	5850				6.9
	16.8	5670				6.8
2-20	18.6	5130	18.3	5400	5.6	5.0
2-21	15.8	5220				6.3
2-22	17.8	5490				6.0
2-23	15.2	5940				8.4
2-24	16.5	6300				8.5
2-25	7.6	5040	14.6	5598	7.9	14.0
Mean=	15.2	5432				8.1
Std. Dev=	4.0	436				3.4
CV (%)=	27%	8%				43%
min=	6.1	4680				3.5
max=	22.0	6300				17.2

Percentiles for individual calculated sulfate values

10th	30th	50th	70th	90th
4.6	6.0	6.9	9.3	12.8

Appendix 4. Statistical characterization of wild rice density in 10 wild rice waters over 12 years

The long-term data collection by the 1854 Treaty Authority (Vogt, 2017) constitutes the best available information on variation over time in average wild rice density among a variety of waterbodies. From 2005 to the present, the 1854 Treaty Authority conducted surveys of wild rice density in ten wild rice waters using a consistent methodology (described in Kjerland, 2015). Surveys were conducted in late August or early September when the rice was standing and reaching maturity. Wild rice density in each waterbody was determined from at least 20 sample plots of an area of 0.5 m^2 each. The annual average density for each of the ten waters (Table A4-1) ranged from a minimum of zero (which occurred three times) to a maximum of 408 stems/m^2, with an average of 46 stems/m^2. The median, or most typical, density was 30 stems/m^2 (Table A4-2).

Table A4-1. Average wild rice density in ten wild rice waters, as monitored by the 1854 Treaty Authority (Vogt, 2017). Density is average stems per square meter from a minimum of 20 fixed sampling points.

Year	Big Rice Lake	Breda Lake	Cabin Lake	Campers Lake	Cramer Lake	Kettle Lake	Little Rice Lake	Round Island Lake	Stone Lake	Vermilion River
2005	58	80	86	29	80	11	61	408	48	88
2006	13	66	56	46	58	36	16	95	17	201
2007	11	53	82	59	46	76	30	40	42	116
2008	11	69	21	67	28	32	14	11	25	153
2009	4	85	26	75	29	19	6	44	10	90
2010	7	76	99	74	74	65	12	88	38	42
2011	5	42	9	27	28	8	11	154	26	87
2012	7	15	20	0	17	0	12	45	5	75
2013	11	25	14	17	17	55	9	60	5	113
2014	5	61	28	35	29	42	4	37	26	97
2015	4	49	27	40	36	64	24	23	25	99
2016	4	11	20	24	85	0	13	24	11	100

Table A4-2. Statistical characterization of wild rice density in 10 wild rice waters over 12 years (data from Table A4-1).

percentile	stems/m^2
10	7
15	11
25	14
50	30
75	65
85	75
90	88

Appendix 5. EC10 values from MPCA-sponsored hydroponic data

Data used

Dr. John Pastor conducted three experiments where his team added sulfate to hydroponic wild rice at concentrations of 0 to 2,880 µg/L, described in Pastor et al. (2017). Pastor's team measured the weight of the plants and the mean sulfide at the beginning of the study and at the end of the study. The variables used for this analysis are:

To measure sulfide concentration:

- Mean initial sulfide concentration (µg/L)
- Arithmetic time weighted mean (TWM) sulfide concentration (µg/L)
- Geometric TWM sulfide concentration (µg/L)

To measure plant growth:

- Weight change (mg)
- Weight gain: the weight change with any weight loss set to 0 (mg)

Curve fitting

Logistic regressions and estimates of EC10, with 95% confidence intervals, were conducted with routine *drc* (R, Ritz et al., 2015).

Predicting weight gain from mean initial sulfide

Fig. A5-1 shows the log logistic curve fits for both predicting the weight change (Fig. A5-1A) and predicting the weight gain (Fig. A5-1B).

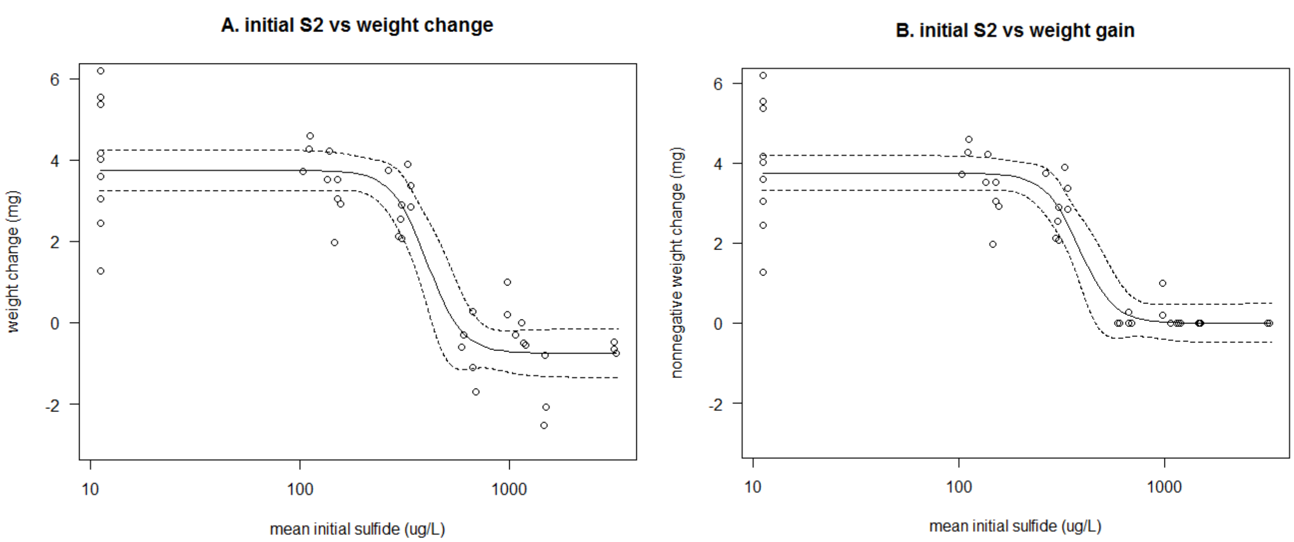


Figure A5-1. Logistic regressions using initial sulfide hydroponic concentration to predict plant growth. A) weight change. B) weight gain.

In both graphs that the weight change stays constant until well over 100 µg/L initial sulfide. The resulting EC10, EC20, and EC50 values are in Table A5-1. While the EC values are lower when using weight gain vs weight change, the numbers are not significantly different. For both, concentrations below 250 µg/L look to be protective.

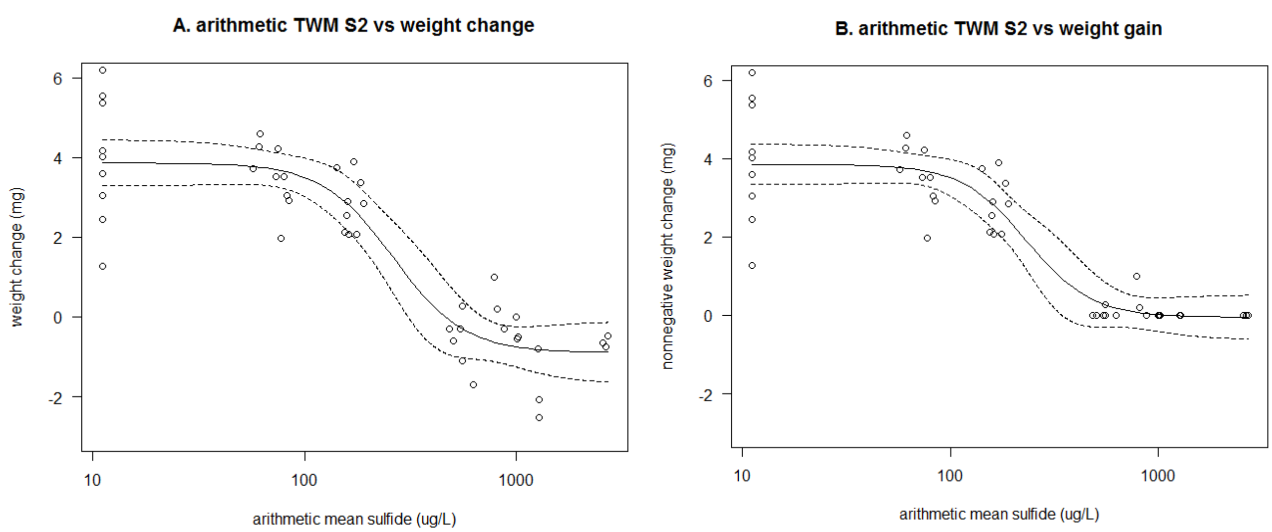
Table A5-1. EC10, EC20, and EC50 values for initial mean sulfide hydroponic concentration.

	Wt change	Estimate	ln 95% CI	Wt gain	Estimate	ln 95% CI
EC10	3.37 mg	255 µg/L	<11 µg/L - 322 µg/L	3.465 mg	251 µg/L	<11 µg/L - 285 µg/L
EC20	2.99 mg	296 µg/L	235 µg/L - 363 µg/L	3.080 mg	294 µg/L	234 µg/L - 353 µg/L
EC50	1.87 mg	378 µg/L	324 µg/L - 474 µg/L	1.925 mg	384 µg/L	331 µg/L - 486 µg/L

Predicting weight gain from arithmetic time weighted mean sulfide concentration

Fig. A5-2 shows the log logistic curve fits for both predicting the weight change (Fig. A5-2A) and predicting the weight gain (Fig. A5-2B).

Figure A5-2. Logistic regressions using arithmetic time-weighted mean (TWM) sulfide hydroponic concentrations to predict plant growth. A) weight change. B) weight gain.



In both graphs that the weight change starts to decrease around 100 µg/L. The resulting EC10, EC20, and EC50 values are in Table A5-2 below. Once again, the EC values for weight gain (i.e. no negative weight change) are lower than the EC values for weight change (which allows for weight loss). However, the numbers are similar, and the confidence intervals are large enough to confirm they are not significantly different. When the arithmetic TWM sulfide concentration is used, the EC10 is between 100 and 110 µg/L.

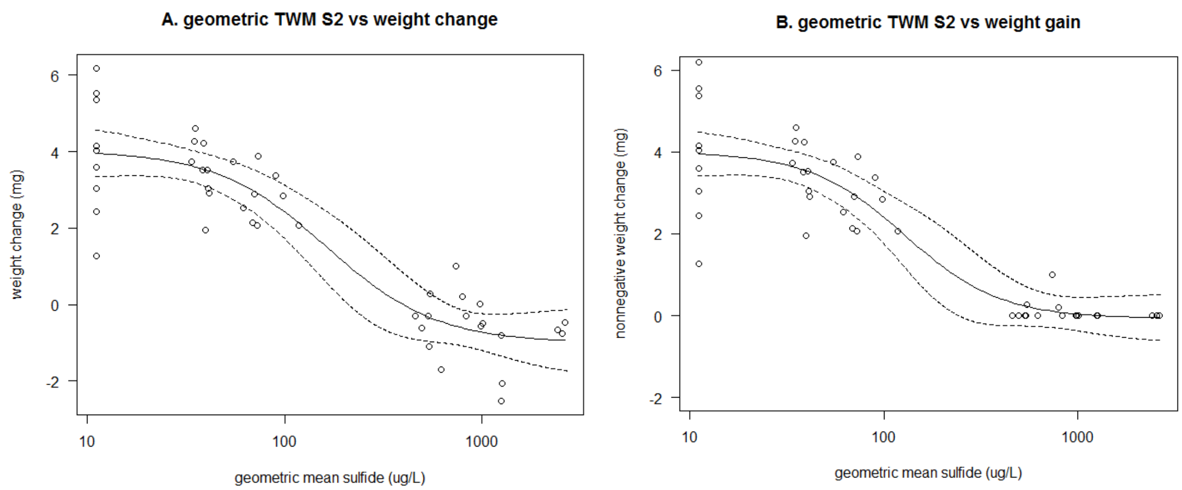
Table A5-2. EC10, EC20, and EC50 values for arithmetic TWM sulfide hydroponic exposures.

	Wt change	Estimate	ln 95% CI	Wt gain	Estimate	ln 95% CI
EC10	3.474 mg	103 µg/L	<11 µg/L - 162 µg/L	3.465 mg	106 µg/L	<11 µg/L - 158 µg/L
EC20	3.088 mg	140 µg/L	95 µg/L - 195 µg/L	3.080 mg	141 µg/L	98 µg/L - 188 µg/L
EC50	1.930 mg	227 µg/L	174 µg/L - 312 µg/L	1.925 mg	231 µg/L	182 µg/L - 335 µg/L

Predicting weight gain from geometric time weighted mean sulfide concentration

Fig. A5-3 shows the log logistic curve fits for both predicting the weight change (Fig. A5-3A) and predicting the weight gain (Fig. A5-3B).

Figure A5-3. Logistic regressions using geometric time-weighted mean (TWM) sulfide hydroponic concentrations to predict plant growth. A) weight change. B) weight gain.



The geometric time weighted mean results in lower mean estimates of sulfide, and therefore, the curve has almost no "plateau", but shows an effect on wild rice growth almost immediately. As a result, the EC10 values are very low (around 40 µg/L), and have tighter confidence intervals than the other two estimates of sulfide concentration.

Table A5-3. EC10, EC20, and EC50 values for geometric TWM sulfide hydroponic exposures.

	Wt change	Estimate	ln 95% CI	Wt gain	Estimate	ln 95% CI
EC10	3.558 mg	38 µg/L	<11 µg/L - 67 µg/L	3.551 mg	39 µg/L	<11 µg/L - 66 µg/L
EC20	3.163 mg	59 µg/L	37 µg/L - 96 µg/L	3.157 mg	60 µg/L	40 µg/L - 90 µg/L
EC50	1.977 mg	128 µg/L	89 µg/L - 216 µg/L	1.973 mg	127 µg/L	91 µg/L - 224 µg/L

Appendix 6. EC10 estimates from experimental mesocosms

Data used

Dr. John Pastor conducted a multi-year experiment where his team added sulfate to outdoor mesocosms in which wild rice grew in natural sediment at five different levels of sulfate (six replicates of each: control, 50, 100, 150, and 300 mg/L). Porewater sulfide was measured in the sediment of each of the 30 mesocosms in August, 2013. The experiment had been initiated in June, 2011.

The variables used for this analysis are:

Porewater sulfide.

To quantify wild rice response:

- Percent of filled (viable) seeds
- Number of plants that emerged from the sediment

Percent filled seeds as a function of porewater sulfide

Using all the data, the EC10 using percent filled seeds and the baseline sulfide of 69.28 µg/L is:
288 µg/L with a 95% confidence interval of (0, 648).
However there was a statistical outlier, mesocosm #29, which had a porewater sulfate of 1180 µg/L but still had 53.5% of the seeds filled. The number of plants that emerged was low. Since this mesocosm had a Cook's distance of 0.6, which was twice as high as the next highest distance (Fig. A6-1), the regression was recalculated without mesocosm #29. Without mesocosm #29, the EC10 is:
228 µg/L with a 95% confidence interval of (0, 414) (Fig. A6-2).

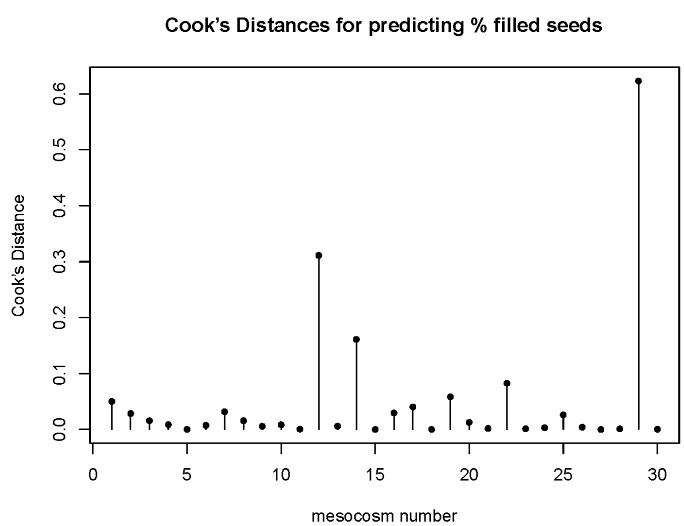


Figure A6-1. Cook's distances for regression of percent filled seeds against porewater sulfide.

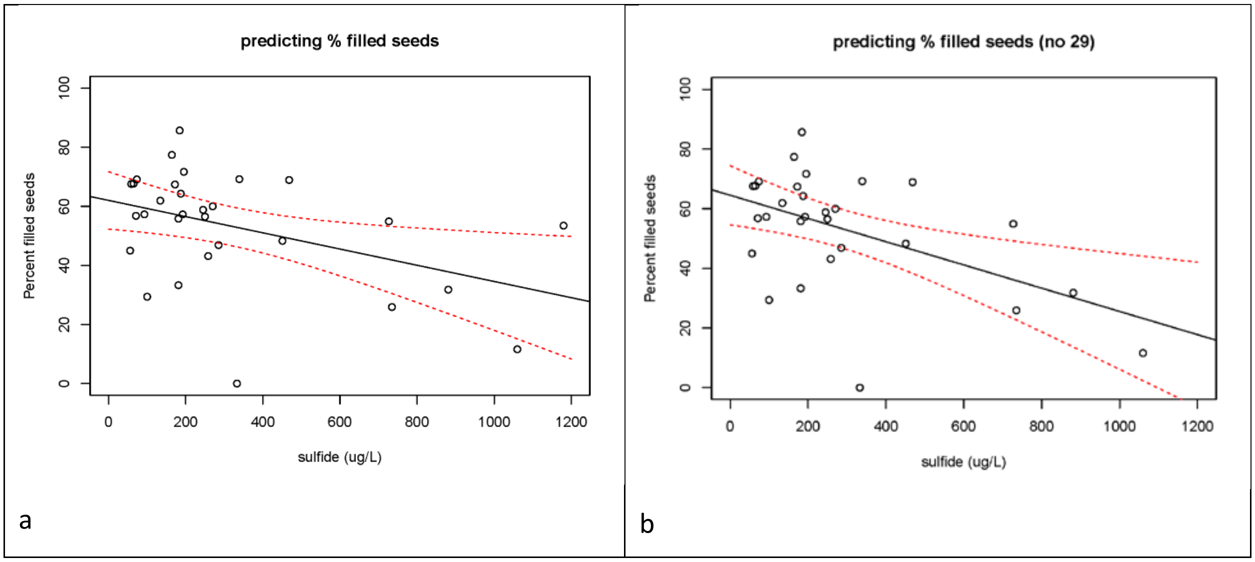


Figure A6-2. Regressions of percent filled seeds against porewater sulfide in wild rice mesocosms sampled August 2013 (Pastor et al., 2017), with all data (a), and without outlier mesocosm #29 (b).

Number of emerged plants as a function of porewater sulfide

The EC10 using number of emerged plants does require a log transformation of sulfide in order to fit a linear model. When this is done, the EC10 is:

121 µg/L with a 95% confidence interval of (6, 241) (Fig. A6-3).

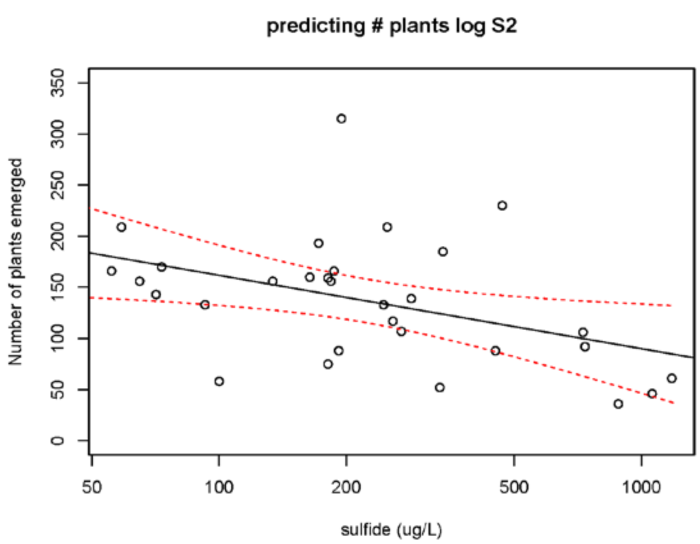


Figure A6-3. Regressions of number of plants emerged against porewater sulfide in wild rice mesocosms sampled August 2013 (Pastor et al., 2017).

Appendix 7. Protective sulfide estimates from MPCA-sponsored field survey

Goal of analysis

Utilizing the large dataset from the MPCA-sponsored wild rice field study, to investigate the relationships between potential protective sulfide levels and error rates, wild rice presence, and wild rice density.

Data used

The Class B data set from the wild rice field study was analyzed to identify potential protective sulfide concentrations. This data set includes 108 different sites measured as close to mid-August as possible. Relevant measurements include:

- Porewater sulfide (in μg/L)
- Wild rice density (stems/m^2)

Potential protective sulfide concentrations

Using the wild rice field survey data, three different methods were used to identify potential protective sulfide concentrations: (1) EC10 estimates from regressions, (2) Visual examination of a graphical representation of the proportion of sites with wild rice present, and (3) Change-point analysis.

1. EC10 estimates from regressions of field data:

The binary logistic regression that relates porewater sulfide to the presence and absence of wild rice can be calculated a number of different ways, producing different EC10 estimates of protective sulfide concentrations. The production of multiple EC10 estimates suggests that the selection of a protective concentration of sulfide should be the outcome of weighing multiple lines of evidence, rather than relying on a single calculation. Each estimate has a range of uncertainty. A reasonable protective sulfide concentration lies within the overlapping uncertainty ranges. An exploration of uncertainty around the estimates was recommended by the independent peer review panel (ERG 2014, p. 6).

Initially, MPCA conducted binary logistic regressions of wild rice presence/absence against linear sulfide concentrations. However, re-examination of the data used in the logistic regression found that porewater sulfide concentrations are skewed (Fig. A7-1a), and that a log-10 transformation would approximate normality (Fig. A7-1b).

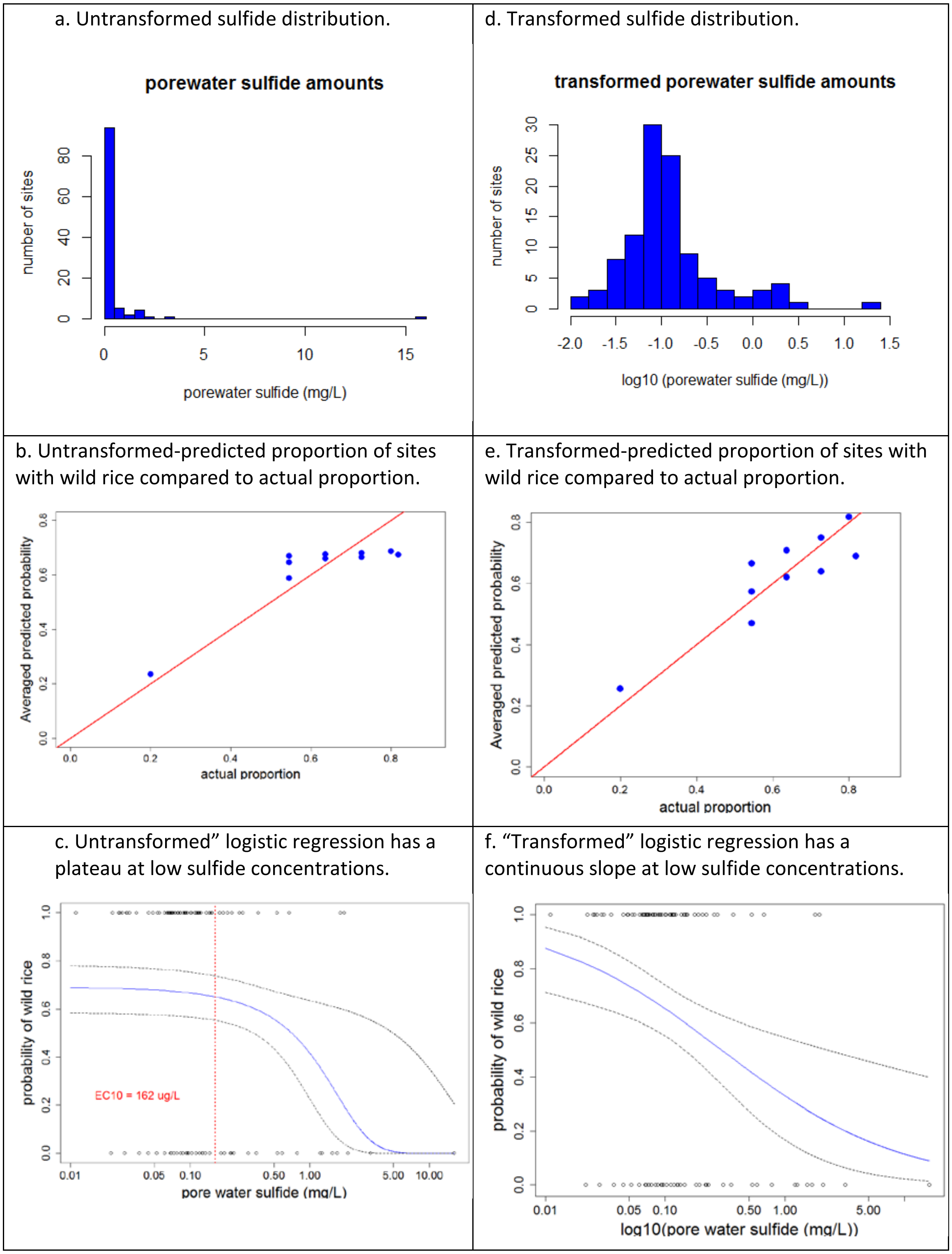


Figure A7-1. Comparison of the use of untransformed data in logistic regression (a-c) to the use of log-10 transformed data (d-f). Sulfide is graphed in both c and f on a log scale, but the modeling used untransformed data in c. In b and e the data are divided into deciles in order to assess the accuracy of the logistic prediction.

It is apparent that transforming the data results in more accurate predictions of the proportion of sites with wild rice (the data follow the 1:1 line better in Fig. A7-1e than in Fig. A7-1b). However, the logistic curve based on transformed sulfide data (Fig. A7-1f) is problematic for the calculation of an EC10

because of the absence of a plateau. Calculation of an EC10 assumes that there is a plateau, or baseline, of "no effect" of a stressor, from which a 10 percent effect adverse can be calculated. But the re-calculated logistic curve (Fig. A7-1 f) exhibits a continuous slope as sulfide declines, all the way down to the analytical reporting limit of 11 µg/L, which makes it difficult to identify a "baseline" probability from which to calculate a 10 percent effect. To complete the exercise of calculating an EC10, MPCA assumed a baseline probability based on the proportion of sites with wild rice for the 10 sites with the lowest sulfide concentration (8 out of 10 sites had wild rice, a baseline probability of 0.80).
Because low-transparency sites (< 30 cm) generally do not support wild rice regardless of how low sulfide is in the porewater, it is likely more accurate to calculate an EC10 for sulfide from a data set that does not include low-transparency sites that did not support wild rice because of low light (Fig. A7-2b).

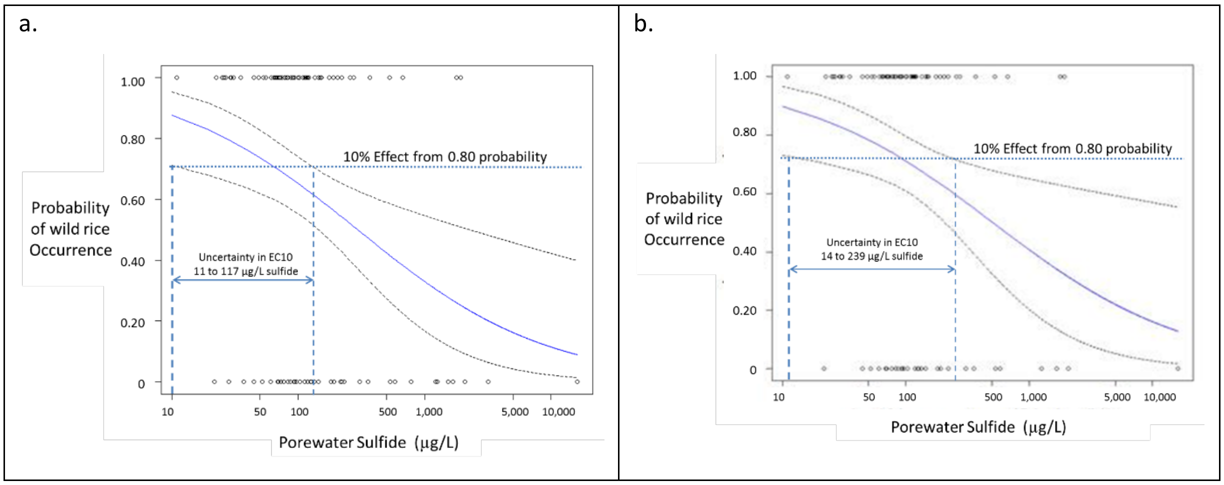


Figure A7-2. a. Logistic regression of all data in Class B, showing the 10% effect horizontal line. b. Logistic regression of all data with transparency > 30 cm. The horizontal 10% effect lines span the distance between the lower and upper 95% confidence intervals (Table A7-1), which is the indication of uncertainty (the confidence intervals shown are calculated for the probability at a given sulfide concentration, not for uncertainty in sulfide for a given effect level).

The calculated EC10 values range from 58 µg/L (all 108 sites) to 93 µg/L (the 96 sites with transparency greater than 30 cm). The uncertainty of the EC10 estimates was quantified by identifying the range of sulfide concentrations that contain a given EC10 wild rice proportion in their 95% confidence interval based on the binary logistic regression (Fig. A7-1; Table A7-1). Note that the uncertainty around the calculated EC10 values is relatively large, ranging from the sulfide reporting limit in the field survey, < 11 µg/L, to 239 µg/L (Table A7-1).

Table A7-1. Calculated sulfide EC10 values, based on wild rice presence/absence.

Data Set	EC_{10} (µg/L)	Uncertainty of sulfide concentrations around the EC10 (µg/L)	
		Lowest value within the 95% CI	Highest value within the 95% CI
All Sites (N=108)	58	< 11	117
Sites with transparency > 30 cm (N=96)	93	14	239

The peer review panel concluded that the MPCA field survey provided some of the best data available to investigate the relationship between wild rice and sulfide, and recommended that MPCA conduct a statistical analysis of the probability of wild rice occurrence as a function of the porewater sulfide levels (ERG, 2014). Binary logistic regression (BLR), described in Part B of Chapter 1, is "binary" in the sense that it classifies field sites as having, or not having, a wild rice population – the density of the wild rice is irrelevant to the classification. It is useful to note that Minnesota lakes with wild rice that are monitored by the 1854 Treaty Authority average 46 stems/m^2 with a median density of 30 stems/m^2 (Appendix 4), and in the MPCA-sponsored field survey, average wild rice density was 51 stems/m^2 with a median density of 41 stems/m^2 (Myrbo et al., in press-1).

MPCA's use of the binary logistic regression for the calculation of an EC10 was questioned in a comment on the March 2015 Draft Proposal as a non-standard statistical technique (MCC, 2015). MPCA found no objections raised in the scientific literature when this same statistical technique was used to assess the effect of selenium on mallard egg viability and duckling mortality (Adams et al., 2003). The Adams et al. (2003) study was subsequently cited favorably in an EPA guidance document (EPA, 2007); this guidance was subsequently explicitly approved by the EPA Science Advisory Board as an exceptional analysis of toxicity in a field setting: "Toxicity in wildlife from metals exposures is generally poorly understood and is rarely quantified in field settings. A few notable exceptions are those mechanisms described in avian waterfowl exposure to [selenium] (Adams et al., 2003)…" Thus, it appears that MPCA's statistical analysis of the wild rice field data, although perhaps not traditional, is supported by the scientific literature, EPA guidance, and the Science Advisory Board.

A protective sulfide concentration was identified as a 10% decrease (a 10% effect concentration, or EC10) from control conditions using a logistic regression where the probability of wild rice presence was predicted against log 10 transformed sulfide concentration (Class B data with water transparency > 30 cm data). The EC10 was 93 µg/L (95% confidence interval of 14 -239 µg/L). However, the "control" condition, or baseline, was difficult to define, since there was no range of sulfide concentrations where the probability of wild rice was constant. Therefore, the EC10 of 93 µg/L is misleadingly precise.

2. Visual examination of a graphical representation of the proportion of field sites with wild rice present against sulfide concentrations:

The visual examination identified a protective sulfide concentration of 120 µg/L. Focusing on sulfide between 20 and 1000 µg/L, the proportion of sites with wild rice present above each measured sulfide concentration was graphed for (1) all sites or (2) for all sites with water transparency greater than 30 cm.

(30 cm is identified as a threshold because 11 of 12 sites with lower transparency did not have wild rice; Myrbo et al. (submitted-2) identified water transparency as one of the environmental variables aside from porewater sulfide that controls wild rice presence in Minnesota waterbodies). The proportions above each sulfide concentration were graphed versus the sulfide concentration. In both graphs, a potential protective sulfide concentration was identified as a dip at 120 µg/L in the proportion of sites with wild rice (Fig. A7-3).

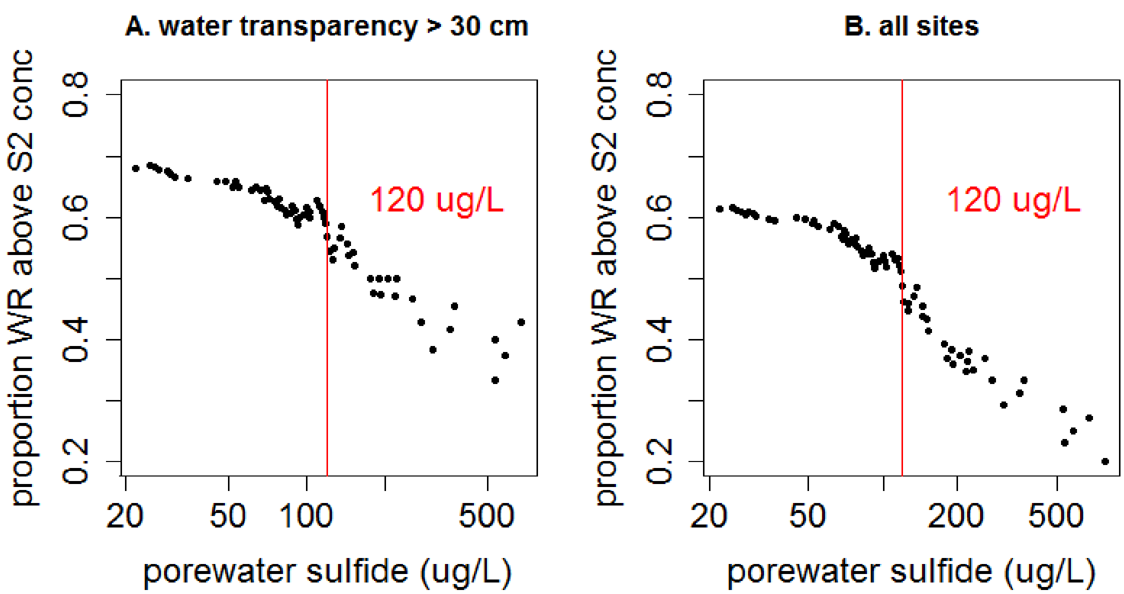


Figure A7-3. Percent of sites above the sulfide concentration that contain wild rice. A. Class B sites where water transparency was greater than 30 cm (N=96). B. All sites in Class B (N=108).

3. Change-point analysis of the field data:

To assess whether the visual identification of 120 µg/L is supported through a recognized objective procedure, change-point analysis was used to identify sulfide concentrations that are associated with changes in the trend in the density of wild rice in relation to porewater sulfide. A potential protective sulfide concentration was found by ordering the data from lowest sulfide to highest sulfide concentration, then performing change-point analysis on the wild rice density (average number of stems per square meter). The resulting sulfide concentrations was 112 µg/L, although the confidence interval is wide (95% confidence interval 25-368 µg/L).

Appendix 8. Empirical demonstration that a MBLR probability of 0.5 is most accurate

Background

The MPCA used multiple binary logistic regression (MBLR) to develop an equation to calculate the surface-water sulfate concentration corresponding to a porewater sulfide concentration of 120 µg/L (given the TOC and extractable iron in the sediment of a particular wild rice water). MPCA chose to use MBLR to avoid re-transformation bias in solving for the sulfate concentration that is incurred with some other statistical models, following the recommendation in Pollman et al. (in press).

However, many people are unfamiliar with the steps necessary to derive an equation that predicts sulfate from a MBLR model. First, the output of a logistic regression cannot be used to directly predict the sulfate concentration of interest. Rather, the MBLR-based model output is an equation that predicts the probability that sulfide would be greater than 120 µg/L (given the TOC and extractable iron in the sediment of the wild rice water). The model can be rearranged to predict the sulfate concentration of interest, but only if a probability is inserted into the model. This TSD asserts that the appropriate probability is 0.5.

Theoretical basis for choosing 0.5

A probability of 0.5 yields sulfate concentration predictions that have an equal chance of being too high or too low. Choosing probabilities that are higher or lower than 0.5 would bias predictions either generally higher than the best sulfate standards (probabilities greater than 0.5) or lower (probabilities less than 0.5). For instance, if a probability of 0.8 is used, a sulfate standard would be calculated that produces an 80% probability of the of the porewater sulfide being over 120 µg/L, which would be under-protective. Conversely, if an equation is developed with a probability of 0.2, the resulting equation would produce an 80% probability of porewater sulfide being below 120 µg/L, which would be over-protective. A probability of 0.5 is balanced between the possibilities of over- and under-protection, and is most likely to accurately calculate a sulfate standard that is related to 120 µg/L.

Choosing a probability of 0.5 therefore has a result similar to the goal of the more familiar statistics that seek to characterize the most likely prediction, by achieving a “best fit” or describing the “central tendency” through calculations of medians, means, or linear regressions. All of these approaches use a variety of methods to identify a value that is neither too high nor too low. MBLR maximizes the probability of choosing an accurate dependent variable (sulfate, in this case), whereas other approaches maximize accuracy through other methods; for instance linear regression minimizes the distance of the best fit line to the data points of the dependent variable.

Empirical demonstration that 0.5 yields the most accurate prediction of a protective sulfate concentration

The MPCA has identified a porewater sulfide concentration of 120 µg/L as the optimal concentration to serve as a regulatory protective threshold. This concentration of 120 µg/L is optimal to protect wild rice because the MPCA-sponsored survey of potential wild rice waters found that the density and probability of occurrence of wild rice decreases at or above that concentration.

If porewater sulfide could be directly regulated, there would be no need to regulate sulfate. However, porewater sulfide is a function of three variables (sulfate, sediment TOC, and sediment iron), and only sulfate makes sense to regulate, since the sediment characteristics are natural landscape features. Therefore, the goal is to choose a model that can predict sulfate concentrations that most accurately correspond to actual porewater sulfide concentrations.

Even though 120 µg/L is the optimal sulfide concentration to serve as a threshold, it is not perfect. That is, wild rice does sometimes occur in waterbodies where the field survey found porewater sulfide at concentrations greater than 120 µg/L. In addition, although the density of wild rice (measured in stems per square meter, stems/m^2) was generally lower when sulfide concentrations were greater than 120 µg/L, some of the waterbodies had dense rice (described here as greater than 40 stems/m^2).

Nevertheless, it is clear that wild rice is more likely to be present, and more likely to be dense, if a waterbody has porewater sulfide less than 120 µg/L (Table A8-1).

Table A8-1. Rates of wild rice presence and density above and below 120 µg sulfide/L. (Class B dataset)

	Sulfide less than 120 µg/L			Sulfide greater than 120 µg/L		
Stems/m^2	Number of sites	% of all sites	% of sites with wild rice	Number of sites	% of all sites	% of sites with wild rice
Over 40	28	41%	57%	6	15%	33%
Between 10 & 40	15	22%	31%	3	8%	17%
Less than 10	6	9%	12%	9	23%	50%
No wild rice observed	20	29%	0%	21	54%	
Total	69	100%	100%	39	100%	100%

In waterbodies with porewater sulfide less than 120 µg/L, it is 2.7 times more likely to encounter dense wild rice (over 40 stems/m^2) than in higher (>120 µg/L) sulfide waters (41% vs. 15%). In addition, wild rice is less likely to be found in waterbodies with higher sulfide; in 54% of high-sulfide waterbodies wild rice was not found, in contrast to 29% of the low-sulfide waterbodies. Furthermore, when wild rice is present in a high-sulfide waterbody, it is 4.1 times more likely to have low density wild rice (less than 10 stems/m^2) (50% vs 12%). A low density of wild rice (less than 10 stems/$m^{2)}$ may indicate that the population is not reproducing or germinating well (Table A8-1).

The goal of choosing an equation that calculates the sulfate concentration corresponding to a sulfide concentration of 120 µg/L is to find an equation that best corresponds to the empirical observations seen in the effect of porewater sulfide on both wild rice density and presence/absence (Table A8-1).

The ability of the MBLR-based equation to reproduce the pattern of empirical observations can be assessed with the data from the MPCA field survey. The proposed equation produces a calculated protective sulfate concentration (CPSC) that corresponds to 120 µg/L, based on the sediment TOC and iron from each waterbody. In principle, sulfate concentrations greater or less than the CPSC should have the same effect on wild rice density and presence/absence as when porewater sulfide is greater or less than 120 µg/L. The question is, then, what probability produces the most accurate equation at reproducing the pattern of measured porewater sulfide?

First, let us examine the effect that using different probability levels to develop sulfate equations have on the number of waterbodies with different levels of wild rice density. If equations are developed with a high probability that sulfide would be greater than 120 µg/L (e.g., 0.9), then CPSCs are very high; only 4 waterbodies would exceed the calculated sulfate standards to protect wild rice, and only one of the four had wild rice, and the density is less than 10 stems/m^2 (Table A8-2). Using a high probability would therefore produce calculated standards that would be severely under-protective. Conversely, if equations are developed with a low probability that sulfide would be less than 120 µg/L (e.g., 0.1), then CPSCs are very low, and 76% of waterbodies would exceed the calculated sulfate standards (Table A8-2). In reality, only 36% of waterbodies have porewater concentrations greater than 120 µg/L, so using a low probability would be severely over-protective.

In Table A8-2, the number waterbodies predicted by the equations developed with a range of probabilities (0.1 to 0.9) that sulfide would exceed 120 µg/L can be compared to the empirically observed sulfide levels in the wild rice survey of 108 potential wild rice waterbodies. The predicted numbers that most closely match the empirical observations are printed in bold. Densities that have no bold densities are associated with probabilities of 0.1, 0.2, 0.8, and 0.9. Therefore, equations developed with probabilities 0.3 through 0.7 are most likely to reflect the observed relationship between porewater sulfide and wild rice density.

Table A8-2. Effect that different probability levels (that sulfide would exceed 120 µg/L) have on the number of waterbodies in four levels of wild rice density, compared to the empirically observed relationship of wild rice with porewater sulfide (last line of the table). Calculations are based on the Class B data set, which best approximates a probabilistic data set.

	Sulfate less than CPSC				**Sulfate greater than CPSC**			
Probability that sulfide >120 µg/L	Density over 40 stems/m^2	Density between 10 & 40 stems/m^2	Density less than 10 stems/m^2	No wild rice observed	Density over 40 stems/m^2	Density between 10 & 40 stems/m^2	Density less than 10 stems/m^2	No wild rice observed
~~0.9~~	~~34~~	~~18~~	~~14~~	~~38~~	~~0~~	~~0~~	~~1~~	~~3~~
~~0.8~~	~~32~~	~~18~~	~~13~~	~~35~~	~~2~~	~~0~~	~~2~~	~~6~~
0.7	***29***	***16***	*8*	*33*	***5***	***2***	*7*	*8*
0.6	*26*	***16***	*8*	*29*	*8*	***2***	*7*	*12*
0.5	*24*	***16***	*8*	*24*	*10*	***2***	*7*	*17*
0.4	*24*	***14***	***5***	*22*	*10*	***4***	***10***	*19*
0.3	*21*	*13*	*3*	***19***	*13*	*5*	*12*	***22***
~~0.2~~	~~16~~	~~11~~	~~2~~	~~18~~	~~18~~	~~7~~	~~13~~	~~23~~
~~0.1~~	~~9~~	~~5~~	~~0~~	~~12~~	~~25~~	~~13~~	~~15~~	~~29~~
	Observed sulfide less than 120 µg/L				**Observed sulfide greater than 120 µg/L**			
	28	15	6	20	6	3	9	21

Second, the range of potential probabilities can be further narrowed by comparing the success of the calculated equations in reproducing the pattern that is empirically observed between porewater sulfide and the presence and absence of wild rice, in contrast to comparing against wild rice density (evaluated above). The best matches occur when the probability is set to 0.5 (Table A8-3).

Two logical goals of developing a water quality standard to protect wild rice is to maximize the occurrence of wild rice when a waterbody conforms to the standard, and to minimize the occurrence of wild rice when a waterbody exceeds the standard. While wild rice occurrence is the protection goal, significant occurrence of wild rice at levels above the calculated standards would mean the calculation is inaccurate. These two goals are best met with a probability of 0.5. When sulfate is less than the calculated standard, the maximum proportion with wild rice occurs when the equation is developed with a probability of 0.5 (Table A8-3). Conversely, when sulfate is greater than the calculated standard, the minimum proportion also occurs when the equation is developed with a probability of 0.5 (Table A8-3).

Table A8-3. Effect that different probability levels (that sulfide would exceed 120 µg/L) have on the number of waterbodies with and without wild rice, compared to the empirically observed relationship of wild rice with porewater sulfide (last line of the table). (WR = wild rice) (Class B dataset)

	Sulfate less than CPSC			**Sulfate greater than CPSC**		
Probability that sulfide >120 µg/L	WR vs no WR	total	% with wild rice	WR vs no WR	Total	% with wild rice
0.7	53 vs 33	86	62%	14 vs 8	22	64%
0.6	50 vs 29	79	63%	17 vs 12	29	59%
0.5	**48 vs 24**	**72**	**67%**	**19 vs 17**	**36**	**53%**
0.4	43 vs 22	65	66%	24 vs 19	43	56%
0.3	37 vs 19	56	66%	30 vs 22	52	58%
	Observed sulfide less than 120 µg/L			**Observed sulfide less than 120 µg/L**		
	49 vs 20	69	71%	18 vs 21	39	46%

In conclusion, use of a probability of 0.5 produces an equation that produces sulfate concentrations that correspond most accurately to the sulfide threshold of 120 µg/L. Use of probabilities less than 0.5 produce equations that are over-protective; the calculated sulfate standards are lower, and would classify more waterbodies as exceeding standards that have porewater sulfide less than 120 µg/L and dense wild rice populations. Conversely, use of probabilities greater than 0.5 produce equations that are under-protective; the calculated standards are higher, and would classify fewer waterbodies as exceeding standards that actually have porewater sulfide greater than 120 µg/L and less dense wild rice populations. Use of a probability of 0.5 is therefore the best approach for developing an equation that calculates protective sulfate concentrations.

Appendix 9. Examination of a proposed protective sulfide of 300 µg/L

Goal of analysis

Other scientists have presented evidence in favor of 300 µg/L as a potential protective sulfide concentration threshold. The goal here is to examine 300 µg/L versus 120 µg/L as potential protective sulfide thresholds by looking at how each concentration is associated with wild rice occurrence and density.

Data analyzed

The field data from 2012-2013 was analyzed, during which time 108 different waterbodies were sampled. If there was more than one sample from a waterbody in this time, the sample that was closest to August 11th was used to ensure consistency. This dataset, which approximates a probabilistic survey of potential wild rice waters, is referred to as the Class B dataset. Wild rice density (in stems per square meter) and porewater sulfide (in µg/L), among other variables, were measured at each site.

Wild rice presence

In order to examine the pattern of wild rice occurrence and density associated with the two potential sulfide concentrations thresholds, three groups were created: a group with sulfide below the MPCA proposed standard of 120 µg/L, a group with sulfide concentrations between 120 µg/L and the proposed 300 µg/L threshold, and, finally, a group with sulfide concentrations above 300 µg/L. If the 300 µg/L sulfide concentration is protective, then it would be expected to only find a significant difference between the group under 300 and the group over 300, but not between the group under 120 and the group over 120 but less than 300. If the 120 µg/L is the better choice for a protective sulfide threshold, it would be expected that wild rice presence is significantly greater below 120 than above 120 (both the 120-300 group and the above 300 group). However, it would not be expected to see a significant difference between the 120-300 µg/L group and >300 µg/L group. The number of waters for each group are in Table A9-1:

Table A9-1. Number of Class B waters in three different groups, separated by porewater sulfide concentration.

	Under 120 µg/L	between 120 and 300 µg/L	Over 300 µg/L
Wild rice present	49	13	5
Wild rice absent	20	9	12

First, the question is if there are any differences between the three groups. A chi square test for independence was performed to see if any of the three sulfide level groups were different with respect to wild rice presence. With a p value of 0.0063, there is evidence of a significant difference among the three sulfide level groups with regards to presence or absence of wild rice.

To find out where the difference lies, the odds of wild rice presence for any two sulfide concentration groups were compared, and a two sample proportion test with continuity correction was conducted to obtain the p value (Table A9-2).

Table A9-2. Comparison of the odds of wild rice presence between any two sulfide concentration groups. Significant differences are in bold.

Group 1	Group 2	Odds ratio	95% Confidence Interval	P value
Under 120	Between 120 & 300	1.70	(0.63, 4.59)	0.434
Under 120	**Over 300**	**5.88**	**(1.83, 18.86)**	**0.0037**
Between 120 & 300	Over 300	3.47	(0.90, 13.31)	0.1286
Under 120	**Between 120 & 300 plus Over 300**	**2.86**	**(1.26, 6.47)**	**0.0334**
Under 120 plus between 120 & 300	**Over 300**	**5.13**	**(1.65, 15.93)**	**0.0060**

One advantage of expressing statistical results with odds ratios is that they are relatively easy to put into words. For example, looking at the second line of Table A9-2, the odds of having wild rice when the sulfide is under 120 (group 1) is 5.88 times the odds of having wild rice when the sulfide is over 300 (group 2). The 95% confidence interval for this odds ratio of 5.88 ranges from 1.83 to 18.86. Since this interval does not include 1.0 (a value of 1.0 means the odds are the same), there is a significant difference between the under 120 and the over 300 groups. Since the interval is entirely over 1.0, the under 120 µg/L group (group 1) has significantly higher odds of having wild rice than the over 300 group (group 2). The p value for a proportion test based on these numbers is 0.0037.

Based on these odds ratios and p values, there is not a significant difference between the under 120 and the between 120 & 300 groups with regards to wild rice presence (Table A9-2). However, there is not a significant difference between the between 120 & 300 group and the over 300 group, either. Only the under 120 is significantly different from the over 300 group. Since there is not a significant difference between the 120 to 300 group versus the over 300 group, it is not possible to definitively say that 300 is protective. However, this could be largely due to the small number of sites in each group—the odds ratio is a not-statistically-significant 3.47 (p=0.13), which means that the odds of having wild rice when the sulfide is between 120 and 300 µg/L would be almost 3.5 times the odds of having wild rice when the sulfide is above 300 µg/L. Further, there is not a significant difference between under 120 and between 120 & 300 (p=0.43), so even though wild rice is significantly more likely to be present under 120 µg/L sulfide than above 300 µg/L, based on presence/absence, it is not possible to conclude that 120 is better than 300 as a protective sulfide value.

The final two lines of Table A9-2 are calculated in an attempt to merge groups to look at 120 as a cutoff versus 300 in hopes it is possible to derive a more definitive answer. If the two groups are merged together and compared to the third group, there are significant differences between the groups. The odds of having wild rice when sulfide is under 120 µg/L are 2.86 times the odds of having wild rice when the sulfide is over 120 µg/L. Since the confidence interval is entirely above 1.0, the sites with sulfide under 120 µg/L are significantly more likely to have wild rice than those over 120 µg/L sulfide (p=0.03). Moreover, the odds of having wild rice below 300 µg/L sulfide are 5.13 times the odds of finding wild rice above 300 µg/L, and this is also statistically significant. Therefore, based on presence/absence data it is not possible to determine whether the 120 µg/L or 300 µg/L sulfide concentration threshold is more protective.

Wild rice density

The analysis was then expanded to examine the density of the wild rice stands above and below these potential protective sulfide concentrations. Because wild rice density fluctuates from year to year in natural wild rice waters, low density is not necessarily indicative of an unhealthy population in any single waterbody. However, any condition that is statistically associated with lower density among a variety different waterbodies should be suspected of impairing the reproduction and/or germination of wild rice populations, and therefore decreasing the probability that a population will successfully persist over the long term. Conversely, conditions statistically associated with higher wild rice density can be interpreted as associated with a higher probability that a wild rice population will persist over the long term.

To statistically associate porewater sulfide with low and high wild rice densities, reasonable thresholds for identification of relatively low density and high density were identified. Low and high density thresholds of 10 and 40 stems/m^2 were assessed against the long-term wild rice surveys conducted by the 1854 Treaty Authority on ten relatively un-impacted wild rice waters over 12 years (Appendix 4). The long-term data have a median, or most typical density, of 30 stems/m^2 among the ten waterbodies. The "high" density of 40 stems/m^2 corresponds to the 56th percentile (44% of annual visits to these ten waterbodies had wild rice density greater than 40 stems/m^2). The "low" density of 10 stems/m^2 corresponds to the 14th percentile; in the long-term survey, 86% of the visits to these ten waterbodies were greater than 10% stems/m^2. For comparison, the sites with wild rice in the Class B dataset have a median density of 41 stems/m^2. In other words, Class B sites rated as "high density" had greater wild rice density than 50% of the Class B sites with any wild rice, and 56% of the surveys conducted by the 1854 Treaty Authority.

Therefore, the number of sites in the Class B dataset with wild rice density was examined in three categories: over 40 stems/m^2, below 10 stems/m^2, and in between those two ranges. Therefore, there are four groups for analysis: the dense group (over 40 stems/m^2), the intermediate group (between 10 and 40 stems/m^2), the sparse group (under 10 stems/m^2), and the group with no wild rice. The information is in Table A9-3, below. There are not only differences in the proportion with wild rice, there are also differences among the density groups.

Table A9-3. Number of Class B sites of different density in three different sulfide concentration groups.

	Under 120 µg/L	between 120 and 300 µg/L	Over 300 µg/L
Over 40 stems/m^2	28	5	1
Between 10 and 40 stems/m^2	15	2	1
Below 10 stems/m^2	6	6	3
Wild rice absent	20	9	12

There are enough groups with a low number of observations per group that a Fisher's test (nonparametric) is preferred over a Chi square test (parametric) to confirm statistical differences. A Fisher's test of independence resulted in a p value of 0.002, which indicates that at least two groups differ.

The odds ratios and confidence intervals were then calculated to compare the under 120 to the 120-300 group. In addition, a two-sample proportion test with continuity correction was calculated to find the probability that the groups have the same proportion in each group. The use of the continuity correction on small sample sizes per group results in a slightly different test than the odds ratio, so a confidence interval that does not include 1 (and indicates a significant difference) may occur when the p value is over the standard cutoff of 0.05. For the sites with sulfide over 300 µg/L, there are not enough lakes per group in the 3 wild rice groups to run odds ratios or proportion tests. Therefore, the odds ratios all compare the under 120 group to the 120-300 group (Table A9-4).

Table A9-4. Results of a two-sample proportion test to find the probability of groups having the same proportion in each group. Comparisons that are significantly different are in bold.

Group 1	Group 2	Stem density	Odds ratio	95% Confidence Interval	P value
Under 120	Between 120 & 300	>40 vs 10-40	0.75	(0.13, 4.32)	1.0
Under 120	***Between 120 & 300***	***>40 vs <10***	***5.60***	***(1.28, 24.56)***	***0.044***
Under 120	Between 120 & 300	>40 vs no WR	2.13	(0.73, 7.46)	0.235
Under 120	Between 120 & 300	>40 vs <40	3.47	(0.90, 13.31)	0.375
Under 120	**Between 120 & 300**	**>40 vs <10 & no WR**	**3.23**	**(1.03, 10.45)**	**0.072**
Under 120	**Between 120 & 300**	**10-40 vs <10**	**7.50**	**(1.17, 48.15)**	**0.065**
Under 120	Between 120 & 300	10-40 vs no WR	3.38	(0.63, 17.97)	0.262
Under 120	***Between 120 & 300***	***10-40 vs <10 & no WR***	***3.54***	***(1.28, 9.84)***	***0.024***
Under 120	***Between 120 & 300***	***>10 vs <10***	***6.14***	***(1.54, 24.54)***	***0.018***
Under 120	Between 120 & 300	>10 vs no WR	2.76	(0.90, 8.48)	0.127
Under 120	***Between 120 & 300***	***>10 vs <10 & no WR***	***3.55***	***(1.28, 9.84)***	***0.024***
Under 120	Between 120 & 300	<10 vs no WR	0.45	(0.11, 1.79)	0.429

The comparisons in Table A9-4 show that the groups with wild rice density at or above 10 stems/m^2 (whether they are over 40, between 10 and 40, or 10 and up) are significantly different from the groups with wild rice density below 10 stems/m^2 (whether they are between 0 and 10, or both no wild rice and between 0 and 10). Since the confidence intervals are all over 1.0, there is significantly higher odds of observing dense wild rice if the sulfide concentration is below 120 µg/L than if the sulfide concentration is between 120 and 300 µg/L.

Discussion

Based on wild rice presence versus absence, it is not possible to find a statistically significant difference between those sites with sulfide below 120 µg/L and those with sulfide between 120 µg/L and 300 µg/L. However, when wild rice density is examined, there is significantly higher density for those sites with sulfide below 120 µg/L compared to those with sulfide between 120 µg/L and 300 µg/L. Therefore, while sulfide concentrations between 120 µg/L and 300 µg/L do not produce a significant difference in the proportion of sites with wild rice, sites with porewater sulfide less than 120 µg/L are more likely to have dense wild rice than stands with sulfide between 120 µg/L and 300 µg/L. Wild rice waters with sulfide less than 120 µg/L are 5.6 times as likely as sites with sulfide between 120 and 300 µg/L to have dense (>40 stems/m^2) than sparse wild rice (<10 stems/m^2).

It should be noted that the statistical tests described in this report were conducted in accordance with a fundamental assumption of statistical analysis, which is that groups being compared are independent of each other. That is, there was no overlap in the waterbodies between groups; no waterbody was in more than one group in any given statistical test. For instance, it would not be appropriate to statistically compare under 300 µg/L to under 120 µg/L, since 79% of the data in the under 300 µg/L group is the data from the under 120 µg/L group.

Conclusions

Based on a statistical analysis of the MPCA field survey, a protective sulfide concentration of 300 µg/L would not be as protective of wild rice as a concentration of 120 µg/L. The 22 waterbodies in the survey with sulfide concentrations between 120 and 300 µg/L were just as likely to have wild rice as waterbodies with sulfide below 120 µg/L, but were significantly less likely to have dense wild rice (greater than 40 stems/m^2). Waterbodies in the <120 µg/L sulfide group are 5.6 times as likely to have dense wild rice as waterbodies in the 120-300 µg/L sulfide group.

Appendix 10. Educational credentials and qualifications of TSD and SONAR authors

The following MPCA staff conducted research, analyzed data, and authored the documents that are the basis for the MPCA proposal for establishing the level of sulfide and sulfate to protect wild rice.

Name	Qualifications
David Bael Economic Policy Analyst	Ph.D. Candidate, Applied Economics (University of Minnesota); Masters of Public Policy (University of Minnesota); B.S. Biology and B.S. Management Science (Massachusetts Institute of Technology); 5 years experience in the analysis of issues related to environmental economics and finance
Baishali Bakshi Economist, Water Quality Standards	Ph.D. Economics (University of California-Irvine); 8 years experience in data analysis and natural resources policy.
Gerald Blaha Research Scientist	University of Minnesota / Century College – coursework in biology / air and water analysis; 40 years experience in water quality standards and water use classifications
William Cole Supervisor	M.Aq. Aquaculture (Auburn University); B.S. Biology (John Brown University); 10 years experience developing and implementing water quality standards
Elise Doucette Policy Specialist	B.S. Biology (University of Minnesota-Duluth); 15 years experience in water quality regulations.
Patricia Engelking Planner Principal	B.A. Chemistry (Washington University); 28 years of experience in water quality
Stephanie Handeland Hydrologist	B.S. Geology (Winona State University); 22 years experience in water quality (NPDES) wastewater permitting; 9 years experience mining permitting
Elizabeth Kaufenberg Research Scientist	M.S. Water Resources Science (University of Minnesota); B.S. Environmental Science (UW-River Falls); 8 years experience in water quality (co-authored 4 papers)
Scott Kyser Wastewater Engineer	M.S. Civil and Environmental Engineering (University of Minnesota-Twin Cities); B.A. Biology (Gustavus Adolphus College); Registered Professional Engineer in Minnesota; 6 years experience in environmental engineering
Shannon Lotthammer Director	M.S. Ecology (University of Minnesota-Twin Cities); B.S. Biology (University of Minnesota-Duluth); 23 years experience in state and local environmental management.
Phillip Monson Research Scientist	M.S. Entomology (University of Maine); B.S. Biology (University of Minnesota-Duluth); 15 years experience developing and implementing water quality standards
Carol Nankivel Planner Principal	B.S. Soil Science (University of Minnesota); 35 years experience in preparation of administrative rules
Catherine Neuschler Manager	Master of Public Affairs (School of Public and Environmental Affairs, Indiana University); B.A. Environmental Studies (Macalester College); 11 years experience at the MPCA.

(continued)

Emily Peters Data Analyst (now at MDNR)	Ph.D. Ecology (University of Minnesota); B.S. Ecology (University of California Santa Cruz); 12 years experience analyzing ecological data and publication of peer-reviewed findings (authored or co-authored 15 papers)
Michael Schmidt	J.D. (University of Minnesota); 8 years experience in the Clean Water Act and state water law
Marta Shore Data Analyst (now teaching in the biostatistics program at the University of Minnesota)	M.S. Statistics with supporting work in Biostatistics (University of Minnesota); B.A. Biology (University of Chicago); 10 years experience performing statistical analyses
Edward Swain Research Scientist	Ph.D. Ecology (University of Minnesota); B.A. Biology (Carleton College); 33 years experience in aquatic ecology research and publication of peer-reviewed findings (authored or co-authored 30 papers)

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OAH 80-9003-34519
Revisor R-4324

In the Matter of the Proposed Rules of the Pollution Control Agency Amending the Sulfate Water Quality Standard Applicable to Wild Rice and Identification of Wild Rice Rivers, Minnesota Rules parts 7050.0130, 7050.0220, 7050.0224, 7050.0470, 7050.0471, 7053.0135, 7053.0205 and 7053.0406

CHIEF ADMINISTRATIVE LAW JUDGE'S ORDER ON REVIEW OF RULES UNDER MINN. STAT. § 14.16, SUBD. 2, AND MINN. R. 1400.2240, SUBP. 5.

Background

The Minnesota Pollution Control Agency (MPCA or Agency) proposes to amend the state's existing rules governing Minnesota's water quality standard to protect wild rice from excess sulfate. The current standard limits sulfate to 10 milligrams per liter in waters used for the production of wild rice as well as in wild rice waters that do not contain cultivated wild rice.[1] The proposed rule amendments identify approximately 1,300 bodies of water in Minnesota as "wild rice waters" designated as subject to the new sulfate standard.[2]

The new standard is set forth in proposed rule at Minn. R. 7050.0224, subd. 5(B).[3] The proposed standard establishes an equation used to calculate the sulfate limit for each MPCA-designated body of water. The equation factors site-specific information and establishes a unique sulfate limit based upon the concentration of iron, organic carbon, and sulfide in the sediment of each designated body of water.[4]

When sulfate in water interacts with iron and organic carbon in sediment, sulfide can form, which the MPCA has determined is toxic to wild rice.[5] Key features of the proposed rules include limits on the amount of sulfide in the sediment of designated waters, and sampling and analytical methods to determine the amount of sulfide, carbon and iron present in the saturated sediment.[6]

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[1] *See, e.g.,* Minn. R. 7050.0224, subps. 1 and 2 and Minn. R. 7050.0220, subps. 1, 3a, 4a,5a, and 6a (2017).
[2] MPCA Resubmission at 8 and Attachment 8, at 58 – 116.
[3] In the July 24, 2017 version of the proposed rules, the methods for calculating sulfate limits were found in part 7050.0224, subp. 5(B)(1). In the revised draft dated March 16, 2108, the requirements appear in part 7050.0224, subp. 5(B).
[4] *See* MPCA's Resubmission, Attachment 1, at 1, and Attachment 8, at 54-55.
[5] Report of the Administrative Law Judge, OAH Docket No. 80-9003-34519, at 1, 5 (January 9, 2018) (Report of the Administrative Law Judge).
[6] *See generally,* MPCA Resubmission, Attachment 8.

Procedural Posture

The Minnesota Pollution Control Agency commenced this rulemaking process on October 26, 2015 with its publication of a Request for Comments in the *State Register*.[7] With necessary approval, the Agency published its initial Notice of Hearing on August 21, 2017[8] and announced a series of hearings scheduled in October and November, 2017.[9] Over 350 individuals attended the six public hearings.[10] Members of the public submitted approximately 4,500 written comments on the proposed rule amendments.[11]

In a report dated January 9, 2018, Administrative Law Judge LauraSue Schlatter disapproved many of the proposed revisions to Minn. R. 7050.0220, 7050.0224 and 7050.0471. The matter then came before the Chief Administrative Law Judge pursuant to Minn. Stat. § 14.15, subd. 3 (2016), and Minn. R. 1400.2240, subp. 4 (2017). These authorities require that the Chief Administrative Law Judge review an Administrative Law Judge's disapproval of an Agency's proposed rule.

In a Report dated January 11, 2018, the Chief Administrative Law Judge concurred with the disapproval determinations of the Administrative Law Judge.[12] As a result:

1. The following proposed rules were disapproved:

    a. Proposed Minn. R. 7050.0220, subps. 3a, 4a, 5a, 6a
    b. Proposed Minn. R. 7050.0224, subp. 2
    c. Proposed Minn. R. 7050.0224, subp. 5, A
    d. Proposed Minn. R. 7050.0224, subp. 5, B (1)
    e. Proposed Minn. R. 7050.0224, subp. 5, C
    f. Proposed Minn. R. 7050.0224, subp. 6
    g. Proposed Minn. R. 7050.0471, subps. 3 through 9

2. The following modifications to rules as originally proposed were also disapproved:

    a. Proposed changes to Minn. R. 7050.0224, subp. 5, B (1)
    b. Proposed changed to Minn. R. 7050.0224, subps. 5, E, F
    c. Proposed changes to Minn. R. 7050.0224, subp. 5, B (2)

[7] *Id.* at 9, Finding 17.
[8] A second Notice of Hearing was published in September 2017 after the Agency scheduled a hearing to be held at the Fond du Lac Tribal Community College.
[9] *Id.* at 9, Finding 20.
[10] *Id.* at 2-3.
[11] *Id.* at 4.
[12] Report of the Chief Administrative Law Judge, OAH Docket No. 80-9003-34519, at 1, 5 (January 11, 2018) (Report of the Chief Administrative Law Judge).

The Report of the Chief Administrative Law Judge specifically instructed the MPCA on the statutory procedure for the Agency to follow in the event it decided not to correct the defects identified in the proposed rules, as follows:

> If the Department elects not to correct the defects associated with the repeal of the existing rules and the defects associated with the proposed rules, the Department must submit the proposed rules to the Legislative Coordinating Commission and the House of Representatives and Senate policy committees with primary jurisdiction over state governmental operations, for review under Minn. Stat. § 14.15, subd. 4 (2016).[13]

Effective on April 2, 2018, the MPCA requested that the Chief Administrative Law Judge review additional submissions in the matter, including the following:

a) March 28, 2018, Letter Response to the Report of the Chief Administrative Law Judge dated January 11, 2018 (Response), with the following attachments:

- Attachment 1: March 5, 2018 Letter from Christopher Korleski, Environmental Protection Agency, Region V, to Shannon Lotthammer, Assistant Commissioner, MPCA (EPA 2018 Letter);
- Attachment 2: November 5, 2015 Letter from Tinka G. Hyde, Environmental Protection Agency, Region V, to Rebecca Flood, MPCA (EPA 2015 Letter);
- Attachment 3: EPA's Review of Revisions to Minnesota's Water Quality Standards: Human Health Standards Methods (Nov. 5, 2015);
- Attachment 4: November 22, 2017 Letter from Christopher Korleski, Environmental Protection Agency, Region V, to LauraSue Schlatter, Administrative Law Judge with enclosed comments on Minnesota's "Proposed Rules Relating to Wild Rice Sulfate Standard and Wild Rice Water" (EPA 2017 Comments);
- Attachment 5: Sampling and Analytical Method for Wild Rice Methods (March 2018);
- Attachment 6: Technical Discussion of Proposed Equation Related Changes to the Rule;
- Attachment 7: List of Proposed Rule Changes;

[13] Report of the Chief Administrative Law Judge at 2.

- Attachment 8: Revisor's March 16, 2018, version of Proposed Rule incorporating changes as proposed in March 28, 2018 filing (Revisor's AR4324);

- Attachment 9: January 19, 1999 Memorandum from Marvin E. Hora, Manager, Environmental Research and Reporting, Environmental Outcomes Division to the Minnesota Pollution Control Agency Board Water Quality Committee regarding Proposed Revisions of Minn. Rules ch. 7050;

- Attachment 10: Statement of Need and Reasonableness "In the Matter of the Proposed Revisions to the Rules Governing the Classification and Standards for Waters of the State, Minnesota Rules Chapter 7050" page 54 (April 27, 1993) and attached draft rule page;

b) Draft Order Adopting Rules (filed April 2, 2018); and

c) Revisor's July 24, 2017, version of Proposed Rules (Revisor's RD4324A).

The MPCA's request for review was made pursuant to Minn. Stat. § 14.16, subd. 2 (2016) and Minn. R. 1400.2240, subp. 5 (2017).

Legal Analysis

Rulemaking is a statutory process governed by the provisions of the Minnesota Administrative Procedure Act (Act), Minn. Stat. Ch. 14. The Office of Administrative Hearings is statutorily required to review rulemaking matters in accordance with the dictates of that Act.[14]

Relevant to the current proceeding, Minn. Stat. § 14.14, subdivision 2 (2016), provides as follows:

> **At the public hearing** the agency shall make an affirmative presentation of facts establishing the need for and reasonableness of the proposed rule and fulfilling any relevant substantive or procedural requirements imposed on the agency by law or rule. The agency may, in addition to its affirmative presentation, rely upon facts presented by others on the record during the rule proceeding to support the rule adopted.[15]

In this case, the Administrative Law Judge determined that the MPCA failed to meet this and other requirements of the Act and therefore disapproved the proposed rule.[16] As required by law, the disapproval was reviewed by the Chief Administrative Law

[14] Minn. Stat. §§14.05 and 14.08 (2016).
[15] Emphasis added.
[16] Report of the Administrative Law Judge at 5-6.

Judge and, in a January 11, 2018 Report, the MPCA was advised regarding how to correct the determined defects.

Building upon the statutory directive that an agency meet all requirements of the Act relevant to rulemaking, Minn. Stat. § 14.15, subd. 4, provides as follows:

> If the chief administrative law judge determines that the need for or reasonableness of the rule has not been established pursuant to section 14.14, subdivision 2, and if the agency does not elect to follow the suggested actions of the chief administrative law judge to correct that defect, then the agency shall submit the proposed rule to the Legislative Coordinating Commission and to the house of representatives and senate policy committees with primary jurisdiction over state governmental operations for advice and comment. The agency may not adopt the rule until it has received and considered the advice of the commission and committees. However, the agency is not required to wait for advice for more than 60 days after the commission and committees have received the agency's submission.

The MPCA has not complied with the law in this regard. In its Resubmissions, it has not followed the Chief Administrative Law Judge's directives regarding how to correct the defects in the proposed rule, nor has it submitted the disapproved rule to the identified legislative bodies for advice. Instead, the MPCA has, in effect, requested reconsideration of the rule's disapproval and seeks an order allowing adoption of the proposed rule, in modified form.

The Chief Administrative Law Judge declines to grant the MPCA its requested relief. While it is clear that the Agency has made significant efforts to reexamine the proposed rule and make clarifications and revisions where deemed appropriate, it is just as clear that the Agency has not followed the provided directives for curing all identified defects, nor identified other record-based and public-vetted solutions to achieve the same ends consistent with the spirit and the letter of the Minnesota Administrative Procedure Act.[17] Neither has the Agency availed itself of the only other statutory alternative: seeking legislative advice as required by the law.

The Chief Administrative Law Judge is cognizant of the fact that the Agency is dedicated to protecting the quality of the waters in the state and so has invested significant human, temporal and financial resources in this effort. Mindful that the protection of Minnesota's wild rice waters will remain an important policy and regulatory goal for and in the state, the Chief Administrative Law Judge has set forth below additional information that may prove useful to the Agency as it continues to address this issue on behalf of all Minnesotans.

[17] Minn. Stat. 14.001 (2016).

Substantive Review of Agency Resubmissions

The Agency submitted three categories of information to the Chief Administrative Law Judge in support of its request for review. The bulk of the submissions constitute legal argument intended to serve as a basis for reversal of various findings of rule disapproval contained in both the Administrative Law Judge's Report and the Chief Administrative Law Judge's Report.[18] In addition, the submissions include proposed modifications to portions of the disapproved rule. Last, the filings encompass other proposed rule changes not recommended by the Administrative Law Judge.[19] The MPCA's filings are silent on many of the disapproved rule parts notwithstanding the fact that the Administrative Law Judge specified various legal grounds for their disapproval.

Below, the Chief Administrative Law Judge has summarily addressed each of the major issues raised in the MPCA's Resubmissions.

I. Equation-Based Standard

A. Numeric Expression of the Standard

The MPCA argues that the Administrative Law Judge found the proposed equation-based standard to be *per se* invalid, and argues that the existence of other approved rules which rely on mathematical equations proves the Administrative Law Judge's determination to be incorrect.[20] In fact, it is the MPCA that is incorrect. The Administrative Law Judge did not disapprove the proposed standard based on the fact that it contained an equation, but instead determined that the Agency had met its statutory burden to show the equation-based standard to be necessary and reasonable.[21] The Administrative Law Judge went on to find that the proposed implementation of the equation-based standard requires measurement of 1,300 identified waters, a feat that will require approximately ten years to accomplish, and until that is completed no one can know exactly what standard applies and must be met in each identified body of water.[22] Given these facts, the Administrative Law Judge determined that the proposed rule was insufficiently specific to be approved[23] and that it was not "rationally related to the Agency's objective" of "protect[ing] wild rice from the impact of sulfate, so that wild rice can continue to be used as a food source by humans and wildlife."[24] Pursuant to Minn. R. 1400.2100.B., a rule cannot lawfully be approved if it does not rationally relate to the

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[18] The Report of the Chief Administrative Law Judge concurred in all respects with the findings and conclusions contained in the Report of the Administrative Law Judge. For the convenience of the reader, further references to the issued Reports will cite only to the Report of the Administrative Law Judge.
[19] MPCA Resubmission at 1.
[20] MPCA Resubmission at 1-4.
[21] Report of the Administrative Law Judge at 60-61, Findings 251, 256, 257.
[22] *Id.* at 61, Finding 258 and at 55-59, Findings 234-249.
[23] *Id.* at 58, Finding 247. *See also Minnesota Chamber of Commerce v. Minnesota Pollution Control Agency*, 469 N.W.2d 100, 107 (Minn. Ct. App. 1991) ("A rule, like a statute, is void for vagueness if it fails to give a person of ordinary intelligence a reasonable opportunity to know what is prohibited or fails to provide sufficient standards for enforcement") (citing *Grayned v. City of Rockford,* 408 U.S. 104, 108-09 (1972)).
[24] Report of the Administrative Law Judge at 58, Finding 246.

Agency's objectives. Having reached this conclusion, the Administrative Law Judge disapproved the proposed rule.

In its Resubmissions the Agency reverts to its argument that:

> "[e]ffluent limit review is case-specific and includes evaluating information such as pollution concentrations in the receiving water and the discharge . . . and how many sources contribute to the receiving water. … Until that information is reviewed and the effluent limit is established, no permittee can know if or to what extent they will have to treat their wastewater discharge for the given pollutant, even if the standard that the effluent limit is protecting is a single numeric value."[25]

In essence, the Agency ignores the Administrative Law Judge's rational relationship analysis and continues to insist that the proposed equation-based rule should be approved based upon the fact that it is necessary and reasonable. Unfortunately, the Administrative Procedure Act does not provide for approval based on that factor alone; all other requirements of statute and rule must also be met in order for rule approval to be lawfully granted.[26]

Even while continuing to argue that the proposed equation-based standard is legally sufficient and should be approved, the MPCA's Resubmissions include several key clarifications and revisions to the equation and required analysis. Three major revisions, and the Chief Administrative Law Judge's responses to each, are addressed below.

(1) Removal of Second Lake

The MPCA revised the proposed equation through the removal of one of four identified outliers in the dataset upon which it had relied in originally promulgating the formulaic equation. This proposed change was made as a result of the Agency's apparent post-January 2018 recognition, grounded in "new information" published in a 2017 study which the Agency relied upon at the rulemaking hearings,[27] which established that "the equation would potentially be made inaccurate if the concentrations [of sulfate compared between groundwater and surface water] were significantly different."[28] A significant difference in the concentrations suggests that upwelling groundwater rather than downward-moving sediment from overlying surface water could be responsible for the "observed false positives in the MPCA data set (false positives are waterbodies for which the equation predicts that sulfide should exceed 120 micrograms per liter, but the sulfide is less than 120)."[29] Having found the concentrations to be materially different in four water bodies, but only having data documenting the fact of upwelling groundwater in one of the four (Second Creek), the Agency proposes removal of this one outlier water body

[25] *Id*. at 4.
[26] Minn. Stat. § 14.05 (2016).
[27] *See* Hearing Exhibit L.2, Ng et al., 2017.
[28] MPCA Resubmissions, Attachment 6 at 1.
[29] *Id.*

from the data set. The result of this removal is a resulting in a change in the mathematical terms included in the equation.[30]

The Agency's newly-submitted revision, based on the exclusion of one outlier in the data set, is based on information available at the time of hearings. This indicates that the Agency's discernment of the proper criteria for inclusion/non-inclusion in the proposed equation-based standard continues to evolve. While this is laudatory, it supports the view expressed at hearing that the proposed standard is too much a continuing work-in-progress to be adopted as an enforceable rule.

By law, a rule is defined as an "agency statement of general applicability and future effect, including amendments, suspensions, and repeals of rules, adopted to implement or make specific the law enforced or administered by that agency or to govern its organization or procedure."[31] It is not difficult to understand how the public questions whether a standard that is unknowable until sufficiently sampled and calculated over a period of ten years, which consists of an equation with mathematical terms that continue to evolve even before adoption, can constitute a rule by which their actions can be regulated.

(2) Inserted Caps

In the proposed revised standard, the MPCA sets minimum and maximum sulfate limits separate and apart from the site-specific limits derived from the equation calculation in proposed rule Minn. R. 7050.0224, subd. 5(B). Functioning as boundaries on the standard, the Agency proposes that the minimum numeric expression of the sulfate standard would be 0.5 milligrams per liter and the maximum numeric expression of the standard would be 335 milligrams per liter.[32]

The insertion of capped boundaries appears to be a prudent and reasonable change to the proposed standard. The Chief Administrative Law Judge notes, however, that the public has had no opportunity to comment regarding whether these specific, proposed caps are the appropriate ones for inclusion in the proposed rule.

(3) Choosing Between Competing Values

The Administrative Law Judge disapproved the proposed rule, in part, based upon the fact that the Agency allowed for any person to measure and propose the standard for an identified water body but had provided no written, transparent process or criteria for doing so. Neither had the Agency identified what process it would rely upon when required to choose among differing, submitted numeric standards.[33]

In its Resubmissions, the Agency clarified that any person, including persons who are not MPCA staff, are allowed to calculate the allowable amount of sulfate for a

[30] *Id.*; Part 7050.0224, subp. 5, Item B.
[31] Minn. Stat. § 14.02, subd. 4 (2016).
[32] MPCA Resubmissions, Attachment 8 at 55.
[33] Report of the Administrative Law Judge at 74, Findings 308-310.

particular body of water by undertaking collection and calculation processes in compliance with the Agency's publication titled *Sampling and Analytical Methods for Wild Rice Waters*.[34] This required technical methodology is incorporated by reference at proposed Minn. R. 7050.0224, subd. 5 (E).

In an apparent attempt to address the issue of choosing between competing and differently valued samples, the Agency's Resubmissions provide as follows:

> All data collected in a wild rice water would be used to set the numeric expression of the standard for that wild rice water. If MPCA has already collected and analyzed 15 (or more) values, then the next 15 (or more) values would be added to the calculation. Moving to a percentile approach will provide greater stability in the numeric expression of the standard – as more data is collected, the numeric expression will converge on the "true" value. This will reduce the likelihood of major changes in the calculated expression of the standard.[35]

The Chief Administrative Law Judge finds this statement to be an insufficient response to the stated concern. First, the statement is not contained in the language of the proposed rule; it is included only in correspondence filed with the Chief Administrative Law Judge as part of the Agency's Resubmissions. This will not become part of any published rule available for future reference or review, and will not have the force and effect of law. Second, the described process does not address the Agency's planned response when less than 15 samples are submitted. For example, assume that Measurer A samples, calculates and submits a proposed standard of .1X for an identified water and Measurer B samples, calculates and submits a proposed standard of 100X for the same body. While the Resubmissions imply that the Agency would average the two submissions into its existing 15 or more samples, that process is not explicitly stated.

In addition, the Agency's Resubmissions clearly indicate that "as more data is collected" the standard for any specified water body will continue to change.[36] In essence, then, the public will be unable to rely upon even the Agency's publication of any specified standard. As an example, consider a situation wherein a water body is sufficiently sampled and the standard calculated to be Y, a value with the Agency publishes on its website and is relied upon by the public. An hour after publication, a different measurer gathers, calculates and submits 15 additional samples to the Agency, which promptly "add[s] them to the calculation" so as to allows the standard to "converge on the 'true' value."[37] As a result, the enforceable standard is immediately changed, and the public would have no knowledge of the change absent continual monitoring of the Agency's website. In essence, the proposed standard becomes not a measuring stick, but a slide

[34] MPCA Resubmission at 4 ("the proposed wild rice rule requires sampling from specific water bodies in order to generate data needed to plug into the equation before a numeric expression can be developed and provides notice of how that data should be gathered and the numeric expression to be determined"). Part 7050.0224, subp. 5, item E.
[35] *Id*., Attachment 6 at 10.
[36] *Id.*
[37] *Id.*

rule. It is difficult to conclude that such a process could ever "give a person of ordinary intelligence a reasonable opportunity to know what is prohibited or … provide sufficient standards for enforcement."[38] Failing to do so, the proposed rule cannot withstand legal scrutiny.

Overall, it is possible that the Agency's submitted clarifications and revisions noted above may represent improvements in the proposed rule. Even so, the fact remains that none of these refinements were made available for public comment or discussion, at hearing or otherwise.

B. Repeal of existing 10 mg/L standard

In her Report disapproving the rule, the Administrative Law Judge noted the public's significant concern that increases in sulfate could lead to increases in methyl mercury, which bio-accumulates in fish and has long-term serious health effects on humans.[39] The MPCA agreed that "enhanced production of methylmercury is a significant concern,"[40] but insisted that this issue was outside the scope of this rulemaking process.[41]

In its Resubmissions, the Agency clarified that it would continue to rely on the state's existing eutrophication standards and mercury standards to ensure that all applicable water standards are met.[42] The Agency admitted that this fact was "so fundamental" to its work that it "escaped mention" in its written response to the public's comments on this issue.[43] If the Agency resubmits this rule in the future, it should include evidence in the record to support its allegations regarding its ability to ensure that all applicable water standards are met.

C. Downstream Waters: Tribes

Both the Fond du Lac Band and the Grand Portage Band of Lake Superior Chippewa have in place wild rice water quality standards that limit sulfate to 10 milligrams/liter. These standards are federally approved and not alterable by the state.[44] The Administrative Law Judge expressed a concern that loosening the sulfate standard for the state's designated waters could degrade the quality of the Bands' wild rice waters.[45]

In its Resubmissions, the Agency recognized the possibility that completing the calculation in proposed Minn. R. 7050.0224, subd. 5(B), might result in numeric expressions of the sulfate standard that are greater than 10 milligrams per liter. In such

[38] *Minnesota Chamber of Commerce v. Minnesota Pollution Control Agency*, 469 N.W.2d 100, 107 (Minn. Ct. App. 1991).
[39] Report of the Administrative Law Judge at 51-52, Findings 219-221.
[40] *Id.* at 52, Finding 220.
[41] *Id.* at 52, Finding 221.
[42] MPCA Resubmission at 5.
[43] *Id.* at 6.
[44] Minn. R. 7050.0155; Report of the Administrative Law Judge at 52, n. 326, citing Hearing Ex. 1020.
[45] Report of the Administrative Law Judge at 52-53, Findings 223-225.

cases, the Agency asserts that it would use other regulatory controls to ensure that waters flowing downstream into areas still governed by the current 10 milligram per liter standard continue to meet applicable water quality standards.[46] If this rule is resubmitted for approval, the Agency should include in the record sufficient evidence to support this assertion.

II. Proposed List of Waters

Federal law delegates to states the authority to establish designated uses of waters and to establish water quality criteria to protect those designated uses in bodies of water.[47] States are prohibited from removing a designated use, if such a use is an "existing use," unless a use with more stringent criteria is added.[48] An existing use is one "actually attained in the water body on or after November 28, 1975, whether or not it is included in the water quality standards."[49]

In the proposed rule, the Agency identified a list of approximately 1,300 waters at Minn. R. 7050.0471. The MPCA based its list upon, among other sources, a comprehensive, reviewed list compiled by the Minnesota Department of Natural Resources (DNR) in a 2008 Report to the Legislature.[50] The MPCA recognized that the DNR's list "is widely considered the most comprehensive source of information regarding where rice may be found in Minnesota" and so extensively reviewed the DNR list when making its designations.[51] In compliance with its legislative directive, the MPCA also consulted with the various Tribes when compiling its list.[52]

In making its determinations as to which water bodies would be included in the list, the MPCA did not explicitly apply the standards it intends to use in future rulemakings to determine whether a water body should be added to the list of wild rice waters.[53] Instead, the Agency used a "weight of evidence" standard to identify waters that met its criteria for "beneficial use as a wild rice water."[54] The rulemaking record does not identify each water considered and rejected for inclusion on the list, nor does it reveal on what basis the Agency rejected any proposed water from inclusion on the list.[55] The MPCA

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[46] MPCA Resubmission, at 6 ("Protection of downstream waters is required by 40 CFR 131.10(b). The MPCA already complies with this requirement and there is now a state rule that expressly requires such compliance, Minn. R. 7050.0155…. [To protect these waters, MPCA will] 'facilitate consistent and efficient implementation and coordination of water quality-related management actions' such as permits.").
[47] 40 C.F.R. § 131.3.
[48] 40 C.F.R. § 131.11(h)(1).
[49] 40 C.F.R. § 131.3(e); *See* Report of the Administrative Law Judge at 65, 68, Findings 269, 283.
[50] Report of the Administrative Law Judge at 63-64, Findings 263, 265.
[51] *Id.* at 64, Finding 265.
[52] *Id.* at 62, Finding 261.
[53] *Id.* at 67, Finding 279.
[54] *Id.* at 67, Finding 278.
[55] *Id.* at 67, Finding 279. According to its Resubmissions, the Agency recently asked the federal Environmental Protection Agency (EPA) how uses are designated and whether an existing use can be a designated use. The EPA responded in a March 5, 2018 letter to the Agency (March 28 letter, Att. 1, at 5-8). The only discussion of "existing use" is a clarification of the regulatory definition at 40 CFR 131.3 (e) ("those uses actually attained in the water body on or after November 28, 1975, whether or not they are included in the water quality standards.") The EPA explains "that existing uses are known to be 'actually

acknowledged that it may not have included in the proposed list all waters where the wild rice use has existed since Nov. 28, 1975.[56]

The Administrative Law Judge disapproved the proposed list, concluding that the MPCA's approach excluded hundreds of water bodies previously on lists from the DNR and other sources, including the 1854 Treaty Authority's 2016 and 2017 lists of wild rice waters.[57] The Administrative Law Judge determined that these exclusions violated the federal prohibition against removing a designated use if such a use is an existing use.[58] She also expressed concerns with the reasonableness of the Agency's exclusion of waters without any explicit standards or discussion.[59]

In its Resubmissions, the Agency argued that it compiled its list in consultation with the DNR and tribes, but insisted that it alone can determine what constitutes an "existing use" in Minnesota for purposes of the federal Clean Water Act (CWA).[60] Citing Minn. Stat. §§ 115.03, subd. 1(b) and 115.44, the MPCA argues that it is the only state agency with legal authority to classify waters of the state and assign designated uses.[61]

The Agency's authority is not as clear as it asserts. Minn. Stat. §§ 115.03, subd. 1(b) and 115.44 address the Agency's authority to classify waters, not specifically to determine existing uses for purposes of the CWA. While federal law provides that "the state" may determine existing uses, it does not specify which agency within a state has that unique authority.[62]

Even if the MPCA can establish that its authority trumps that of the DNR or any other state agency, it cannot establish that it is the sole decider of what constitutes an existing use for purposes of federal law. The CWA specifically authorizes certain Indian tribes to make designations as well. The Fond du Lac Band and the Grand Portage Band of Lake Superior Chippewa are both authorized to do so based on approved agreements with the federal government regarding water quality standards.[63] Both Bands agreed that, in rejecting the DNR's report and the 1854 Treaty Authority's list, the MPCA was removing waters that the Bands had already designated as having wild rice as an existing use under federal law.[64]

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attained' when theh use has actually occurred *and* the water quality necessary to support the use has been attained. EPA recognizes, however, that all necessary data may not be available to determine whether the use actually occurred or the water quality to support the use has been attained. When determining an existing use, the EPA provides substantial flexibility to states and authorized tribes to evaluate the strength of the available data . . . ." *See* MPCA Resubmissions, Attachment 1 at 8, citing 80 Fed. Reg. 51027.

[56] Report of the Administrative Law Judge at 67, Findings 280-282.

[57] *Id.* at 65, Finding 269.

[58] *Id.* at 69, Finding 287.

[59] *Id.* at 68, Finding 283.

[60] MPCA Resubmissions at 8-10.

[61] *Id.* at 9.

[62] The Chief Administrative Law Judge notes that the MPCA is designated as the "agency responsible for providing section 401 certifications for nationwide permits: under the CWA. Minn. Stat. 115.03, subd. 4a (2016).

[63] MPCA Resubmissions at 9, n 44.

[64] Report of the Administrative Law Judge at 65, Finding 269, n 395.

III. **Narrative criteria**: Minn. R. 7050.0224, subp. 6

In Part 7050.0224, subp. 6,[65] the MPCA leaves in place an existing (but slightly re-worded) narrative standard for protecting certain wild rice waters. The Administrative Law Judge disapproved this standard because it applies only to some, and not all, wild rice waters.[66] The record reveals no showing of need and/or reasonableness for distinguishing between application of the narrative standard to some waters and the numeric standard to others.[67]

In its resubmissions, the Agency clarified that establishing a sulfate limit standard for certain bodies of water designated in the proposed rule does not remove protections under the federal Clean Water Act for other bodies of water not designated in the proposed rule.[68] The Agency argued that federal law allows a narrative standard to be applied to a set of identified waters that are not the same set to which a numeric standard applies.[69]

Without more, this argument is not convincing. While federal law clearly allows for different regulatory standards for subgroups of waters, Minnesota's rulemaking statute requires an explanation for differentiating between similarly situated groups in these circumstances. The missing explanation relates to whether the differentiation is necessary and reasonable, a foundational criteria for approval of any proposed rule.

IV. Unaddressed Technical Errors[70]

The Chief Administrative Law Judge's review of the Agency's resubmissions has revealed the following instances wherein the Agency has failed to address technical errors identified as additional bases for disapproval.

A. Part 7050.0220, subp. 5a.[71]

According to a review of the 2017 rule language published at the Revisor of Statutes website, the existing rule language highlighted below continues to be missing from the proposed rule amendment.

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[65] *See* Lines 9.13 - 9.18 in 7/24/17 version and lines 56.18 - 56.23 in 3/16/18 version.
[66] Report of the Administrative Law Judge at 69, Finding 287b.
[67] Report of the Administrative Law Judge at 69-70.
[68] MPCA Resubmissions at 7 ("[H]aving different standards for different reaches is not inherently unprotective of downstream waters. As required by federal law, the MPCA has met, and will continue to meet requirements to ensure that downstream standards are protected in the permitting process. The MPCA submits that ... with respect to the proposed rule, as with all its rules, it has and is obligated to implement its rules so as to be protective of downstream uses.").
[69] *Id.*, Attachment 1 at 8-9. The EPA cited to 40 CFR 131.10(c), which provides that "States may adopt sub-categories of a use and set the appropriate criteria to reflect varying needs of such sub-categories of uses, for instance, to differentiate between cold water and warm water fisheries." The MPCA offers no explanation for distinguishing between the categories of wild rice waters.
[70] MPCA Resubmissions, Proposed Order at 7, comment 28.
[71] *See* Lines 4.19-4.24 of 7/24/17 version and lines 38.21-39.3 of 3/16/18 version.

Subp. 5a.

Cool and warm water aquatic life and habitat and associated use classes.

Water quality standards applicable to use classes 2B, 2Be, 2Bg, 2Bm, or 2D; 3A, 3B, or 3C; 4A and 4B; and 5 surface waters. See parts 7050.0223, subpart 5; 7050.0224, subpart 4; and 7050.0225, subpart 2, for class 3D, 4C, and 5 standards applicable to wetlands, respectively. The water quality standards in part 7050.0222, subpart 4, that apply to class 2B also apply to classes 2Be, 2Bg, and 2Bm. In addition to the water quality standards in part 7050.0222, subpart 4, the biological criteria defined in part 7050.0222, subpart 4d, apply to classes 2Be, 2Bg, and 2Bm.

B. Part 7050.0470, subps. 1 through 9.[72]

Based on the 2017 rule language available for review on the Revisor of Statutes website, the Agency is proposing to amend an outdated version of subparts 1-9. Subpart 1 is given as an example, below. The highlighted language is the language on the Revisor's website and noted as "published electronically on November 20, 2017." The language without highlighting is the language the Agency now presents as the current language, with proposed amendments indicated.

Subpart 1.

Lake Superior basin.

The water use classifications for the listed waters in the in the Lake Superior basin are as identified in items A to D. See parts 7050.0425 ~~and~~, 7050.0430, and 7050.0471 for the classifications of waters not listed. Thus, it appears that the Agency proposes to amend an out-of-date version of the rule. This applies to all 9 subparts of part 7050.0470.

Lake Superior basin.

The water-use classifications for the stream reaches within each of the major watersheds in the Lake Superior basin listed in item A are found in tables entitled "Beneficial Use Designations for Stream Reaches" published on the Web site of the Minnesota Pollution Control Agency at www.pca.state.mn.us/regulations/minnesota-rulemaking. The tables are incorporated by reference and are not subject to frequent change. The date after each watershed listed in item A is the publication date of the applicable table. The water-use classifications for the other listed waters in the Lake Superior basin are as identified in items B to D. See parts 7050.0425 and 7050.0430 for the classifications of waters not listed. Designated use information for water bodies can also be accessed through the agency's

[72] *See* Lines 9.21-11.13 of 7/24/17 version and lines 57.3-58.17 of 3/16/18 version.

Environmental Data Access (http://www.pca.state.mn.us/quick-links/eda-surface-water-data).

V. Approved Rule Modifications

In Attachment 7 of its Resubmissions, the Agency provides a list of 22 proposed rule changes for consideration by the Chief Administrative Law Judge. Upon review, the Chief Administrative Law Judges finds as follows:

- Proposed Rule Changes 1 – 4: Already approved in the Report of the Administrative Law Judge
- Proposed Rule Changes 5 – 8: Relate to the proposed equation-based standard and not approved for the reasons specified in the Report of the Administrative Law Judge and this Order.
- Proposed Rule Changes 9 – 11: Already approved in the Report of the Administrative Law Judge
- Proposed Rule Changes 12 – 13: Approved as related to Proposed Rule Change 11
- Proposed Rule Changes 14 – 16: Approved as minor clarifications
- Proposed Rule Changes 17 – 21: Already approved in the Report of the Administrative Law Judge
- Proposed Rule Change 22: Not approved for the reasons set forth in the Report of the Administrative Law Judge and this Order.

Based upon a review of the rulemaking docket, the Report of the Administrative Law Judge, the Report of the Chief Administrative Law Judge and the Agency's Resubmissions, the Chief Administrative Law Judge issues the following:

ORDER

1. The proposed rules, dated July 27, 2017, as modified by the Agency's Resubmissions, remain disapproved for the reasons set forth in the Report of the Administrative Law Judge, as modified and or clarified by the provisions of this Order.

2. Pursuant to Minn. Stat. 14.15, subd. 4, if the Agency elects not to correct the identified defects as identified in the Report of the Chief Administrative Law Judge, the Agency shall submit the proposed rule to the Legislative Coordinating Commission

and to the legislative policy committees with primary jurisdiction over state governmental operations for advice and comment. The Agency may not adopt the rule until it has either: received and considered the advice of the commission and committees; or 60 days have passed following the Agency's submission of the rule to the commission and committees.

Dated: April 12, 2018

TAMMY L. PUST
Chief Administrative Law Judge

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March 28, 2018

Chief Administrative Law Judge Tammy L. Pust
Office of Administrative Hearings
P.O. Box 64620
600 Robert Street North
St. Paul, MN 55101

Re: In the Matter of Proposed Rules of the Minnesota Pollution Control Agency Amending the Sulfate Water Quality Standard Applicable to Wild Rice and Identification of Wild Rice Waters

OAH Docket # 80-9003-34519, Revisor ID #4324

Dear Judge Pust:

The Minnesota Pollution Control Agency (MPCA) submits this letter in response to the Report of the Chief Administrative Law Judge dated January 11, 2018, In the Matter of the Proposed Rules of the Pollution Control Agency Amending the Sulfate Water Quality Standard Applicable to Wild Rice and Identification of Wild Rice Waters (Report) (OAH 80-9003-34519). Below, MPCA addresses specific grounds for disapproval of the proposed rule amendment and the proposed changes or actions noted by the Chief Administrative Law Judge (CALJ) as necessary for approval of the disapproved rules.

The Proposed Equation-Based Sulfate Standard Should Be Approved

The proposed equation-based sulfate standard in Minn. R. 7050.0224, subp. 5, B (1), was disapproved by the Administrative Law Judge (ALJ).[1] Underlying the disapproval is the determination that a numeric standard presented in the form of an equation from which a numeric expression or value is derived based on parameters or values for which data collection will be required is not a valid form for a water quality standard and is not protective.[2] Specifically, the ALJ found that the proposed standard is not rationally related to the Agency's objective (1400.2100B),[3] that the use of such a standard is unconstitutionally void for vagueness (1400.2100E),[4] that this form of standard cannot have the force and effective of law within 5 days of adoption (1400.2100G),[5] and that "the MPCA failed to make an affirmative presentation of facts that implementation of the equation-based standard, or the alternate standard, would provide for the attainment and maintenance of the water quality standards to known downstream waters."

While disapproving the proposed rule, the Report contained several findings confirming that the MPCA did demonstrate by affirmative presentation of facts and sufficient evidence that the proposed equation-based standard was needed and reasonable, rational from a scientific standpoint, and

[1] Report of the Chief Administrative Law Judge In the Matter of the Proposed Rules of the Pollution Control Agency Amending the Sulfate Water Quality Standard Applicable to Wild Rice and Identification of Wild Rice Rivers, Minnesota Rules parts 7050.0130, 7050.0220, 7050.0224, 7050.0470, 7050.0471, 7053.0135, 7053.0205, and 7053.0406 (Report) (OAH 80-9003-34519), January 11, 2018, Findings 246 – 248 and 258, pages 58 and 61
[2] *Ibid.*
[3] *Id.* at Finding 246
[4] *Id.* at Finding 247
[5] *Id.* at Finding 248

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"describes a manner of calculating a sulfate level resulting in a level of sulfide in porewater protective of wild rice."[6] These findings support approval of the proposed rule if the stated grounds for disapproval can be overcome. The following paragraphs address the stated grounds for disapproval.

Equation-based Standards Are Established and Protective Expressions of a Numeric Standard

Numeric standards may be either specific or equation-based. In developing the proposed rule, MPCA has used the established and valid process of developing an equation-based standard that results in a numeric expression of that standard; this is not in conflict with or contrary to the Clean Water Act (CWA) or other law. In fact, the development of equations as water quality standards under the CWA is supported by the U.S. Environmental Protection Agency (EPA). In its March 5, 2018, letter to the MPCA,[7] EPA points to publicly available documents or references that demonstrate its support for and use of equation-based standards. In the Executive Summary of its 1985 Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses,[8] EPA discusses development of a numeric criteria, noting that a concentration or criteria may justifiably be made a function of a water quality characteristic (i.e., value or parameter such as pH, salinity, or hardness).[9] In other words, an equation may be used as a standard to address situations where the effect of the pollutant of concern varies based on another water quality characteristic(s).

Similar methods of deriving protective criteria for waters in the Great Lakes basin are described in 40 CFR 132.[10] (These and other methodologies have been incorporated by reference into Minn. Rule 7052.0015.) EPA has expressed criteria for cadmium, chromium III, lead, nickel, silver and zinc as equations as a function of hardness.[11] EPA points out further examples of the use of equation-based standards for copper using the Copper Biotic Ligand Model (BLM) that expresses the criteria for copper as an equation as function of multiple characteristics (parameters), temperature, pH, dissolved organic carbon (DOC), calcium, magnesium, potassium, sulfate, chloride and alkalinity.[12] EPA also referenced its 2013 Ammonia Criteria and its pending draft Aluminum Criteria, both expressed as an equation as a function of multiple characteristics.[13,14] (Minnesota has equation-based metals standards; MPCA has not yet adopted the copper BLM, ammonia, or aluminum criteria into rule, but expects to do so in the future.) These examples demonstrate that EPA is increasingly recognizing the need for standards that vary based on specific water quality characteristics. If MPCA cannot adopt such criteria, Minnesota's water quality rules will increasingly diverge from the national guidance and those of other states and will fail to reflect the latest water quality science.

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[6] *Id.* at Findings 251, 256 and 257

[7] See Attachment 1, EPA 3/5/2018 letter to MPCA, pages 1-4

[8] See 1985 Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses; (https://www.epa.gov/wqc/guidelines-deriving-numerical-national-water-quality-criteria-protection-aquatic-organisms-and). Note also that EPA uses the phrasing of numeric or narrative "criteria" where MPCA refers to the numeric or narrative "standard"

[9] *Id.* at page iv.

[10] See 40 CFR 132, Appendix A to Part 132 - Great Lakes Water Quality Initiative Methodologies for Development of Aquatic Life Criteria and Values; and Appendix D to Part 132 - (Great Lakes Water Quality Initiative Methodology for the Development of Wildlife Criteria)

[11] National Recommended Water Quality Criteria - Aquatic Life Criteria Table; (https://www.epa.gov/wqc/national-recommended-water-quality-criteria-aquatic-life-criteria-table#b). See for example Appendix B

[12] EPA Copper Biotic Ligand Model, (https://www.epa.gov/wqs-tech/copper-biotic-ligand-model)

[13] Final Aquatic Life Ambient Water Quality Criteria For Ammonia-Freshwater 2013 webpage; (https://www.federalregister.gov/documents/2013/08/22/2013-20307/final-aquatic-life-ambient-water-quality-criteria-for-ammonia-freshwater-2013)

[14] EPA Aquatic Life Criteria; (https://www.epa.gov/sites/production/files/2017-07/documents/draft-ambient-water-quality-criteria-aluminum.pdf)

Minnesota rules include other examples of previously approved rules in which a standard was acceptably expressed in the form of an equation. Specific examples include:

1. Minn. Rule 7050.0218 FOR TOXIC POLLUTANTS: DEFINITIONS AND METHODS FOR DETERMINATION OF HUMAN HEALTH-BASED NUMERIC STANDARDS AND SITE-SPECIFIC NUMERIC CRITERIA FOR AQUATIC LIFE, HUMAN HEALTH, AND FISH-EATING WILDLIFE at subparts 2, 4 , 5 and 9, respectively, related to site-specific criteria, determining final acute values, toxicity-based criteria, wildlife-based criteria, and 10;
2. Minn. Rule 7050.0219 HUMAN HEALTH-BASED CRITERIA AND STANDARDS at subparts 13, 14, and 15, respectively, related to algorithms (i.e., equations) for establishing human health-based criteria or standards for Class 2A and Class 2Bd surface waters, algorithms for establishing human health-based criteria or standards for Class 2B, 2C and 2D surface water, and algorithms for Class 2 fish tissue;
3. Minn. Rule 7050.0222 SPECIFIC WATER QUALITY STANDARDS FOR CLASS 2 WATERS OF THE STATE; AQUATIC LIFE AND RECREATION at subparts 2, 3, and 4 (see specifically CS, FAV or MS[15] equations for cadmium, trivalent chromium, copper, lead, nickel, pentachlorophenol, silver, and zinc); and
4. Minn. Rule 7052.0100 WATER QUALITY STANDARDS at subp. 6, related water quality standards that vary with water characteristics.

Each of the above-listed rule parts or subparts provide for the use of an equation that depends upon multiple characteristics or parameters to ultimately derive a numeric expression of the criteria or standard, e.g., chronic standard, final acute value, or maximum standard. Each require sampling as a necessary part of implementing the equation-based standard. Each of these rules required and received approval by the EPA that documents that they were duly issued and protective. A recent example is provided by EPA's publicly available approval of revisions to Minn. Rule Chapters 7050 and 7052, adopted March 6, 2015.[16] In Attachment 3, EPA provided a discussion of the basis for approval, subpart by subpart, including statements indicating that the use of algorithms, equations or formula are consistent with the CWA.[17]

With respect to the proposed equation, in its comments of November 22, 2017, EPA expressly states that "[t]he approach of adopting an equation as a water quality criterion is an accepted way of presenting a water quality criterion for a pollutant that is affected by other water quality parameters" and that "the proposed criterion appears to have a scientifically sound basis and to be protective of the wild rice use, consistent with federal regulations at 40 CFR 131.11."[18]

The foregoing discussion points to the use of equation-based standards as a recognized form of standards for the protection of water quality associated with various beneficial uses. They are used for the protection of water bodies of international value, the Great Lakes, and for the protection of waters within the State of Minnesota. This form of rulemaking has previously been reviewed and evaluated under the rulemaking process prescribed by the state Administrative Procedures Act. Equation-based standards are currently in effect under Minnesota Rules and have been found to be protective of the

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[15] CS means chronic standard. FAV means final acute value. MS means maximum standard.

[16] See Attachment 2, EPA Approval Letter to MPCA, and Attachment 3, EPA's Review of Revisions to Minnesota's Water Quality Standards: Human Health Standards Methods, both dated November 5, 2015.

[17] Attachment 3, pages 39-62

[18] See Attachment 4, EPA Comment Letter to ALJ dated November 22, 2017, Enclosure at pp. 6-7

associated designated uses and classes of waters, rationally related to Agency objectives, and to provide sufficient water quality protection.

Equation-based standards are not per se unconstitutionally vague and the above-identified state rules have not been disapproved because they included standards in the form of equations. Equation-based standards do inform and give notice to regulated parties, and the public in general, of what is expected. Here, what is expected is protection of the wild rice beneficial use and the equation provides a way to determine what level of sulfate in the water column is protective of that beneficial use.[19] Equation-based standards are no less protective than a narrative standard which does not itself identify or describe how to calculate a numeric value or other mechanisms for implementation in permits. Both are statements that the designated use should be protected and both require additional steps to arrive at a numeric value, ultimately resulting in effluent limits where needed to meet the standard and protect the beneficial use. Further, equation-based standards have been determined by EPA to be consistent with the CWA and have been found to be an appropriate form of rulemaking in administrative proceedings before the Office of Administrative Hearings (OAH).

Proposed Equation-Based Numeric Standard Is Rationally Related to the Agency's Objective

Finding 246 of the Report states that the equation-based standard is not rationally related to the Agency's objective of amending the state water quality standards to protect wild rice from the impacts of elevated sulfate. This conclusion is substantially based on the supposition that an equation-based standard cannot be protective because sampling is required to gather the information needed to develop the numeric expression of the standard. However, MPCA submits that it has shown that equation-based standards are protective and are not deficient solely because sampling is needed to generate the inputs for the equation and develop a numeric expression. As is the case in the above identified state rules and federal rules and guidance, the proposed wild rice rule requires sampling from specific water bodies in order to generate data needed to plug into the equation before a numeric expression can be developed and provides notice of how that data should be gathered and the numeric expression to be determined. The numeric values derived from equation-based standards ultimately form the basis for development of effluent limits in the permitting process.

No matter the form of a standard for a particular pollutant, numeric (both specific and equation-based) or narrative, implementation via permits requires establishing an effluent limit for inclusion in a permit condition, where a limit is needed to ensure that a permitted discharge will not cause or contribute to an exceedance of the standard. Effluent limit review is case-specific and includes evaluating information such as pollution concentrations in the receiving water and the discharge (determined through water quality monitoring and sampling), flow rates of both the discharge and the receiving water, and how many sources contribute to the receiving water.

Until that information is reviewed and the effluent limit is established, no permittee can know if or to what extent they will have to treat their wastewater discharge for the given pollutant, even if the standard that the effluent limit is protecting is a single numeric value. This is not a matter of regulatory uncertainty, vagueness or indefiniteness. Rather this represents a practical reality of the water quality regulatory process and the difference between a standard, which applies to a water body, and an effluent limit, which applies to a permitted discharge. The proposed rule gives notice to regulated parties on how sampling is to be conducted and how numeric expressions of the standard will be derived.

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[19] While a specific sulfate value is not provided, the equation-based rule does provide a numeric value that regulated parties can rely upon in that the rule is designed to maintain sulfide concentrations in pore water at 120 micrograms per liter or less.

MPCA has demonstrated that the proposed use of an equation-based standard is rationally related to the Agency's objective in this proceeding, is not unconstitutionally vague, and is needed and reasonable. MPCA submits this basis for disapproval has been overcome.

The Proposed Repeal and Replacement of the 10 mg/L Sulfate Standard Should Be Approved

The proposed repeal of the 10 mg/L sulfate standard ("existing standard") at Minn. R. 7050.0220, subps. 3a, 4a, 5a, 6a and Minn. R. 7050.0224, subp. 2, was disapproved due to the Agency's failure to establish the reasonableness of the repeal, and because the repeal conflicts with the requirements of 33 U.S.C. § 1313(c), 40 C.F.R.§ 131.10(b) (2015) and Minn. R. 7050.0155 (2017). The analysis and discussion of the basis for this disapproval are found in Report Findings 217 through 229. With respect to the grounds for disapproval referenced in Finding 227, MPCA references and relies upon its above discussion addressing equation-based standards without repeating that discussion here. MPCA now addresses the remainder of the ALJ's analysis regarding the disapproval of the proposed repeal.

Impacts of Increased Sulfate on Other Pollutants; Impacts to Downstream Waters

In Report Findings 215 through 229, there is discussion regarding public comments and findings addressing:

- potential impacts of increased sulfate on other pollutants, particularly mercury;
- whether the proposed rule is "protecting the public health or welfare, enhancing the quality of water;" and
- whether the proposed water quality standards provide for the attainment and maintenance of the water quality standards of downstream waters, as required by federal and state law.

The findings reflect a misunderstanding of standard setting and implementation in the context of the CWA and the MPCA here will clarify and better explain how the proposed standard is protective, that repeal of the existing standard does not violate or conflict with other applicable rule or law, and therefore, that the proposed repeal and replacement of the current standard is reasonable.

Other Stressors

Specific comments were made that, because the proposed rule could allow increases in sulfate concentrations in some instances, other potential impacts could occur due to increases in methylation of mercury or nutrient-caused eutrophication. The MPCA was not dismissive or non-responsive to the concerns expressed by those commenters. Rather, MPCA notes now, as it did in its response to comments, that the stressor or pollutant of concern in this rulemaking is sulfate and the objective of the rulemaking is to set a standard that protects the specific beneficial use (wild rice) from that specific stressor. This the MPCA has done using a long-established and accepted form of rulemaking under the CWA. The equation-based sulfate standard, or the existing sulfate standard for that matter, does not regulate mercury or nutrient impacts on beneficial uses, including human health. Minnesota already has standards in place to address these impacts (e.g., eutrophication standards and mercury standards), and setting effluent limits requires ensuring that all applicable water quality standards will be met. See for example Minn. R. 7050.0220, subps. 3a, B. (16) and (17); and 7050.0222, subp. 3 with respect to mercury; and 7050.0220, subps. 3a (A) (11) and 7050.0222, subps. 4, 4a and 5, with respect to eutrophication. Also, MPCA has a statewide mercury reduction plan in place that includes a statewide mercury Total Maximum Daily Load (TMDL) study. The mercury TMDL has been approved by EPA in 2008 and with revisions approved in 2010, 2013 and 2014.[20] This clearly demonstrates that mercury

[20] See MPCA website at https://www.pca.state.mn.us/water/statewide-mercury-reduction-plan.

regulation is a complex, ongoing effort separately directed at that specific stressor, just as sulfate regulation in protection of the wild rice beneficial use is separately addressed by the existing standard and the proposed amendment.

Water quality standards are independently applicable to water resources to meet their specified beneficial uses, and permits must be protective of the water quality based on all applicable standards. In the course of implementation in permitting, a facility or permittee typically has to comply with multiple standards. This is not just the case for the MPCA but for EPA and other states with delegated authorities under the Clean Water Act and standard setting for most other regulatory programs.[21] This – the application of multiple standards - is so fundamental to MPCA's implementation of permitting discharges from a facility or operation that it escaped mention in the MPCA's response to comments.

As mentioned previously, a water quality standard, particularly a numeric standard, is specific to the beneficial use being protected and a specific pollutant or class of chemically similar pollutants that can negatively impact that beneficial use. Such a standard is not intended to, and practically cannot, target a broad suite of pollutants or stressors. In the Technical Support Document and exhibits presented for this rulemaking, MPCA has established that sulfate impacts wild rice independently of other known stressors. The MPCA has further established that sulfate can be detrimental to the wild rice beneficial use and is proposing to replace the existing standard for that specific stressor (sulfate) with an equation-based standard to more precisely protect this specific use from this specific stressor. As previously noted by the MPCA, water quality standards, by their nature, stand alone and do not depend on the resolution of all other issues to justify their ability to protect a beneficial use.

From the statements contained in Report Findings 215 through 226, the underlying basis for disapproval appears to be the use of an equation-based standard and the fact that the proposed rule's focus and objective is sulfate not mercury. Having demonstrated that an equation-based standard is an acceptable, protective form of standard and that there are separate and applicable standards and regulatory schemes for mercury and eutrophication to protect other beneficial uses, the MPCA submits that it has overcome the basis for disapproving the repeal of the existing standard.

Downstream Waters

The ALJ noted that "the MPCA failed to make an affirmative presentation of facts that implementation of the equation-based standard, or the alternate standard, would provide for the attainment and maintenance of the water quality standards to known downstream waters."[22] Protection of downstream waters is required by 40 CFR 131.10(b). The MPCA already complies with this requirement and there is now a state rule that expressly requires such compliance, Minn. R. 7050.0155.

The EPA document entitled *Protection of Downstream Waters in Water Quality Standards: Frequently Asked Questions* provides guidance to states in how to approach the protection of downstream uses.[23] Question 3 of this document provides possible options for developing criteria that ensure the attainment and maintenance of downstream uses. The guidance notes that "a broad narrative criterion approach may be advantageous, as such an approach is quickly and easily developed and provides basic legal coverage for a variety of water quality bodies and pollutants...Narrative criteria approaches are adaptive, allowing for protection of downstream WQS in a changing environment." The guidance also states that criteria that protect downstream waters "facilitate consistent and efficient implementation and coordination of water quality-related management actions" such as permits.

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[21] Attachment 1, pages 4-5

[22] Report, Finding 258

[23] https://nepis.epa.gov/Exe/ZyPDF.cgi/P100LIJF.PDF?Dockey=P100LIJF.PDF

This broad narrative approach is the approach that Minnesota has taken in rule. Minn. R. 7050.0155, approved by EPA, states that "All waters must maintain a level of water quality that provides for the attainment and maintenance of the water quality standards of downstream waters, including the waters of another state." The MPCA actively implements this approach in permitting and water quality management actions, ensuring that downstream uses are protected by analyzing the impact of a discharge on potentially impacted downstream reaches and setting effluent limits when needed to avoid causing or contributing to water quality standard violations in those reaches.

As noted previously, waterbodies may have different applicable water quality standards, depending on their respective beneficial uses. For instance, one reach may have health-based standards for drinking water due to the presence of a drinking water intake. This does not mean that an upstream reach must also meet a drinking water standard when no drinking water intake is present. It simply means that the analysis of what effluent limits are needed must evaluate the standards in all downstream reaches, including the standards of other States or Tribes where the discharge impacts their waters, and ensure the discharge is protective of those reaches.

Therefore, the MPCA finds that having different standards for different reaches is not inherently unprotective of downstream waters. As required by federal law, the MPCA has met, and will continue to meet requirements to ensure that downstream standards are protected in the permitting process. The MPCA submits that the foregoing affirmatively demonstrates that with respect to the proposed rule, as with all its rules, it has and is obligated to implement its rules so as to be protective of downstream uses.

Proposed Revisions to the Equation and Sampling Methodology and Other Rule Changes

The MPCA is proposing to make certain changes to the rule in response to the OAH report and the comments received. The changes include revisions to the equation and "bounding" of the equation, resulting in a maximum numeric expression of the sulfate standard of 335 mg/L and a minimum numeric expression of the sulfate standard of 0.5 mg/L. The MPCA finds that these changes follow the science around sulfate/sulfide and the impact on wild rice, are clarifying in nature, and also provide more assurances that the equation-based standard will be protective of wild rice.

The MPCA is proposing to revise proposed Minn. R. 7050.0224, subp. 5, B (1). The proposed revision is to change the equation that serves as the standard to protect wild rice from adverse impacts of sulfate. The change is proposed based on new information in a publication of a detailed study of Second Creek, which was one of the four sites identified by the MPCA as possibly affected by upwelling groundwater because sulfide levels were much lower than predicted. See Ng et al. 2017, Hearing Exhibit L.2. Based on the new information, the MPCA has determined that it was inappropriate to include Second Creek in the dataset used to develop the equation.

Having removed Second Creek from the dataset, the equation has been revised as follows:

~~Calculated~~ Numeric expression of the sulfate standard = ~~0.0000121~~ 0.0000854 x iron ~~1.923~~ 1.637

Organic carbon ~~1.197~~1.041

The MPCA is also proposing to bound the equation and to add rule language that notes that the numeric expression of the standard/calculated sulfate standard will not be below 0.5 mg/L (minimum) and may not be above 335 mg/L sulfate (maximum). This results in a maximum and minimum sulfate numeric expression of the standard. This provides notice of the minimum and maximum sulfate values that will be expected to apply to wild rice waters and addresses the issues and concerns raised by the ALJ regarding the use of an equation-based standard generally and specifically addresses those raised in Findings 225-227 and 243-248. Bounding of the equations also provides the "sulfate cap" the ALJ found to be needed and reasonable in Finding 298.

MPCA also proposes the following sampling related changes:

- Revisions to the sampling methods portion of the sampling and analytical methods, to provide more clarity on how sampling is conducted; and
- Revisions to the sampling methods and analytical document that describe how to calculate the numeric expression of the standard, now the 20th percentile value to better accommodate multiple sampling events.

The revisions to sampling and analytical methodologies are provided as Attachment 5, Sampling and Analytical Methods for Wild Rice Waters.[24] The technical basis for and reasonableness of the proposed revisions to the equation and sampling methodology are provided with detail in Attachment 6, Technical Discussion of Proposed Equation Related Changes to the Rule.[25]

The MPCA proposes additional changes to the rule besides changes related to the equation. All proposed changes are presented for consideration by the Chief Administrative Law Judge in Attachment 7, List of Proposed Rule Changes,[26] and Attachment 8, the March 16, 2018, Revisor's draft rule.[27] In Attachment 7, proposed rule changes that were previously proposed and approved are identified.

The MPCA does not believe that the proposed revisions constitute a substantial change because the changes are made in direct response to concerns raised in public comments and in the Report or are clarifying in nature.

The Proposed List of Wild Rice Waters Should Be Approved

A major component of the proposed rule replaces the existing vague reference to "water used for the production of wild rice"[28] with a specific list of water bodies to be protected as Class 4D "wild rice waters"[29] to which the equation-based sulfate standard will apply. MPCA proposed listing approximately 1300 wild rice waters.[30]

To identify wild rice waters, the MPCA engaged in a process required by the Minnesota Legislature.[31] The process required the MPCA to "designate each body of water, or specific portion thereof, to which wild rice water quality standards apply..."[32] The process also required the MPCA to "establish criteria for the waters after consultation with the Department of Natural Resources, Minnesota Indian tribes, and other interested parties and after public notice and comment. The criteria shall include, but not be limited to, history of wild rice harvests, minimum acreage, and wild rice density."[33] The MPCA satisfied all the legislative requirements by engaging in consultation, establishing criteria, and applying the criteria to identify a list of wild rice waters.[34] The proposed wild rice waters are those waters where the

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[24] See Attachment 5, Sampling and Analytical Methods for Wild Rice Waters, March 2018
[25] See Attachment 6, Technical Discussion of Proposed Equation Related Changes to the Rule
[26] See Attachment 7, List of Proposed Rule Changes
[27] See Attachment 8, Revisor's Draft Rule, March 16, 2018
[28] Minn. R. 7050.0224, subp. 2
[29] Proposed Rule Part 7050.0471, subparts 3 through 9
[30] *Ibid.*
[31] 2011 Minn. Laws, 1st Sp. Sess. ch. 2, art. 4, § 32(a)-(d)
[32] *Ibid.*
[33] *Ibid.*
[34] See Hearing Exhibit D, SONAR, pp. 36-61

MPCA determined there is sufficient information to conclude the wild rice designated[35] use is an existing use or has been an existing use since November 28, 1975.[36] Where information was currently insufficient but may be sufficient in the future, the rule provides a process for future listing of additional wild rice waters.[37]

The ALJ found, and the CALJ agreed, that the proposed list of wild rice waters excluded waters that were previously "designated" as wild rice waters in lists created by the 1854 Treaty Authority and the Minnesota Department of Natural Resources (MDNR); and that by excluding from the proposed list these previously "designated" waters, the MPCA violated the CWA because such exclusion removed a protected designated use from a water that had already been designated with that use.[38]

The 1854 Treaty Authority and MDNR Do Not Have Authority to Designate Uses Under the CWA

The disapproval is based on the faulty assumption that the 1854 Treaty Authority and the MDNR have the authority under the CWA to designate uses and that they, at some point in the past, undertook the steps necessary to designate certain waters for a wild rice-related designated use. Neither the 1854 Treaty Authority nor the MDNR has the authority to designate uses under the CWA. The MPCA is the only entity with the authority to administer the CWA in Minnesota, including the authority to classify waters of the state and assign designated uses.[39] As legislatively required, the MPCA consulted with MDNR and Minnesota Indian Tribes to identify potential wild rice waters; however, the MPCA cannot and did not delegate its statutory authority for designating uses to either the MDNR or the 1854 Treaty Authority.

As defined by the CWA, water quality standards have three components – a designated use, a "criteria"[40] to protect that use, and antidegradation.[41] Thus, designated uses are a component of water quality standards[42] and defined in federal regulations at 40 CFR § 131.3(f) as "those uses specified in water quality standards for each waterbody or segment whether or not they are being attained." In its March 5, 2018, letter to MPCA,[43] the EPA provides a description of the process for designating uses under the CWA.[44] This process requires a state to adopt designated uses in state rule and to receive EPA approval of the designations.[45] The water bodies on the 1854 Treaty Authority and MDNR lists are not

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[35] The term "designated use" is used throughout this section. It is used to have the same meaning as "beneficial use" as that term is used in the CWA. "Designated use" is also a term used in the CWA and is used here because it more accurately describes the outcome of the process of designating a beneficial use for a specific water body.
[36] *Ibid.*
[37] Proposed Rule Part 7050.0471, subpart 2
[38] ALJ Report Finding 287
[39] Minn. Stat. §§ 115.03, subd. 1(b) and 115.44
[40] The term "criteria" as used in the CWA is the same as the term "standard" in Minn. R. 7050.0210 through .0227. Thus, Minnesota's "standard" is just one component of the three CWA water quality standard components.
[41] 40 CFR § 131.10 through 131.12
[42] 40 CFR § 131.10
[43] Attachment 1, pages 5-8
[44] Note – In its 3/5/2018 letter to MPCA, the EPA uses the phrases "states and tribes" or "states and authorized tribes." The reference to tribes in these phrases is a reflection of the CWA structure which allows for tribes to apply for and receive "treatment as a state" under CWA Section 518(e). If a tribe is granted treatment as a state by the EPA, the authorized tribe can implement certain sections of the CWA on terms similar to a state within the federally recognized reservation boundaries of the tribe. However, the only tribes in Minnesota that have been granted treatment as a state authority to adopt water quality standards and designate uses are the Fond du Lac Band of Chippewa and the Grand Portage Band of Chippewa. The 1854 Treaty Authority has not applied for, nor received, treatment as a state authority under the CWA.
[45] Attachment 1, pages 5-6

designated uses because the lists have not been adopted into state rule nor approved by the EPA. Because the 1854 Treaty Authority and MDNR lists do not function to designate uses, the MPCA does not "de-list" a water body on either of those lists by not including it on the list of proposed "wild rice waters."

The disapproval also appears to be based on confusion between, or conflation of, the two separate CWA concepts of 1) the designation of a use, which is a water quality standards action that requires state rulemaking and EPA approval, and 2) existing use(s). This confusion or conflation is understandable because the MPCA used the concept of existing use to determine whether a water body should have the designated use of being a "wild rice water." The MPCA used the presence, extent, and density of wild rice as proven by a credible history of wild rice harvest combined with densities and acreage information, to support the choice to designate a particular water body as a "wild rice water." However, not all evidence is uniform or equal and it is reasonable that some water bodies were determined to not have sufficient evidence of existing wild rice use.

Existing uses describe a specific type of use. An existing use is defined at 40 CFR § 131.3(e) as "those uses actually attained in the waterbody on or after November 28, 1975, whether or not they are included in the water quality standards." States may not remove designated uses if they are existing uses.[46] The MPCA's intent in identifying wild rice waters in the proposed rule is to have a complete listing of those waters where the wild rice designated use is an "existing use" and it will be these waters that will be designated as those where the wild rice based sulfate standard will apply.[47] Among other sources of information used to determine existing wild rice uses in water bodies, the MPCA considered the 1854 Treaty Authority and MDNR lists as sources of information regarding potential water bodies with wild rice existing uses. For a variety of reasons, the MPCA did not consider some water bodies on each list as having sufficient evidence of existing wild rice use as the use is defined in the water quality standard (i.e., "The harvest and use of grains from this plant serve as a food source for wildlife and humans.").[48] Because the 1854 Treaty Authority and MDNR lists were not lists identifying designated uses (under the CWA framework), MPCA could use the lists as informational only to determine existing wild rice uses and MPCA was not required to use the entirety of the lists. However, the MPCA did consider these two sources along with other information and did include some waters from these lists amongst the waters to be listed in this rulemaking.

The Proposed List of Wild Rice Waters Should Be Approved

Because the 1854 Treaty Authority and the MDNR do not have authority to designate uses, nor did they undertake the rulemaking and EPA approval process necessary to designate uses under the CWA, their lists of wild rice waters at no time had the effect of designating a use for those waters. Furthermore, because the 1854 Treaty Authority and MDNR lists were not lists of designated uses, the exclusion of any water on those lists could not have the effect of removing a protected designated use. Therefore, the presumption upon which the disapproval of the proposed list of wild rice waters is based is fundamentally flawed and should be reversed.

Because the ALJ's finding that the proposed list of wild rice waters violates the CWA is faulty, and because the MPCA followed CWA and state law requirements in identifying wild rice waters, the MPCA requests approval of the proposed list of wild rice waters.

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[46] 40 CFR § 131.10(h)

[47] See Hearing Exhibit D, SONAR, pp. 110-111

[48] See Hearing Exhibit D, SONAR, pp. 39-54; and Minn. R. 7050.0224 subp. 1

The Narrative Standard Can Be Applied to a Subset of Specifically Designated Waters

The proposed revisions specifically identify each water to which the numeric sulfate standard is applicable, eliminating the existing phrase "water used for production of wild rice," which resulted in the need for case-by-case determination of whether a water body met the definition. Similarly, the proposed revisions (7050.0224, subp. 6) retain the list of selected wild rice waters, designated "[WR]," where the narrative standard applies, and the uses but restates the uses protected to improve grammatical expression.[49]

In Finding 287, the ALJ disapproved the application of the narrative standard because "it does not apply to all wild rice waters."

<u>A Narrative Standard Can Be Applied to a Set of Identified Waters That Are Not the Same Set of Waters to Which a Numeric Standard Applies</u>

In its March 5, 2018, letter to MPCA, the EPA clarifies that the CWA allows states to adopt "sub-categories" of designated uses.[50] The letter cites the CWA provision, 40 CFR § 131.10 (c), which provides that "States may adopt sub-categories of a use and set the appropriate criteria to reflect varying needs of such sub-categories of uses, for instance, to differentiate between cold water and warm water fisheries." The existing rule language at 7050.0224, clearly states that "*selected* wild rice waters have been specifically identified [WR]," showing (as further described in the SONAR, especially part 4.B), the clear intent to designate only some waters with wild rice as waters subject to the narrative standard. Therefore, the proposed application of the narrative standard should be upheld.

The Numeric Sulfate Standard in Current Rule Applies to the Designated Use as Defined in Minn. R. 7050.0224, Subp. 2, Not "Wild Rice Present"

In Findings 272 and 273, the ALJ summarizes an assertion from one commenter that the current numeric sulfate standard protects waters used for the production of wild rice <u>and</u> applies to wherever there is "wild rice present." This summary incorrectly expands the concept of which waters are protected by the current standard.

Minn. Rule 7050.0224, subp. 2, clearly establishes the 10 mg/L numeric sulfate standard as "applicable to water used for production of wild rice during periods when the rice may be susceptible to damage by high sulfate levels."

<u>The Phrase "wild rice present" Is Shorthand Used by the Revisor of Statutes and Is Not Controlling</u>

The Revisor of Statutes uses word processing software that has difficulty producing information in table format. Because of this constraint, the Revisor of Statutes has difficulty codifying tables associated with MPCA water quality standards rules in Minn. R. ch. 7050. One of the constraints is that only a limited number of text characters can be included in any "line" or "cell" of a water quality standard table in Minn. R. pt. 7050.0220.[51] The limitation on the number of text characters led the Revisor of Statutes to

[49] See Hearing Exhibit D, SONAR, p. 11-12

[50] Attachment 1, pages 8-9

[51] Attachment 9 contains an extract from a 1/19/1999 Memorandum from MPCA staff, Marvin Hora, to the MPCA Board Water Committee Regarding Proposed Revisions to Minn. R. ch. 7050. On page 5 of the extract is "Attachment 2" of the Memorandum that contains a list of all the proposed housekeeping changes in the rule. Item 6. on the list states, "Minn. R. pt. 7050.0220. Reformat tables of standards in 64 character width maximum... [Note: If reformatting consistent with the Revisor's Office word processing limitations is not possible, the tables will be left as is]"

create a shorthand phrase (i.e., "wild rice present"[52]) to be used in the standards tables in Minn. R. pt. 7050.0220 in place of the full designated use in Minn. R. 7050.0224, subp. 2.

The SONAR for the 1993 rule amendments to the Minn. R. 7050.0220 tables anticipated the confusion that might be caused by the use of such a shorthand phrase in a table. Page 54 of the SONAR[53] gives direction as to which provision is controlling:

> "Should any discrepancy occur between a standard listed in the proposed tables (part 7050.0220, subparts 3 through 6) and the standards listed under each use class separately (parts 7050.0221 through 7050.0227), the latter, class by class listings of standards, will be considered the correct standards for application and compliance determinations..."

This SONAR statement makes it clear that the correct standard is the standard in Minn. R. 7050.0224, subp. 2, which states that the current numeric sulfate standard is "applicable to water used for the production of wild rice during periods when the rice may be susceptible to damage by high sulfate levels." It also makes clear that the term "wild rice present" in the tables in Minn. R. 7050.0220, subparts 3 through 6, is not controlling and is merely a product of the limitations of the Revisor's word processing limitations.

The Proposed List of Wild Rice Waters Should Be Approved

In Finding 287, the ALJ appears to expand the application of the existing numeric sulfate designated use to waters that do not meet the limited standard in Minn. R. 7050.0224, subp. 2, including expanding the application to waters that meet the shorthand phrase "wild rice present." By making this substitution, the ALJ expands the application of the designated use to water bodies that are not covered by the designated use. Because the numeric sulfate standard in the current rule applies only to "waters used for production of wild rice" and not to an expanded list of water bodies where wild rice is merely present without any credible history of wild rice harvest or density or acreage information, the disapproval is not supported and should be reversed.

Response to CALJ Suggested Actions to Cure Defects

The Chief Administrative Law Judge adopted the actions suggested by the Administrative Law Judge to correct identified defects. There were three specific actions proposed to cure specific defects identified by the Administrative Law Judge. They are contained in Findings 228, 249 and 288. The MPCA submits that it has addressed the defects in its discussion above and the underlying basis for those defects have been overcome. Consequently, the MPCA requests that the Chief Administrative Law Judge confirm that the defects have been resolved and there is no need to take the suggested actions.

Conclusion

The MPCA believes that this document demonstrates that technical changes have been made to the proposed rule that reasonably address concerns raised during the public comment period and in the ALJ report. The MPCA also believes that the analysis presented here shows that:

- An equation-based standard is reasonable and in compliance with state and federal law, and the revised equation should replace the existing 10 mg/L sulfate standard;
- The proposed standard appropriately protects the specific beneficial use from the specific identified pollutant;

[52] One example found at Minn. R. 7050.0220 subp. 3a(A)(31)

[53] Attachment 10 (extract of page 53 of the 1993 SONAR for proposed amendments to Minn. R. ch. 7050)

- Minnesota rules adequately protect downstream uses; and
- The proposed rule does not remove existing designation of wild rice waters.

Therefore, the MPCA submits that the proposed rule should be approved with the modifications described above.

We welcome the opportunity to provide clarification of our remarks and proposed rule changes. If you have any questions or need clarification, please contact us.

Sincerely,

Shannon M. Lotthammer
Assistant Commissioner

ATTACHMENT 1

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION 5
77 WEST JACKSON BOULEVARD
CHICAGO, IL 60604-3590

MAR 0 5 2018

REPLY TO THE ATTENTION OF:

WQ-16J

Ms. Shannon M. Lotthammer
Assistant Commissioner
Minnesota Pollution Control Agency
520 Lafayette Road North
St. Paul, MN 55155-4194

Dear Shannon:

Thank you for your letter of February 22, 2018 where you requested that the U.S. Environmental Protection Agency (EPA) provide responses to five questions pertaining to designated uses and criteria. EPA's responses to these questions are enclosed.

If you have any questions regarding the enclosed comments, or require any additional assistance, please contact me or have your staff contact Katharine Marko of my staff. Ms. Marko may be reached at (312) 886-1473 or marko.katharine@epa.gov.

Sincerely,

Christopher Korleski
Director, Water Division

Enclosure

Enclosure

1. **Can water quality criteria be expressed as an equation? Can EPA provide examples of equation based criteria that incorporate multiple environmental factors that allow the criteria to be customized to environmental conditions in specific waterbodies?**

Yes, EPA supports the use of equations as a basis for setting water quality criteria where doing so is supported by the available scientific data. The following materials provide a synopsis of EPA's position on expression of a water quality criterion as an equation.

EPA guidance on deriving aquatic life criteria

EPA's 1985 *Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses*, provide:

> Derivation of numerical national water quality criteria for the protection of aquatic organism and their uses is a complex process (Figure 1 [omitted here, available online]) that uses information from many areas of aquatic toxicology. After a decision is made that a national criterion is needed for a particular material, all available information concerning toxicity to, and bioaccumulation by, aquatic organisms is collected, reviewed for acceptability, and sorted. If enough acceptable data on acute toxicity to aquatic animals are available, they are used to estimate the highest one-hour average concentration that should not result in unacceptable effects on aquatic organisms and their uses. If justified, this concentration is made a function of a water quality characteristic such as pH, salinity, or hardness. Similarly, data on the chronic toxicity of the material to aquatic animals are used to estimate the highest four-daily average concentration that should not cause unacceptable toxicity during a long-term exposure. If appropriate, this concentration is also related to a water quality characteristic. [Page iv, emphasis added.]
>
> F. If the acute toxicity of the material to aquatic animals apparently has been shown to be related to a water quality characteristic such as hardness or particulate matter for freshwater animals or salinity or particulate matter for saltwater animals, a Final Acute Equation should be derived based on that water quality characteristic. [Page 15, emphasis added.]
>
> V. **Final Acute Equation**
> A. When enough data are available to show that acute toxicity to two or more species is similarly related to a water quality characteristic, the relationship should be taken into account as described in Sections B-G below or using analysis of covariance. The two methods are equivalent and produce identical results. The manual method described below provides an understanding of this application of covariance analysis, but computerized versions of covariance analysis are much more convenient for analyzing large data sets. If two or more factors affect toxicity, multiple regression analysis should be used. [Page 17, emphasis added.]

> M. The Final Acute Equation is written as: Final Acute Value = $e^{(V[\ln(\text{water quality characteristic})] + \ln A - V[\ln Z])}$, where V = pooled acute slope and A = Final Acute Value at Z. Because V, A, and Z are known, the Final Acute Value can be calculated for any selected value of the water quality characteristic. [Page 18 – 19, emphasis added.]

https://www.epa.gov/sites/production/files/2016-02/documents/guidelines-water-quality-criteria.pdf.[1] The procedures contained in the federal regulations at 40 CFR 132 for deriving criteria and values to protect the uses of surface waters in the Great Lakes basin contain similar recommendations.

EPA's 304(a) criteria recommendations: EPA's published 304(a) criteria guidance [https://www.epa.gov/wqc/national-recommended-water-quality-criteria] express the criteria for cadmium, chromium III, lead, nickel, silver and zinc as equations where the value of the criterion is a function of hardness in the receiving water. EPA's current criterion recommendation for copper is expressed as an equation that is a function of temperature, pH, dissolved organic carbon (DOC), calcium, magnesium, sodium, potassium, sulfate, chloride and alkalinity (See also EPA Copper Biotic Ligand Model: https://www.epa.gov/wqs-tech/copper-biotic-ligand-model). EPA's 2007 *Factsheet: Aquatic Life Ambient Freshwater Quality Criteria; Copper 2007 Revision*, provides this description of EPA's copper criterion recommendation:

> Since EPA published the hardness-based recommendation for copper criteria in 1984, new data have become available on copper toxicity and its effects on aquatic life. The Biotic Ligand Model (BLM) – a metal bioavailability model that uses receiving water body characteristics to develop site-specific water quality criteria – utilizes the best available science and serves as the basis for the new national recommended criteria.
>
> The BLM requires ten input parameters to calculate a freshwater copper criterion (a saltwater BLM is not yet available): temperature, pH, dissolved organic carbon (DOC), calcium, magnesium, sodium, potassium, sulfate, chloride, and alkalinity. The BLM is used to derive the criteria rather than as a post-derivation adjustment as was the case with the hardness-based criteria. This allows the BLM-based criteria to be customized to the particular water under consideration.

https://nepis.epa.gov/Exe/ZyPDF.cgi/P1008J80.PDF?Dockey=P1008J80.PDF

EPA's 2013 Ammonia Criteria [https://www.epa.gov/sites/production/files/2015-08/documents/aquatic-life-ambient-water-quality-criteria-for-ammonia-freshwater-2013.pdf] are also expressed as equations that are a function of pH and temperature. The following discussion is taken from the Executive Summary:

> The criteria magnitude is affected by pH and temperature. After analysis of the new data, EPA determined that the pH and temperature relationships established in the 1999 ammonia criterion document still hold. When expressed as total ammonia nitrogen

[1] Note: The *Guidelines* contain similar recommendations pertaining to development of a Final Chronic Equation, see pp. 22 – 25.

(TAN), the effect concentrations for fish are normalized only for pH, reflecting the minimal influence of temperature on TAN toxicity to fish. For invertebrates, TAN effect concentrations are normalized for both pH and temperature. At water temperatures greater than 15.7°C, the 2013 acute criterion magnitude is determined primarily by effects on freshwater unionid mussels. At lower temperatures, the acute criterion magnitude is based primarily on effects on salmonids and other fish. Throughout the temperature range, the 2013 chronic criterion magnitude is determined primarily by the effects on freshwater mollusks, particularly unionid mussels.

At an example pH of 7 and temperature of 20°C, the 2013 acute criterion magnitude is 17 mg TAN/L and the chronic criterion magnitude is 1.9 mg TAN/L. At pH 7 and 20°C the 2013 acute criterion magnitude is 1.4-fold lower than the 1999 acute criterion magnitude. At this pH and temperature, the 2013 chronic criterion magnitude is 2.4-fold lower than the 1999 chronic criterion magnitude. See the Criterion Statements (pages 40-49) for the criterion concentrations at other pH and temperature conditions. The decreases in acute and chronic criteria magnitudes below those of 1999 reflect the inclusion of the new data discussed above.

EPA's 2017 Draft Aluminum Criteria are also expressed as a function of total hardness, pH and dissolved organic carbon as described in the Executive Summary:

This update establishes a freshwater criteria magnitude that is affected by total hardness, pH and dissolved organic carbon (DOC) and expands on the toxicity database to include those studies below pH 6.5. The criteria durations are one-hour average for acute and 4-day average for chronic, respectively, and both criteria frequencies are once in 3 years on average, consistent with the 1985 Guidelines recommendations.

Multiple linear regression (MLR) models were developed to characterize the bioavailability of aluminum in aquatic systems based on the effects of pH, hardness and DOC (DeForest et al. 2017). The authors used 22 chronic tests with the fathead minnow (*Pimephales promelas*), and 23 chronic tests with *Ceriodaphnia dubia* to evaluate the ability of MLR models to predict chronic toxicity of aluminum as a function of multiple combinations of pH, hardness, and DOC conditions. These three parameters are thought to be the most influential for aluminum bioavailability and can be used to explain the magnitude of differences in the observed toxicity values. Two models, one for invertebrates and one for vertebrates, were used to normalize freshwater aluminum toxicity values. These separate models correspond to effects on invertebrates and vertebrates due to differing effects of pH, hardness and DOC on aluminum toxicity, and therefore allow the criteria magnitudes to be a function of the unique chemistry conditions at a given site. EPA reviewed these models, published by DeForest et al (2017), and verified the results. Thus, the aluminum criteria were derived using MLR models that incorporate pH, hardness and DOC as input parameters to normalize the freshwater acute and chronic toxicity data to a set of predetermined water quality conditions based on the models published (DeForest et al. 2017) in the peer-reviewed open literature.

https://www.epa.gov/sites/production/files/2017-07/documents/draft-ambient-water-quality-criteria-aluminum.pdf.

2. Is a criteria (sic) established for a designated use and pollutant required to protect any other designated uses or from other pollutant(s)?

Water quality criteria are generally developed to protect a specific designated use. Section 303(c)(2)(A) of the Clean Water Act (CWA) discusses the adoption of new and revised water quality standards by states and authorized tribes.[2]

With respect to MPCA's question, section 303(c)(2)(A) of the CWA states, "Such revised or new water quality standard shall consist of the designated uses of the navigable water involved and the water quality criteria for such waters based upon such uses." [Emphasis added.] Note that the words "criteria" and "uses" are plural. According to 40 CFR §131.3(i) "Water quality standards are provisions of State or Federal law which consist of a designated use or uses for the waters of the United States and water quality criteria for such waters based upon such uses. Water quality standards are to protect the public health or welfare, enhance the quality of water and serve the purposes of the Act." As defined at 40 CFR § 131.3(b), water quality criteria are "elements of State water quality standards, expressed as constituent concentrations, levels, or narrative statements, representing a quality of water that supports a particular use. When criteria are met, water quality will generally protect the designated use." [Emphasis added.]
40 CFR § 131.11(a)(1) establishes the requirements for states in adopting criteria as follows:

> States must adopt those water quality criteria that protect the designated use. Such criteria must be based on sound scientific rationale and must contain sufficient parameters or constituents to protect the designated use. For waters with multiple use designations, the criteria shall support the most sensitive use.

Section 304(a) directs EPA to publish criteria recommendations to assist states in adopting criteria to protect the designated uses of their waters, "The Administrator… shall develop and publish… criteria for water quality accurately reflecting the latest scientific knowledge." Consistent with this requirement, EPA develops and makes available methods for developing criteria that correspond to specific uses. National criteria methods developed by EPA include:

> *Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses (EPA, 1985)* [https://www.epa.gov/sites/production/files/2016-02/documents/guidelines-water-quality-criteria.pdf]

> *Methodology for Deriving Ambient Water Quality Criteria for the Protection of Human Health (EPA, 2000)* [https://www.federalregister.gov/documents/2000/11/03/00-27924/revisions-to-the-methodology-for-deriving-ambient-water-quality-criteria-for-the-protection-of-human]

[2] The CWA authorizes tribes to be treated as states where they have met the requirements set forth at CWA section 518(e), 33 U.S.C. 1377(3).

Microbial (Pathogen) /Recreational Water Quality Criteria
[https://www.epa.gov/wqc/microbial-pathogenrecreational-water-quality-criteria]

Consistent with this approach, EPA's published 304(a) recommendations for specific pollutants are presented in table form with separate criteria recommendations for each pollutant for the protection of aquatic life and human health. In addition, the Final Water Quality Guidance for the Great Lakes System (EPA, 1995) includes a method for deriving water quality criteria to protect wild life uses of waters within the Great Lakes system. This approach to criteria is also found in Chapter 3 of EPA's *Water Quality Standards Handbook* available at https://www.epa.gov/wqs-tech/water-quality-standards-handbook.

3. **How are uses designated? Can an existing use be a designated use?**

Designated uses are an essential component of water quality standards. Section 303(c)(2)(A) of the CWA states that "...revised or new water quality standard(s) shall consist of the designated uses of the navigable waters involved and the water quality criteria for such waters based upon such uses," and federal regulations at 40 CFR § 131.3(i) define "water quality standards" as:

> Provisions of State or Federal law which consist of a designated use or uses for the waters of the United States and water quality criteria for such waters based upon such uses. Water quality standards are to protect the public health or welfare, enhance the quality of water and serve the purposes of the Act.

Designated uses are defined in the federal regulations at 40 CFR § 131.3(f) as "those uses specified in water quality standards for each waterbody or segment whether or not they are being attained." [Emphasis added.]

The federal regulations at 40 CFR § 131.4(a) describe states' authority with respect to the water quality standards program:

> States (as defined in §131.3) are responsible for reviewing, establishing, and revising water quality standards. As recognized by section 510 of the Clean Water Act, States may develop water quality standards more stringent than required by this regulation.

Consistent with this authority, one of states' key roles is to designate uses for surface waters within the state. According to 40 CFR § 131.10(a):

> Each State must specify appropriate water uses to be achieved and protected. The classification of the waters of the State must take into consideration the use and value of water for public water supplies, protection and propagation of fish, shellfish and wildlife, recreation in and on the water, agricultural, industrial, and other purposes including navigation.

In 2013, EPA published proposed revisions to the water quality standards regulations at 40 CFR § 131. 78 *Fed. Reg.* 54517 (September 4, 2013). The preamble to these proposed regulations includes a substantive discussion of the process for designating uses by states beginning at page 54522. Portions of the preamble discussion relevant to this question are provided below:

> Designated uses communicate a state's or tribe's environmental management objectives for its waters and drive on-the-ground water quality decision-making and improvements. To establish appropriate [water quality standards], states and tribes define the water quality goals of a water body first by designating the use(s) and second by setting criteria that protect those uses. [water quality standards] are the foundation of other CWA requirements applicable to a water body, such as [water quality-based effluent limits] for point source dischargers, as well as assessment of waters and establishment of [total maximum daily loads] for waters not meeting applicable [water quality standards].
>
> . . .
>
> Under section 303 (33 U.S.C. 1313) of the CWA, states and authorized tribes are required to develop [water quality standards] for waters of the United States within their state. [Water quality standards] shall include designated use or uses to be made of the water and criteria to protect those uses.

78 *Fed. Reg.* 54522. In the 2015 final preamble for EPA's revisions to the water quality standards regulations at 40 CFR § 131, EPA describes the distinctions between uses designated for protection under sections 101(a)(2) and 303(c)(2) of the CWA at page 51024:

> The CWA distinguishes between two broad categories of uses: uses specified in section 101(a)(2) of the Act and uses specified in section 303(c)(2) of the Act. For the purposes of this final rule, the phrase "uses specified in section 101(a)(2) of the Act" refers to uses that provide for the protection and propagation of fish, shellfish, and wildlife, and recreation in and on the water, as well as for the protection of human health when consuming fish, shellfish, and other aquatic life. A "subcategory of a use specified in section 101(a)(2) of the Act" refers to any use that reflects the subdivision of uses specified in section 101(a)(2) of the Act into smaller, more homogenous groups for the purposes of reducing variability within the group. A "non-101(a)(2) use" is a use that is not related to the protection or propagation of fish, shellfish, wildlife or recreation in or on the water. Non-101(a)(2) uses include those listed in CWA section 303(c)(2), but not those listed in CWA section 101(a)(2), including use for public water supply, agriculture, industry, and navigation.

80 *Fed. Reg.* 51019, 51024 (August 21, 2015). Consistent with the federal regulations at 40 CFR § 131.21(c), new and revised water quality standards are not effective for CWA purposes until they are approved by EPA.

40 CFR § 131.6 provides the minimum requirements for water quality standards submission:

> The following elements must be included in each State's water quality standards submitted to EPA for review:

(a) Use designations consistent with the provisions of sections 101(a)(2) and 303(c)(2) of the Act.
(b) Methods used and analyses conducted to support water quality standards revisions.
(c) Water quality criteria sufficient to protect the designated uses.
(d) An antidegradation policy consistent with §131.12.
(e) Certification by the State Attorney General or other appropriate legal authority within the State that the water quality standards were duly adopted pursuant to State law.
(f) General information which will aid the Agency in determining the adequacy of the scientific basis of the standards which do not include the uses specified in section 101(a)(2) of the Act as well as information on general policies applicable to State standards which may affect their application and implementation.

The federal regulations employ the term "existing use" to describe a specific type of use. Existing uses are defined at 40 CFR § 131.3(e) as "those uses actually attained in the waterbody on or after November 28, 1975, whether or not they are included in the water quality standards." [Emphasis added.] The concept of "existing uses" appears in the water quality standards regulations in the following locations for the specific purposes described in the regulations [Emphasis added below:]

40 CFR § 131.10 Designation of uses.
(g) States may designate a use, or remove a designated use that is *not* an existing use, if the State conducts a use attainability analysis as specified in §131.10(j) that demonstrates attaining the designated use is not feasible because of one of the six factors in this paragraph. If a State adopts a new or revised water quality standard based on a required use attainability analysis, the State shall also adopt the highest attainable use, as defined in §131.3(m).
...
(h)States may not remove designated uses if:
(1) They are existing uses, as defined in §131.3, unless a use requiring more stringent criteria is added;
...
(i) Where existing water quality standards specify designated uses less than those which are presently being attained [3], the State shall revise its standards to reflect the uses actually being attained.

40 CFR § 131.12 Antidegradation policy and implementation methods.
(a)(1) Existing instream water uses and the level of water quality necessary to protect the existing uses shall be maintained and protected.
(a)(2) Where the quality of the waters exceeds levels necessary to support propagation of fish, shellfish, and wildlife and recreation in and on the water, that quality shall be maintained and protected... In allowing such degradation or lower water quality, the State shall assure water quality adequate to protect existing uses fully.

[3] Compare to the definition of "existing use" at 40 CFR § 131.3(e), provided above.

In the 2015 final preamble for EPA's revisions to the water quality standards regulations at 40 CFR § 131, EPA provided further clarification on the definition and application of existing uses:

> The [water quality standards] regulation at § 131.3(e) defines an existing use as "those uses actually attained in the water body on or after November 28, 1975, whether or not they are included in the water quality standards." EPA provided additional clarification on existing uses in the background section of the proposed preamble, as well as in a September 2008 letter from EPA to the State of Oklahoma. Specifically, EPA explained that existing uses are known to be 'actually attained' when the use has actually occurred *and* the water quality necessary to support the use has been attained. EPA recognizes, however, that all the necessary data may not be available to determine whether the use actually occurred or the water quality to support the use has been attained. When determining an existing use, EPA provides substantial flexibility to states and authorized tribes to evaluate the strength of the available data and information where data may be limited, inconclusive, or insufficient regarding whether the use has occurred and the water quality necessary to support the use has been attained. In this instance, states and authorized tribes may decide that based on such information, the use is indeed existing.

80 *Fed. Reg.* 51027.

4. **Can a narrative criteria [sic] (standard) apply only to certain specifically designated waters, such as a subset of a certain use classification?**

Section 303(c)(2)(A) of the CWA states, "[w]henever the State revises or adopts a new standard, such revised or new standard shall be submitted to the Administrator. Such revised or new water quality standard shall consist of the designated uses of the navigable waters involved and the water quality criteria for such waters based upon such uses." 33 U.S.C. 1313 (c)(2)(A).

40 CFR § 131.3(b) defines "criteria" as, "elements of State water quality standards, expressed as constituent concentrations, levels, or narrative statements, representing a quality of water that supports a particular use. When criteria are met, water quality will generally protect the designated use."

40 CFR § 131.10 (c) provides that "States may adopt sub-categories of a use and set the appropriate criteria to reflect varying needs of such sub-categories of uses, for instance, to differentiate between cold water and warm water fisheries."

As discussed in Chapter 2 of EPA's *Water Quality Standards Handbook*:

> Subcategories of aquatic life uses may be on the basis of attainable habitat (e.g., coldwater versus warmwater habitat); innate differences in community structure and function (e.g., high versus low species richness or productivity); or fundamental differences in important community components (e.g., warmwater fish communities dominated by bass versus catfish). Special uses may also be designated to protect particularly unique, sensitive, or valuable aquatic species, communities, or habitats. [p. 6]

https://www.epa.gov/sites/production/files/2014-10/documents/handbook-chapter2.pdf

Where a State adopts sub-categories of a use, 40 CFR § 131.11 (a)(1) requires that, for each sub-category, "States must adopt those water quality criteria that protect the designated use. Such criteria must be based on sound scientific rationale and must contain sufficient parameters or constituents to protect the designated use. For waters with multiple use designations, the criteria shall support the most sensitive use." As provided at 40 CFR § 131.11 (b)(2), States may "establish narrative criteria or criteria based upon biomonitoring methods where numerical criteria cannot be established or to supplement numerical criteria."

Thus, if the State determined that a criterion (whether narrative or numeric) was required to protect one sub-category of a use applicable to a subset of surface waters but not another or where a narrative criterion was needed to supplement numerical criteria in only one sub-category of a use applicable to a subset of waters, the CWA and the regulation provides for states and authorized tribes to apply the protective narrative or numeric criterion to that sub-category of use and thus to a subset of waters.

5. **When a state determines that a water quality criterion needs to be revised, what demonstration must the state make to the EPA?**

The intent of the CWA is that water quality criteria be maintained and updated to reflect the most current science. As discussed in the answer to Question 1 above, EPA revisits its own national criteria 304(a) guidance as new information becomes available on the underlying toxicity mechanisms of various pollutants on aquatic species. Section 304(a)(1) of the CWA states:

> The Administrator, after consultation with appropriate Federal and State agencies and other interested persons, shall develop and publish, within one year after October 18, 1972 (and from time to time thereafter revise) criteria for water quality accurately reflecting the latest scientific knowledge (A) on the kind and extent of all identifiable effects on health and welfare including, but not limited to, plankton, fish, shellfish, wildlife, plant life, shorelines, beaches, esthetics, and recreation which may be expected from the presence of pollutants in any body of water, including ground water; (B) on the concentration and dispersal of pollutants, or their byproducts, through biological, physical, and chemical processes; and (C) on the effects of pollutants on biological community diversity, productivity, and stability, including information on the factors affecting rates of eutrophication and rates of organic and inorganic sedimentation for varying types of receiving waters. [Emphasis added.]

33 U.S.C. 1314(a)(1). States are also expected to hold a public hearing periodically to review and update their water quality standards as new information becomes available. CWA section 303(c), 33 U.S.C. § 1313(c), states that "The Governor of a State or the state water pollution control agency of such State shall from time to time...hold public hearings for the purpose of reviewing applicable water quality standards and, as appropriate, modifying and adopting standards. Results of such review shall be made available to the Administrator."

Pursuant to 40 CFR § 131.11 (a)(1):

> States must adopt those water quality criteria that protect the designated use. Such criteria must be based on sound scientific rationale and must contain sufficient parameters or constituents to protect the designated use. For waters with multiple use designations, the criteria shall support the most sensitive use.

Chapter 3 of EPA's *Water Quality Standards Handbook* provides additional guidance on this issue:

> In accordance with 40 CFR 131.11, states and authorized tribes must adopt water quality criteria that '...protect the designated use.' The EPA recommends that states and authorized tribes consider the Agency's national recommended water quality criteria when developing their criteria. However, states and authorized tribes may adopt, where appropriate, other scientifically defensible criteria that differ from the EPA's recommendations." Per 40 CFR 131.11(a)(1), states and authorized tribal criteria must:
>
> 1. Be based on sound scientific rationale
> 2. Contain sufficient parameters or constituents to protect the designated use
> 3. Support the most sensitive designated use of the water body

https://www.epa.gov/sites/production/files/2014-10/documents/handbook-chapter3.pdf.

Federal regulations at 40 CFR § 131.6 describe what states are required to provide to EPA when submitting new or revised water quality standards and 40 CFR § 131.5 explicitly describes what EPA must consider when reviewing a water quality standards submittal.[4] 40 CFR § 131.6 states:

> **§ 131.6 Minimum Requirements for water quality standard submission.**
> The following elements must be included in each State's water quality standards submitted to EPA for review:
> (a) Use designations consistent with the provisions of sections 101(a)(2) and 303(c)(2) of the Act.
> (b) Methods used and analyses conducted to support water quality standards revisions.
> (c) Water quality criteria sufficient to protect the designated uses.
> (d) An antidegradation policy consistent with § 131.12.
> (e) Certification by the State Attorney General or other appropriate legal authority within the State that the water quality standards were duly adopted pursuant to State law.
> (f) General information which will aid the Agency in determining the adequacy of the scientific basis of the standards which do not include the uses specified in section 101(a)(2) of the Act as well as information on general policies applicable to State standards which may affect their application and implementation.

The requirements for EPA's review of water quality standards submittals at 40 CFR § 131.5 parallel the requirements of 40 CFR § 131.6:

[4] EPA Guidance, "What is a New or Revised Water Quality Standard Under CWA 303(c)(3), Frequently Asked Questions, October 2012." https://www.epa.gov/sites/production/files/2014-11/documents/cwa303faq.pdf

§ 131.5 EPA Authority

(a) Under section 303(c) of the Act, EPA is to review and to approve or disapprove State-adopted water quality standards. The review involves a determination of:
  (1) Whether the State has adopted designated water uses that are consistent with the requirements of the Clean Water Act;
  (2) Whether the State has adopted criteria that protect the designated water uses based on sound scientific rationale consistent with § 131.11;
  (3) Whether the State has adopted an antidegradation policy that is consistent with § 131.12, and whether any State adopted antidegradation implementation methods that are consistent with § 131.12;
  (4) Whether any State adopted [water quality standards] variance is consistent with § 131.14;
  (5) Whether any State adopted provision authorizing the use of schedules of compliance for water quality-based effluent limits in NPDES permits is consistent with § 131.15;
  (6) Whether the State has followed applicable legal procedures for revising or adopting standards;
  (7) Whether the State standards which do not include the uses specified in section 101(a)(2) of the Act are based upon appropriate technical and scientific data and analyses, and
  (8) Whether the State submission meets the requirements included in § 131.6 of this part and, for Great Lakes States or Great Lakes Tribes (as defined in 40 CFR 132.2) to conform to section 118 of the Act, the requirements of 40 CFR part 132.

(b) If EPA determines that the State's or Tribe's water quality standards are consistent with the factors listed in paragraphs (a)(1) through (8) of this section, EPA approves the standards. EPA must disapprove the State's or Tribe's water quality standards and promulgate Federal standards under section 303(c)(4), and for Great Lakes States or Great Lakes Tribes under section 118(c)(2)(c) of the Act, if State or Tribal adopted standards are not consistent with the factors listed in paragraphs (a)(1) through (8) of this section.

In the case where EPA disapproves a new or revised water quality standard, if the state or authorized tribe does not adopt necessary changes to address the disapproval within 90 days, CWA 303(c)(4)(A) requires EPA to "...promptly prepare and publish proposed regulations setting forth a revised or new water quality standard."

EPA provided a similar summary of the federal requirements pertaining to water quality standards in a May 13, 2011 letter from EPA Region 5 Water Division Director to the Honorable Messrs. Thomas Bakk and David Dill of the Minnesota State Legislature regarding their request to EPA to provide its views of two draft bills that would have altered MPCA's implementation of the federally approved sulfate criterion for wild rice production waters:

> Should Minnesota choose to revise its existing water quality standards the federal regulations at 40 C.F.R. § 131.6 provide the submittal requirements. These include,

among other things, the methods and analyses conducted to support the water quality standards revisions, including how the revised water quality criteria are sufficient to protect the designated uses (see generally 40 C.F.R. § 131 Subpart B, and 40 C.F.R. §§ 131.11 and 131.20). Federal regulations require that criteria be protective of state's designated uses and EPA approval is based, among other factors, on determining that there is a scientifically defensible basis for finding that criteria are sufficient to protect designated uses (see generally 40 C.F.R. §§ 131.5, 131.11, and 131.21). Absent such showing, EPA would be unable to approve a revised criterion (see generally 40 C.F.R. § 131.6(b)). An EPA decision to approve water quality standards would be available for judicial review.

ATTACHMENT 2

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION 5
77 WEST JACKSON BOULEVARD
CHICAGO, IL 60604-3590

NOV 05 2015

REPLY TO THE ATTENTION OF:
WQ-16J

Rebecca Flood, Assistant Commissioner
Minnesota Pollution Control Agency
520 Lafayette Road North
St. Paul, Minnesota 55155-4194

Dear Ms. Flood:

The U.S. Environmental Protection Agency has completed its review of the water quality standards revisions adopted and published in the Minnesota *State Register* on March 16, 2015. The revisions were submitted to EPA Region 5 for approval with a letter dated March 25, 2015. The submission package included a letter from the State's legal counsel's office certifying that the standards were duly adopted pursuant to State law. Receipt of the newly adopted standards on March 30, 2015 initiated EPA's review pursuant to Section 303(c) of the Clean Water Act (CWA). These revisions pertained to the State's rules governing the methods used for deriving human health water quality criteria related to the protection of aquatic life (fish consumption), domestic consumption and recreational uses. Minnesota Rules, chapter 7050 (Water Quality Standards for Protection of Waters of the State) and chapter 7052 (Lake Superior Basin Water Standards) were both revised. This rule package also included revised recreational criteria applicable to waters in the Lake Superior basin to replace the 2004 federal promulgation under the Beaches Environmental Assessment and Coastal Health (BEACH) Act.

By this letter, EPA approves in accordance with Section 303(c)(2) of the CWA and 40 CFR 131.21(a)(1) the following new or revised water quality standards that were included in Minnesota's amendments as published in the Minnesota *State Register* on March 16, 2015:

> Minn. R. ch. 7050.0150, Subp. 7, Items A, B and C; Minn. R. ch. 7050.0217, Subps. 1 and 2; 7050.0218, Subps. 1-7, 9 and 10; 7050.0219, Subps. 1-15; 7050.0222, Subp. 7; 7052.0005; 7052.0010, Subps. 11, 21, 40, and 41; 7052.0100, Subp. 1; 7052.0110, Subp. 1, 3, and 4; 7052.0220, Subps. 2 and 4; and 7052.0230, Subps. 2 and 3.

EPA notes that, notwithstanding today's approval of the State's rules governing the methods used for deriving human health water quality criteria related to the protection of aquatic life, domestic consumption and recreational uses, Minnesota must submit any criteria that it derives in accordance with such methods to EPA for review and approval in accordance with Section 303(c) of the CWA. EPA's decision whether or not to approve such criteria will be based on the requirements of Section 303(c) of the CWA and applicable federal regulations at 40 CFR Part 131, taking into account the scientific information in existence at that time.

The basis for EPA's approval is set forth in the document entitled "EPA's Review of Revisions to Minnesota's Water Quality Standards: Human Health Standards Methods." This document is available upon request. The approvals in today's letter apply only to waterbodies in the State of Minnesota, and do not apply to waters that are within Indian Country, as defined in 18 U.S.C. Section 1151. EPA, or eligible Tribes, as appropriate, will retain responsibilities for water quality standards for waters within Indian Country.

Of the approved provisions, one requires additional comment.

The new *E. coli* standards applicable to the waters of Lake Superior (Minn. R. ch. 7052.0100 Subp. 1(E)).

> 40 CFR 131.41(d)(1) states that the State's adopted standards take precedence over EPA's promulgation once EPA determines that the State's adopted standards meet the requirements of the Section 303(i) of the CWA. EPA plans on removing the promulgation for Minnesota at some future time when it can be grouped with other state removals to conserve resources.
>
> EPA acknowledges that the *E. coli* rule revision applies only to recreational waters in the Lake Superior basin and in addition to meeting and replacing the requirements under the BEACH Act rule also meet the basic requirements of EPA's 2012 Revised Recreational Water Criteria. The State has informed us that they intend to adopt EPA's 2012 Revised Recreational Water Quality Criteria that will apply at non-coastal waters state-wide. As such, the revised criteria adopted in these amendments will not necessarily need to be revised as part of Minnesota Pollution Control Agency's (MPCA) planned rulemaking to adopt EPA's 2012 revised recreational criteria state-wide.

Section 7 of the Endangered Species Act (ESA) requires federal agencies to consult with the United States Fish and Wildlife Service to ensure that any federal action does not jeopardize the continued existence of any endangered or threatened species or adversely affect its critical habitat. Under 50 CFR §402.03, section 7 applies to agency actions "in which there is discretionary agency action or control." EPA has concluded that certain standards, such as those related to human health protection and antidegradation procedures, are not subject to ESA consultation since EPA lacks control or discretion under the CWA to modify its action based on other endpoints such as impacts to federally-listed threatened or endangered species. Since the rule revision EPA is approving here is related to human health, EPA has determined that consultation under the ESA is not required.

Following Executive Order 13175 and EPA's policy on consultation and coordination with Indian Tribes, Region 5 extended an invitation to consult to the eleven tribal leaders in Minnesota on March 12, 2015. An informational conference call was held on March 31, 2015, where four tribes attended. No written comments or requests to consult were received by the end of the comment period on April 17, 2015, thus concluding this consultation.

EPA congratulates the MPCA on these significant enhancements to Minnesota's water quality standards and to the expected environmental benefits that will result. We recognize and appreciate the immense effort that has gone into these rule revisions over the last several years. In particular, utilization of these new methods will result in criteria that consider and are protective of children who are often more at risk to adverse effects from environmental pollutants. The Region looks forward to working with the State as you use these new methods to develop new and revised criteria and as you make additional improvements to your standards during the next triennial review process.

If you or your staff would like to discuss this matter further, please do not hesitate to contact me at (312) 353-2147 or Tom Poleck, the review coordinator at (312) 886-0217.

Sincerely yours,

Tinka G. Hyde

Tinka G. Hyde
Director, Water Division

Enclosure

EPA'S REVIEW OF REVISIONS TO MINNESOTA'S WATER QUALITY STANDARDS: HUMAN HEALTH STANDARDS METHODS (Minn. R. ch. 7050 and 7052)[1] Adopted March 6, 2015

DATE: NOV 05 2015

CONTENTS

1 This submission is also documented and all electronic files are maintained in the Region 5 Water Quality Standards Tracking System (WQSTS) as submission number: MN2015-614. The proposed rules are documented as submission number: MN2008-223.

I. INTRODUCTION

Minnesota adopted revisions to their water quality standards rules on March 16, 2015 and submitted them to EPA Region 5 for approval with a letter dated March 25, 2015. The submission package included a letter from the Minnesota Pollution Control Agency (MPCA) Legal Counsel certifying that the standards were duly adopted pursuant to State law. Receipt of the revised standards on March 31, 2015 initiated EPA's review pursuant to §303(c) of the Clean Water Act (CWA). These revisions pertained to the State's rules governing water quality: Minnesota Rules, Chapter 7050 (Water Quality Standards for Protection of Waters of the State) and 7052 (Lake Superior Basin Water Standards) and specifically pertained to methods for deriving human health water quality standards and criteria for the protection of aquatic life (fish consumption), recreation, and drinking water. The amendments to Minn. R. ch. 7052 pertained to using the same methods as in Minn. R. ch. 7050 for waters within the Lake Superior basin and also incorporated the federal Beaches Environmental Assessment and Coastal Health (BEACH) Act *E. coli* standards that apply to coastal recreational waters of Lake Superior.

A. EPA's review for consistency with the Clean Water Act and federal regulations:

Water quality standards requirements under CWA Sections 101(a)(2), 118, and 303(c)(2) are implemented through federal regulations contained in 40 CFR Part 131 and 40 CFR Part 132. Under section 303(c) of the CWA, 33 U.S.C. § 1313(c), the EPA Administrator is charged with reviewing and approving or disapproving state-adopted new and revised water quality standards. This authority has been delegated to the ten EPA Regional Administrators and, in Region 5, further delegated to the Director of the Water Division. In making this determination, EPA must consider the following requirements of 40 CFR §131.5.

- Whether state-adopted uses are consistent with CWA requirements; *(no change to designated uses are being made with these WQS revisions)*
- Whether the state had adopted criteria protective of the adopted uses; *(Only one change was made to criteria for E. coli with these WQS amendments; see Section III.C.4(q)).*
- Whether the state has followed legal procedures for revising its standards; *(see Section II.B and C)*
- Whether state standards are based on appropriate technical and scientific data and analyses; *(see Sections II.D and III.B & C)*
- Whether the state's submission includes certain basic elements as specified in 40 CFR §131.6 as follows;
    - a) Use designations consistent with the provisions of sections 101(a)(2) and 303(c)(2) of the Act. *(no change to designated uses are being made with these WQS revisions)*
    - (b) Methods used and analyses conducted to support water quality standards revisions. *(see Sections II.D and III.B & C)*
    - (c) Water quality criteria sufficient to protect the designated uses. *(Only one change was made to criteria for E. coli with these WQS amendments; see Section III.C.4(q)).*
    - (d) An antidegradation policy consistent with § 131.12. *(no change to antidegradation provisions being made by these WQS revisions)*

  - (e) Certification by the State Attorney General or other appropriate legal authority within the State that the water quality standards were duly adopted pursuant to State law. *(See Sections II.B and C)*
  - (f) General information which will aid the Agency in determining the adequacy of the scientific basis of the standards which do not include the uses specified in section 101(a)(2) of the Act as well as information on general policies applicable to State standards which may affect their application and implementation. *(see Sections II.C and D)*
- Whether the state submission meets the requirements of 40 CFR Part 132. *(see Section III.C).*

II. SUMMARY OF SUBMITTED WQS RULE REVISIONS

A. Description of the rule revisions

Minnesota WQS rules in Minn. R. chs. 7050 and 7052 are specifically authorized in Minn. Stat. 115.3 and 115.44. Minn. Stat. 115.03 gives the MPCA the power and duty to *"(a) administer and enforce all laws relating to the pollution of any of the water of the state"* and *"(c) "to establish and alter such reasonable pollution standards for any waters of the state in relation to the public use to whichthey are or may be put as it shall deem necessary for the purposes of this chapter and, with respect to the pollution of waters of the state, chapter 116."* Minn. Stat. 115.44 subdivision 4 states that the *"agency, after proper study, and in accordance with chapter 14, shall adopt and design standards of quality and purity for each classification necessary for the public use or benefit contemplated by the classification."*

Minnesota's WQS in Minn. R. chs. 7050 and 7052 include methods and pollutant-specific numeric standards to protect the beneficial (aka designated) uses of surface waters specific to human health: drinking water, fish consumption, and recreation[2]

The adopted amendments to the human health-based water quality standards (HH-WQS)[3] methods are based on the need to incorporate advances in risk assessment approaches used by EPA, including the current human health methodology guidance from 2000 (USEPA 2000a) and more recent risk assessment guidance, and the Minnesota Department of Health (MDH) (MDH 2008), to ensure the methods in Minn. R. chs. 7050 and 7052 are based on the most recent science, public health practices, and policies for protecting surface water designated uses. The adopted amendments also provide increased state consistency in how the MPCA and MDH

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2 Class 2 surface waters include aquatic life protection as another beneficial use; therefore, toxic pollutants are also evaluated for their acute and chronic effects to aquatic organisms. In the Lake Superior basin, fish-eating wildlife are also considered when developing a chronic standard. MPCA's methods for toxic pollutants address toxicity to all these populations of interest; the final, most stringent criterion are identified as being either aquatic toxicity-, human health-, or wildlife-based (Minn. R. 7050.0218, 7050.0222 and 7052.0100).

3 To assist in describing the Chronic Standard (CS) or site-specific Chronic Criterion (CC) based on human health protection, the MPCA used the alternate term "Human Health-based Water Quality Standard" (HH-WQS).

assess human health risks. Also, given the similarities between EPA's 2000 guidance and the methods provided under the Great Lakes Initiative and adopted by Minnesota into Minn. R. ch. 7052 by reference, revisions were made so that the methods were consistent with a couple of different regional-specific values as discussed below.

The adopted amendments to the methods for deriving HH-WQS include many enhancements to both exposure assessments and toxicological evaluations. The enhancements include higher intake rates based on newer data and early life-stage protections for infants and children; multi-duration toxicological parameters; and additional evaluation approaches for environmental degradates and mixtures of toxic pollutants. New algorithms were also adopted to develop fish tissue-based HH-WQS for pollutants accumulating in fish. Although EPA's most recent guidance (USEPA 2000a) included conservative assumptions with respect to both toxicity and exposure parameters that should result in criteria adequately protective of special subpopulations, there may be some cases where the AWQC based on chronic toxicity may not provide adequate protection for the subpopulation at special risk from shorter-term exposures. EPA has therefore encouraged States to give consideration to such circumstances in deriving criteria to ensure that adequate protection is afforded to all identifiable subpopulations.

Finally, the adopted rules were revised to clarify which *E. coli* numeric WQS established under the BEACH Act rule specifically apply in the Lake Superior Basin. The BEACH Act rule criteria from EPA's 2004 promulgation are directly incorporated into Minn. R. ch. 7052. In addition to incorporating by reference the specific *E. coli* standards that apply to Lake Superior, a definition of the Federal term "recreation season" was made and is the period from April 1 to October 31; the same timeframe as the existing state-wide *E. coli* WQS already in Minn. R. ch. 7050.

B. Rule development and submittal history

These rule amendments to revise the methods used by Minnesota to derive criteria to protect human health were conceived as part of the MPCA's 2003 triennial review and were carried forward into Minnesota's 2008 triennial review. The 2008 triennial review was first public noticed as a Request for Comment (RFC) in the *State Register* on July 29, 2008. The notice indicated that MPCA was considering making revisions to its human health criteria methods. In addition to publication in the *State Register*, notice was also, mailed to the MPCA's mailing list, posted on the MPCA's website, and released through approximately 1,400 media outlets and interested parties. The July 29, 2008 notice also indicated that MPCA would be holding a series of public meetings on September 8, 9 and 15, 2008, held at the MPCA's St. Paul office and video linked to the six MPCA Regional offices. The meetings were held in accordance with CWA and other federal requirements for public hearings including public notice, presentations of the proposed revisions and recording of the meetings.

A second RFC was published in the *State Register* on March 2, 2009 with an associated comment period from March 2 to April 17, 2009. This notice identified the amendments that would be addressed and sought technical advice and comment on those areas of proposed amendment. More than 1,800 entities registered with the MPCA to receive electronic notification of this WQS rulemaking. A second series of public meetings was held November 29 and 30, 2010. Notice of these public meetings was provided, via the MPCA's Triennial Standards Review webpage as well as via postcard notification to interested parties, and E-mail notification to the persons who had indicated an interest in WQS rulemakings.

During the winter of 2012, the MPCA began transitioning to more targeted electronic communication (GovDelivery) and coordinated this with all entities on the previous mailing list. This effort resulted in more than 1,800 entities registering to receive notice of WQS rulemaking. In addition, the MPCA made use of topic-specific webpages on the MPCA website such as the general public notice webpage (*http://www.pca.state.mn.us/yrwc6a9*), the Planned Amendments to Water Quality Standards page (*http://www.pca.state.mn.us/9arfa9u*), and the rulemaking page (*http://www.pca.state.mn.us/chdfaa8*).

MPCA staff briefed the MPCA Citizen's Board (Board) in September 2003 and August 2004. Information briefings before the Board took place on November 29, 2008 and later on September 24, 2013 when the proposed human health methods rule revisions were in the form that was ultimately adopted. These Board meetings were noticed in a similar way as for any rulemaking as described above and were open to the public with comments accepted before and at the meetings. The Order Adopting Rules was signed by the MPCA Commissioner on February 18, 2015. The rules were certified as following all state administrative rules by MPCA legal counsel on March 16, 2015.

The rules proposed and published in the *State Register*, Volume 38, Number 51, pages 1634-1656, June 16, 2014, were adopted with some minor modifications in the *State Register*, Volume 39, Number 37, pages 1329-1372, March 16, 2015. On January 23, 2015 Administrative Law Judge Jeanne M. Cochrane of the Minnesota Office of Administrative Hearings issued an Order on Review approving the rules, finding that the rulemaking proceeding complied with the Minnesota Administrative Procedures Act requirements in Minn. Stat. ch 14, Minn. R. ch. 1400 and other applicable law. On February 18, 2015 MPCA Commissioner John Line Stine signed an order adopting the amendments. A Notice of Adoption of the amendments was published in the Minnesota *State Register* on March 16, 2015. The effective date of the rules is March 23, 2015. Written comments on the proposed rules were accepted along with any written request that a hearing be held on the rules until September 4, 2014. No requests for a public hearing were received. Because of the detailed materials available on this rulemaking, an extended, 80-day comment period was held to ensure ample time for interested parties to review the proposal and contact the MPCA with questions. Written public comments were received from three organizations as described in Section III.A. below along with the MPCA's responses to comments and EPA's review.

C. Documents included in the submittal

- Transmittal letter to EPA Regional Administrator Dr. Susan Hedman from MPCA Commissioner John Linc Stine dated March 31, 2015 with following 5 enclosures:
    - Office of Administrative Hearings (OAH) Docket No. 68-2200-31489, Revisor's ID: 4177 Order Adopting Rules dated February 18, 2015.

- Legal Certification of Amendments to Minn. R. chs. 7050 and 7052 (Human Health Methods and Clarification of Recreational Standards for Coastal Recreation Waters) dated March 16, 2015 from Adonis Neblett, MPCA Staff Attorney.
- Minnesota State Register, Vol. 39, No. 37, Pages 1329-1372 dated March 16, 2015.
- Adopted rules dated 1/27/15.
- Letter to Thomas Poleck, EPA Region 5 from Carol Nankivel, MPCA dated February 3, 2015 regarding early availability of the following submission documents:
  - Statement of Need and Reasonableness (SONAR): Proposed Amendments to Minn. R. chs. 7050, Relating to the Classification and Standards for Waters of the State; and 7052 Relating to Lake Superior Basin Water Standards (Human Health Methods and Clarification of Recreational Standards) dated April 22, 2014.
  - Exhibits (13) cited in SONAR including Human Health-based Water Quality Standards Technical Support Document: Water Quality Standard Amendments – Minn. R. chs. 7050 and 7052. Final draft dated January 2014.
  - Rules as proposed dated May 1, 2014.
  - Notice of Intent to Adopt Rules dated June 2, 2014 (Notice).
  - Comments received in response to the Notice and MPCA document: *Response to comments received during the public comment period on the Notice to Adopt Rules Without a Hearing for revisions to the rules governing the Classification and Standards for Waters of the State, Minnesota Rules, Chapters 7050 and 7052 (Revisor's ID #4177).*
  - MPCA's draft Order Adopting rules (which includes the MPCA's discussion of changes to the rules as proposed).
  - Review of the Administrative Law Judge (Office of Administrative Hearings (OAH 68-2200-31489) order to adopt rules dated January 23, 2015).
  - Copies of MPCA e-mails to tribal contacts providing additional notice of the amendments being proposed.
  - Rules as Adopted dated January 27, 2015, showing revisions to the rules as proposed.

D. Data and Rationale Submitted by the State in support of the WQS Rule Revision

The MPCA's authority to adopt water quality standards and to classify waters of the state is found in Minn. Stat. § 115.03 (2006), particularly subdivisions 1(b) and 1(c). Subdivision 1(b) authorizes the Agency to classify waters, while subdivision 1(c) authorizes the MPCA to "establish and alter such reasonable pollution standards for any waters of the state in relation to the public use to which they are or may be put as it shall deem necessary for the purposes of this chapter and, with respect to the pollution of waters of the state, chapter 116…"

Additional authority for adopting standards is established under Minn. Stat. § 115.44, subd. 2 and 4. Subdivisions 2 and 4. Under these statutory provisions, the MPCA has the necessary authority to adopt these WQS rules.

The primary documents in support of the rule revisions include: the associated *Statement of Need and Reasonableness* (SONAR) (MPCA 2014b) and the *Human Health-based Water Quality Standards Technical Support Document*, January 2014 (TSD) (MPCA 2014a). These two document reference numerous exhibits that were also submitted (see above). The revisions made to the human health methods are based on available and reliable scientific data and information as described in the TSD, primarily from EPA and MDH. Much of the information used was taken from more recent risk assessment guidance published by EPA since 1990. EPA's 2000 human health criteria derivation guidance (USEPA, 2000a) and the supporting technical support documents (USEPA, 2003b, USEPA 2009) were used as the basis for revisions to the bioaccumulation factor (BAF) methods and improvements in determining applicable relative source contribution (RSC) values.

III. EPA's REVIEW FOR CONSISTENCY WITH THE CWA AND FEDERAL REGULATIONS:

This section is organized in the following way. **Section A** provides EPA's review of the state's rulemaking history and public participation as previously described in Section II.B. as well as EPA's review of the public comments received during public comment periods. **Section B** provides a summary table that cites all rule changes being made along with a summary of these changes and EPA's actions regarding the changes. Certain EPA actions required a more detailed rationale than could fit into this summary table (these items are highlighted in the table with a blue background). In these cases, the more detailed rationale discussion is provided in **Section C** below.

Possible EPA actions include:

- **Approval** (where EPA has concluded that approval of certain revisions will have no effect on listed species, or is otherwise not subject to ESA consultation),
- **Approval subject to ESA consultation** (where EPA has concluded that certain revisions may effect listed species (including beneficial effects)),
- **Disapproval** (where EPA has concluded that certain revisions do not meet the requirements of the CWA or federal regulations and guidance), and
- **No EPA action** (where EPA has concluded that certain revisions are not revisions to the State's WQS and therefore do not need to be reviewed under Section 303(c) of the CWA, or that the revisions are non-substantive and do not change the meaning or implementation of the State's WQS. In these cases, the state-adopted provisions do not need EPA approval to become "applicable standards for CWA purposes" [see 40 CFR §131.21]).

A. Public participation, comments, and issues raised regarding the revised human health methods

Although MPCA called what it did in September 2008 'public meetings,' they met EPA's requirements for a 'public hearing' in that they were preceded by a greater than 45-day notice, were recorded and met other requirements for public hearings specified at 40 CFR 25.5. In addition, EPA acknowledges the extensive stakeholder and public outreach as summarized above including a final 80-day comment period.

1. Discussion of Public Comments Made During Rulemaking

Minn. Stat. ch. 14 is the state's Administrative Procedures Act (APA) that govern the state's rulemaking process. The state's formal submittal included a letter from the MPCA's Legal Services Unit dated March 16, 2015, that certified that the state had the legal authority to adopt these rules and that they were adopted in accordance with all applicable administrative procedures.

The MPCA received three comment letters, two with significant comments that required a response; the Minnesota Department of Transportation (MDOT) and the 3M Corporation. The comments were summarized along with the MPCA's responses in a document submitted with these rule amendments (see section II.C.). EPA reviewed the comments and MPCA's responses in deciding whether to approve Minnesota's new and revised water quality standards.

B. Overview summary of all rule revisions and EPA actions

Table 1 provides a comprehensive listing of all rule changes (to Minn. R. chs. 7050 and 7052) and the EPA actions being taken. Items requiring a lengthier discussion than could fit in the table appear as shaded rows and are discussed in more detail after the table in Section C.

Table 1: Comprehensive Listing of Rule Revisions to Minn. R. ch. 7050 and 7052.

Minnesota Rule Citation	Summary Description of Rule Change	EPA Action and Comments
7050.0150, Subp. 7. Impairment of waters relating to fish for human consumption. Item A.	Revised to reference new fish tissue and chronic standard methods in 7050.0218/ 7050.0219 and 7050.0222/7052.0100 respectively when implementing and evaluating narrative standards in subpart 3. New rule language changes for this item: A. In evaluating whether the narrative standards in subpart 3, which prevent harmful pesticide or other toxic pollutant residues in aquatic flora or	**Approved.** References to the new fish tissue methods were added to this subpart that must be used when implementing the narrative standards in subpart 3. EPA notes the appropriateness of this revised rule language regarding the use of the new fish tissue methods and that it is consistent with Section 303(c) of the CWA and Federal regulations at 40 CFR 131.

Minnesota Rule Citation	Summary Description of Rule Change	EPA Action and Comments
	fauna, are being met, the commissioner ~~will~~ must use the methods in: (1) parts 7050.0218 and 7050.0219 for site-specific fish tissue-based chronic criterion (CC_{ft}); or (2) parts 7050.0222 and 7052.0100 for fish tissue-based chronic standard (CS_{ft}).	
7050.0150, Subp. 7, item B.	If a fish tissue chronic standard has not been established for a pollutant with chronic standards applicable in water, the Minnesota Department of Health's fish consumption advice will be used for impairment decisions. Prior to this addition, the residue levels in fish tissue established by the MDH were used. New rule language changes for this item: B. If CS_{ft} has not been established for a pollutant with chronic standards (CS) applicable in water (CS_{dfr}, CS_{dev}, or CS_{fr}), the residue levels in fish muscle tissue established by the Minnesota Department of Health must be used to identify … [see adopted rule language for remainder of text that was not changed from current rules]	**Approved.** This revision pertains to the assessment of meeting WQS as part of the state's 303(d) program and do not constitute a change to WQS. EPA notes the appropriateness of this revised rule language regarding the use of the new fish tissue methods and that it is consistent with Section 303(c) of the CWA and Federal regulations at 40 CFR 131.
7050.0150, Subp. 7, item C.	If both a fish tissue and water column chronic standards exist for a waterbody then data from both are used to make impairment determinations. Rule text: C. When making impairment determinations in an individual water body for a pollutant with both a fish tissue-based CC_{ft} or CS_{ft} and a CS applicable in water, comparison of fish tissue data to the CC_{ft} or CS_{ft} must be the basis for the final impairment determination.	**Approved.** This revision pertains to the assessment of meeting WQS as part of the state's 303(d) program and do not constitute a change to WQS. EPA notes the appropriateness of this revised rule language regarding the use of the new fish tissue methods and that it is consistent with Section 303(c) of the CWA and Federal regulations at 40 CFR 131.
7050.0217, Objectives for Protection of Surface Waters from Toxic Pollutants.	Subpart 1. Purpose and applicability.	**Approved.** Clarifying language and citation references added to be consistent with revisions made to methods. EPA notes the appropriateness of this revised rule language and that it is consistent with Section 303(c) of the CWA and Federal regulations at 40 CFR 131.
	Subp. 2. Objectives. B. Protection of human fish consumers……**New language**: "the combined risk from	**Approved.** Rule language and citation references added to be consistent with revisions made to methods in 7050.0222.

Minnesota Rule Citation	Summary Description of Rule Change	EPA Action and Comments
	mixtures of noncarcinogens and NLC must not exceed the common health risk index endpoints or health endpoints described in part 7050.0222, subpart 7, item D:"	EPA notes the appropriateness of this revised rule language and that it is consistent with Section 303(c) of the CWA and Federal regulations at 40 CFR 131.
7050.0218. For Toxic Pollutants: Definitions and Methods for Determinations of Human Health-based Numeric Standards and Site-Specific Numeric Criteria for Aquatic Life, Human Health, and Fish-eating Wildlife.	Subpart 1. Purpose.	**Approved.** Rule language and citation references added to clarify new purpose for human health methods as pertaining to state-wide standards (chronic standards or CS) as well as the original purpose of developing site-specific criteria (chronic criteria or CC). EPA notes the appropriateness of this revised rule language and that it is consistent with Section 303(c) of the CWA and Federal regulations at 40 CFR 131.
	Subp. 2. Site-specific criteria. The Class 2 and Class 7 numeric water quality standards for toxic pollutants in parts 7050.0220, 7050.0222, 7050.0227, and 7052.0100 do not address all pollutants that may be discharged to surface waters and cause toxic effects. Therefore, methods are established in this part and part 7050.0219 to address on a site-specific basis the discharge into surface waters of toxic pollutants not listed in parts 7050.0220, 7050.0222, 7050.0227, 7052.0100. Class 2 and Class 7 site-specific numeric criteria for toxic pollutants shall be derived by the commissioner using the procedures in this part.	**Approved.** Rule language and citation references added to be clarify new purpose the criteria methods in 7050.0218 and 7050.0219 can be used to develop site-specific numeric criteria for pollutants not currently listed. EPA notes the appropriateness of this revised rule language and that it is consistent with Section 303(c) of the CWA and Federal regulations at 40 CFR 131.
	Subp. 3. Definitions Appendix A2 of the TSD (MPCA 2014a) provides a comparison table of definitions from chs. 7050 and 7052, EPA's 2000 guidance, 40 CFR 132 (GLI), and MDH Minn. R. 4717. Most of the new definitions in this subpart are from the MDH's HRL Rule and from EPA guidance.	
	C. "Adjustment factor, lifetime" or "$AF_{lifetime}$".	**Approved.** New definition to clarify term used in other sections of the rules. Actual rule language changes and discussion of approval action can be found in Section C.4(a) below
	D. "Adverse effect".	**Approved.** New definition to clarify term used in other sections of the rules. This definition is consistent with the MDH HRL Rule and with EPA guidance (USEPA 2000b, USEPA 2015).

Minnesota Rule Citation	Summary Description of Rule Change	EPA Action and Comments
	E. "Age-dependent adjustment factor" or "ADAF". (1) $ADAF_{0<2}$=10 (2) $ADAF_{2to<16}$=3 (3) $ADAF_{16+}$=1	**Approved.** New definition to clarify term used in other sections of the rules. Actual rule language changes and discussion of approval action can be found in Section C.4(a) below.
	F. "Available and reliable scientific data".	**Approved.** Addition of the term "reliable" to existing previously approved definition. This definition is consistent with the way the term is used throughout Minn. R. ch. 7050 and is consistent with current scientific understanding of this term.
	H. "Bioaccumulative chemical of concern" or "BCC".	**Approved.** Non-substantive reference to EPA previously approved definition in ch. 7052. Previously EPA approved definition is not being changed and EPA acknowledges the addition of appropriate cross references.
	J. "Biomagnification" and "Biomagnification factor" or "BMF".	**Approved.** New definition to clarify term used in other sections of the rules. This definition is consistent with EPA guidance (USEPA 2005a) and current science.
	K. "Biota-sediment accumulation factor" or "BSAF".	**Approved.** New definition to clarify term used in other sections of the rules. This definition is consistent with that in previously approved ch. 7052 and also EPA's 2000 guidance.
	L. "Cancer potency slope factor" or "CSF".	**Approved.** Revised definition to clarify term used in other sections of the rules. This definition is consistent with 40 CFR 132.
	M. "Cancer risk Level" or "CR".	**Approved.** New definition to clarify term used in other sections of the rules. This definition is consistent with Federal regulations, EPA guidance and current science.
	N. "Carcinogen, linear" or "C".	**Approved.** New definition to clarify term used in other sections of the rules. This definition is consistent with EPA Risk Assessment Guidelines.
	O. "Carcinogen, nonlinear" or "NLC".	**Approved.** New definition to clarify term used in other sections of the rules. This definition is consistent with EPA Risk Assessment Guidelines.
	Q. "Chronic criterion" or "CC" and "chronic standard" or "CS". (1) CC_{tox} or CS_{tox}. (2) CC_{dfr} or CS_{dfr}.	**Approved.** Revised definition to clarify term used in other sections of the rules. The rules distinguish between chronic criteria (site-specific) and standards

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	(3) CC_{fr} or CS_{fr}. (4) CC_{ft} or CS_{ft}. (5) CC_{w} or CS_{w}.	(state-wide). The subscripts distinguish the types of criteria or standards or the related designated uses.
	I. "Chronic Standard".	**Approved.** Old stand-alone definition deleted and combined with definition in Q above.
	T. "Criterion".	**Approval.** Addition of cross-references to applicable subparts in chs. 7050 and 7052 for the derivation of criteria. Previously EPA approved definition is not being changed and EPA acknowledges the addition of appropriate cross references.
	U. "Developmental health endpoint" or "developmental toxicity" means an adverse effect on the developing organism that may result from parental exposure prior to conception, maternal exposure during prenatal development, or direct exposure postnatally until the time of sexual maturation. Developmental toxicity may be detected at any point in the lifespan of the organism. The major manifestations of developmental toxicity include: (1) death of the developing organism; (2) structural abnormality; (3) altered growth; or (4) functional deficiency..	**Approved.** New definition to clarify term used in other sections of the rules. Discussed below in Section C.1. Health Endpoint are also consistent with EPA's *Guidelines for Carcinogen Risk Assessment* (USEPA 2005a) and EPA's IRIS Vocabulary Catalog (USEPA 2015).
	V. "Duration".	**Approved.** New definition to clarify term used in other sections of the rules. This definition is consistent with EPA guidance (USEPA 1994).
	W. "Durations for human-health based algorithms" or "D". (1) The four default D used in developing reference does and corresponding intake rates are: (a) acute: a period of 24 hours or less; (b) short-term: a period of more than 24 hours, up to 30 days; (c) subchronic: a period of more than 30 days, up to eight years….; (d) chronic: a period of more than eight years. (2) the default durations for use in the linear cancer algorithm with age	**Approved.** New definition to clarify term used in other sections of the rules. The rationale for these durations is discussed below in Section C.3. The default durations for reference dose and for linear cancer algorithms is also consistent with EPA guidance (USEPA 2002b, USEPA 2005b, USEPA 2005c, USEPA 2006b).

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	dependent adjustment factors are: (a) two years for the birth up to two-year age group; (b) 14 years for the two-up to 16-year age group, and; (c) 54 years for the 16- up to 70-year age group.	
	X. "Effect concentration" or "EC50".	**Approved.** New definition to clarify term used in other sections of the rules. This definition is consistent with 40 CFR 132.2.
	Y. "Endocrine" or "E".	**Approved.** New definition to clarify term used in other sections of the rules. This definition is consistent with EPA guidance and current science.
	AA. "Food chain multiplier" or "FCM".	**Approved.** New definition to clarify term used in other sections of the rules. This definition is consistent with Federal regulations, EPA guidance and current science.
	BB. "Frequency".	**Approved.** New definition to clarify term used in other sections of the rules. This definition is consistent with EPA guidance (USEPA 1994).
	DD. "Health risk index".	**Approved.** New definition to clarify term used in other sections of the rules. Discussion of approval action can be found in Section C.1 below.
	EE. "Health risk index endpoint" or "health endpoint".	**Approved.** New definition to clarify term used in other sections of the rules. Discussion of approval action can be found in Section C.1 below.
	FF. "Intake rate" or "IR".	**Approved.** New definition to clarify term used in other sections of the rules. This definition is consistent with EPA Risk Assessment Guidelines (USEPA 2005a).
	HH. "Lowest observable adverse effect level" or "LOAEL".	**Approved.** New definition to clarify term used in other sections of the rules. This definition is consistent with EPA's 2000 guidance (USEPA 2000a).
	II. "Magnitude".	**Approved.** New definition to clarify term used in other sections of the rules. This definition is consistent with EPA guidance (USEPA 1994).
	LL. "MDH".	**Approved.** The addition of this definition helps clarify this acronym which may prevent possible confusion and misinterpretation.
	MM. "Mode of action" or "MOA".	**Approved.** New definition to clarify term

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		used in other sections of the rules. This definition is consistent with EPA Risk Assessment Guidelines (USEPA 2005a).
	OO. "No observable adverse effect level" or "NOAEL".	**Approved.** Revised definition to clarify term used in other sections of the rules. This definition is consistent with EPA's 2000 guidance (USEPA 2000a).
	PP. "Octanol to water partition coefficient" or "K_{ow}".	**Approved.** Revised definition to clarify term used in other sections of the rules. This definition is consistent with Federal regulations, EPA guidance and current science.
	~~X. Parachor~~	**Approved.** Deleted this definition The use of parachor values was included in Minnesota's 1990 BAF methods which are being replaced with these revised methods. The term is therefore no longer relevant.
	RR. "Reference dose" or "RfD".	**Approved.** Revised definition to clarify term used in other sections of the rules. This definition is consistent with Federal regulations, EPA guidance (USEPA 2000a) and current science. Discussion of approval action can be found in Section C.1 below.
	SS. "Relative source contricution factor" or "RSC".	**Approved.** Revised definition to clarify term used in other sections of the rules. This definition is consistent with Federal regulations, EPA guidance (USEPA 2000s) and current science. Discussion of approval action can be found in Section C.3 below.
	VV. "Toxic effect".	**Approved.** New definition to clarify term used in other sections of the rules. This definition is consistent with EPA guidance and current science.
	WW. "Toxic pollutant".	**Approved.** Revised definition to clarify term used in other sections of the rules. This definition is consistent with that in previously approved ch. 7050.
	YY. "Trophic level" or "TL".	**Approved.** New definition to clarify term used in other sections of the rules. This definition is consistent with EPA guidance and current science.
	Subp. 4. Adoption of USEPA national criteria.	**Approved.** Minor editorial change to add "and human health-based" to first sentence. EPA notes the appropriateness of this rule revision to include the human health-based criteria in this subpart.

Minnesota Rule Citation	Summary Description of Rule Change	EPA Action and Comments
	Subp. 4.A.	**Approved.** Minor editorial change to clarify that this item pertains to aquatic life criteria. EPA notes the appropriateness of this rule revision to add clarity to this rule language.
	Subp. 5. Toxicity-based criteria. E and G.	**Approved.** Minor editorial change to add "CC_{tox}" to rule language to distinguish which chronic criteria is pertinent. EPA notes the appropriateness of this rule revision, to add this clarification to the rule language in this item.
	Subp. 6. Human health-based criteria. **Repealed**	**Approved.** This subpart contained provisions for deriving criteria following methods adopted in 1990 and are completely replaced by these newly adopted provisions (specifically 7050.0219, subp 13-16 as discussed below).
	Subp. 7. Bioaccumulation. **Repealed**	**Approved.** This subpart contained provisions for deriving criteria following methods adopted in 1990 and are completely replaced by these newly adopted provisions (specifically 7050.0219, subp. 6-12 as discussed below).
	Subp. 9. Wildlife-based criteria. "…based on available scientific data…" revised to "…based on available and reliable scientific data…".	**Approval.** Non-substantive editorial change. EPA notes the appropriateness of this rule revision, and that it is consistent with Section 303(c) of the CWA and Federal regulations at 40 CFR 131.
	Subp. 10. Applicable criteria or human health-based standard.	**Approved.** Actual rule language changes and discussion of approval action can be found in Section C.4(b) below.
	Subp. 10.A. Applicable criteria or standards for human health by use for Class 2A, 2Bd, 2B, 2C, and 2D…	
	Subp. 10.B. …for Class 7 waters	
	Subp. 10.C.	
	Subp. 10.D. New provision linking back to 7050.0222, subp. 7, item C.	
7050.0219. Human Health-based Criteria and Standards (Entire new Part added to ch. 7050)	Subpart 1. **Objective.** Human health-based criteria and standards protect humans from potential adverse effects of eating fish and edible aquatic organisms and incidental ingestion of water while recreating in Class 2 waters and from the consumption of drinking water from Class 1 surface waters	**Approved**. New rule language appropriately states objective of human health based criteria and standards and applicability to designated uses. EPA notes the appropriateness of this revised rule language and that it is consistent with Section 303(c) of the CWA and Federal regulations at 40 CFR 131.

Minnesota Rule Citation	Summary Description of Rule Change	EPA Action and Comments
	(includes Class 2A and 2Bd waters). Human health-based criteria and standards must be determined using the methods in this part.	
	Subp. 2. **Applicability of methods.** Human health-based chronic criteria (CC) or chronic standards (CS) must be evaluated based on the pollutant's toxicological profile: noncarcinogen or nonlinear carcinogen (NLC), developmental susceptibility, and linear carcinogen (C). A. Algorithms for these toxicological profiles by Class 2 subclasses are described in subparts 13 to 15. Other scientifically defensible algorithms may be applied by the commissioner on a chemical-specific basis for evaluating developmental susceptibility to toxic pollutants in fish tissue based on the consideration listed in subparts 3 to 5. B. The most stringent CC or CS by medium (water or fish tissue), Class 2 subclass, and toxicological profile, or taste and odor criteria as described in part 7050.0218, subpart 8, are the final applicable human health-based CC or CS.	**Approved.** This subpart provides the applicability of the methods found in subparts 13 through 15. Pollutants and corresponding methods are categorized separately for carcinogens and noncarcinogens/non-linear carcinogens following EPA guidance (USEPA 2000a). Item A also provides for the ability to use other scientifically defensible methods on a chemical-specific basis. This is consistent with EPA guidance (USEPA 1994) as an acceptable basis for deriving criteria following EPA approval. This Item B restates the requirement to chose the most stringent value for waters where multiple criteria or standards can be derived. EPA notes the appropriateness of this revised rule language and that it is consistent with Section 303(c) of the CWA and Federal regulations at 40 CFR 131.
	Subp. 3. **Available and reliable scientific data.** The data and information used to develop a site-specific CC or CS must be approved by the commissioner. The commissioner must consider measures of availability and reliability of the data and information.	**Approved.** Provision stating the need to use available and reliable data. EPA notes the appropriateness of this revised rule language and that it is consistent with Section 303(c) of the CWA and Federal regulations at 40 CFR 131.
	Subp. 4. **Toxicological values.** The RfD used to calculate criteria for noncarcinogenic and nonlinear carcinogenic chemicals (NLC) and the CSF and $AF_{lifetime}$ or CSF and ADAF used to calculate CC or CS for linear carcinogenic (C) chemicals are obtained from the MDH or developed according to parts 4717.7820, subparts 5 and 21, and 7050.0218, subpart 3.	**Approved.** Statement of sources for toxicological values. EPA notes the appropriateness of this revised rule language and that it is consistent with Section 303(c) of the CWA and Federal regulations at 40 CFR 131. This information is also discussed in more detail below in Section B.1.
	Subp. 5. **Exposure values.** Drinking water intake rates are obtained from the MDH. RSC uses a default value of 0.2 for most pollutants, unless:	**Approved.** Statement regarding the selection of RSCs using a default of 0.2 or some other value depending on available of sufficient data. This follows

Minnesota Rule Citation	Summary Description of Rule Change	EPA Action and Comments
	A. there are no significant known or potential sources other than those addressed for the designated use, then 0.5 must be used; or B. sufficient exposure data are available to support an alternative pollutant-specific value between 0.2 and 0.8.	the RSC decision tree found in EPA's 2000 guidance (USEPA 2000a). This information is also discussed in more detail below in Section C.3.
	Subp. 6. Bioaccumulation factors.	**Approved.** Actual rule language changes and discussion of approval action can be found in Section C.4(c) below.
	Subp. 7. Chemical categorization.	**Approved.** Actual rule language changes and discussion of approval action can be found in Section C.4(d) below.
	Subp. 8. Methods for baseline BAF.	**Approved.** Actual rule language changes and discussion of approval action can be found in Section C.4(e) below.
	Subp. 9. Hierarchy of acceptable baseline BAF methods.	**Approved.** Actual rule language changes and discussion of approval action can be found in Section C.4(f) below.
	Subp. 10. Species mean baseline BAF.	**Approved.** Actual rule language changes and discussion of approval action can be found in Section C.4(g) below.
	Subp. 11. Final baseline BAF by trophic level.	**Approved.** Actual rule language changes and discussion of approval action can be found in Section C.4(h) below.
	Subp. 12. Final state or site BAF by trophic level.	**Approved.** Actual rule language changes and discussion of approval action can be found in Section C.4(i) below.
	Subp. 13. Algorithms for Class 2A or 2Bd surface waters. This subpart describes human health-based criteria or standards for classes of surface waters designated for drinking water, fish consumption, and recreational uses.	**Approved.** Actual rule language changes and discussion of approval action can be found in Section C.4(j) below.
	Subp. 14. Algorithm for Class 2B, 2C, or 2D surface waters. This subpart describes human health-based criteria or standards for classes of surface waters designated for fish consumption and recreational use (nondrinking water use).	**Approved.** Actual rule language changes and discussion of approval action can be found in Section C.4(k) below.
	Subp. 15. Algorithms for Class 2 fish tissue. This subpart describes algorithms and fish tissue criteria (CC_{ft}) and standards (CS_{ft}) for chemical with BAF greater than 1,000 (BCC threshold) applicable to Class 2 surface	**Approved.** Actual rule language changes and discussion of approval action can be found in Section C.4(l) below.

Minnesota Rule Citation	Summary Description of Rule Change	EPA Action and Comments
	waters.	
7050.0222 Specific Water Quality Standards for Class 2 Waters of the State; Aquatic Life and Recreation.	Subp. 7. Additional standards; Class 2 waters. The following additional standards and requirements apply to all class 2 waters. Subparts C through F pertain to chemical mixtures.	
	Subp. 7.D	**Approved.** Actual rule language changes and discussion of approval action can be found in Section C.4(m) below.
	Subp. 7.E	**Approved.** Actual rule language changes and discussion of approval action can be found in Section C.4(n) below.
	Subp. 7.F. When monitoring indicates that chemical breakdown products or environmental degradates are present in surface water or fish tissue, those products must be considered when meeting the objectives for toxic pollutants in part 7050.0217. When no human health-based CS or other MDH health-based guidance is available for the chemical breakdown product, the CS or CC for the parent chemical must be applied for that product. The parent CS or CC must also be applied to evaluate mixtures of chemicals.	**Approved.** New provision is policy statement to use parent chemical criteria where breakdown products are detected but where no reliable criteria can be determined for the breakdown products.
	Subp. 7.G. ~~The provisions of~~ This item ~~apply~~ applies to maximum standards (MS), final acute values (FAV), and double dashes (–) in this part and part 7050.0220 marked with an asterisk (*). For carcinogenic or highly bioaccumulative chemicals with BCFs greater than 5,000 or log K_{ow} values greater than 5.19, the human health-based chronic standard (CS) may be two or more orders of magnitude smaller than the acute toxicity-based MS. ~~If the commissioner finds that a very large MS and FAV relative to the CS for such pollutants is not protective of the public health, the MS and FAV shall be reduced according to the following guidelines:~~ _______If the ratio of the MS to the CS is greater than 100, the CS times 100 ~~should~~ must be substituted for the applicable MS, and the CS times 200 ~~should~~ must be substituted for the applicable FAV. Any effluent limit derived using the procedures of this	**Approved.** Primarily nonsubstantive clarifying language changes and removal of last sentence in first paragraph. The last sentence is redundant since this capability already exists in 7050.0218, subp. 4, item C. EPA notes the appropriateness of this revised rule language and that it is consistent with Section 303(c) of the CWA and Federal regulations at 40 CFR 131.

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	item ~~should~~ must only be required after the discharger has been given notice of the specific proposed effluent limits and an opportunity to request a hearing as provided in part 7000.1800.	
7052.0005. Scope. A.	Editorial changes to add updated cross references to relevant provisions.	**Approved.** Non-substantive rule language additions to add updated clarifying cross references. EPA notes the appropriateness of this revised rule language and that it is consistent with Section 303(c) of the CWA and Federal regulations at 40 CFR 132.
7052.0010. Definitions.	Subp. 11. Criterion. Added cross reference to 7050.0219 to capture the new methods human health methods.	**Approved.** Revised definition to clarify applicability of new human health methods in 7050.0219. EPA notes the appropriateness of this revised rule language and that it is consistent with Section 303(c) of the CWA and Federal regulations at 40 CFR 132.
	Subp. 21. GLI pollutant.	**Approved.** Revised definition to clarify term used in other sections of the rules. This definition is consistent with Federal regulations, EPA guidance and current science.
	Subp. 40. Tier I. Removal of human health from the Tier I designation.	**Approved.** Revised definition to clarify term used in other sections of the rules. This definition is consistent with 40 CFR 132.2.
	Subp. 41. Tier II. Removal of human health from the Tier II designation.	**Approved.** Revised definition to clarify term used in other sections of the rules. This revision removes the use of Tier II from human health criteria as discussed in more detail below in Section C.4(o).
7052.0100 Water Quality Standards.	Subpart 1. Applicability. Subpart 1.A and B.	**Approved.** Rule language additions to add updated clarifying cross references. EPA notes the appropriateness of this revised rule language and that it is consistent with Section 303(c) of the CWA and Federal regulations at 40 CFR 131.
	Subpart 1.C. C. The definitions and methods for human health-based chronic standards and site-specific chronic criteria in parts 7050.0217 to 7050.0219 are incorporated by reference and are further described in part 7052.0110, subpart 4.	**Approved.** New provision to incorporate by reference revisions made to 7050.0217 to 7050.0219.
	Subpart 1.D. D. The Class 2A human health-based chronic standards listed in chapter 7050 are incorporated by	**Approved.** New provision to incorporate by reference the Class 2A human health criteria in ch. 7050 as modified using the

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	reference as modified by the procedures in part 7052.0110, subpart 3.	previously approved (under the GLI) lipid fractions that apply to both trophic levels 3 and 4. This latter point is also discussed in Section C.4(p) below.
	Subpart 1.E. *Escherichia (E.) coli* water quality standards for coastal recreational waters…..	**Approved.** Actual rule language changes and discussion of approval action can be found in Section C.4(q) below.
	Subpart 1.F.	**Approval.** Rule language change to distinguish subpart item F that formally was a stand alone paragraph under subp. 1. EPA notes the appropriateness of this rule revision, and that it is consistent with Section 303(c) of the CWA and Federal regulations at 40 CFR 131.
	Subpart 1.G. The CS and MS are averaged over the following durations: (1) the MS is a one-day average; (2) the CS, based on toxicity to aquatic life, is a four-day average; and (3) the CS applied in water, based on human health or wildlife toxicity, is a 30-day average.	**Approved.** This provision provides explcit mention of applicable durations for various standards to enhance implementation such as CWA 303(d) reporting. These durations are consistent with EPA guidance (USEPA 1994).
7052.0110. Methodologies for Development of Standards and Criteria and Bioaccumulation Factors.	Subpart. 1. **Applicability**. This part identifies the methods that must be used to develop aquatic life and wildlife-based Tier I and Tier II standards and criteria and human health-based chronic standards and criteria. Subparts 3 and 4 also list exceptions to some of the assumptions used in the GLI Guidance methods. These exceptions are based on Minnesota-specific data.	**Approved.** This provision was modified to maintain the Tier I and Tier II distinction for aquatic life and wildlife criteria but not for human health criteria. The newly adopted human health methods provide the ability to derive criteria based on variable datasets eliminating the need for the Tier II designation. EPA notes the appropriateness of this revised rule language and as being consistent with Section 303(c) of the CWA and Federal regulations at 40 CFR 131. This is discussed further below in Section C.4(o) for Minn. R. ch. 7052.0010, Subp. 41. Definition of Tier II.
	Subp. 3. Bioaccumulation factors. A new lipid fraction of 0.020 for TL_3 for Class 2B, 2Bd, 2C and 2D was added and the existing lipid fraction of 0.015 now only pertains to TL_4 and 0.020 for TL_3.	**Approved.** A detailed rationale for determining lipid values for non-trout waters can be found in Apprndix A5 of the TSD (MPCA 2014a). This appendix summarizes available data and determines, based on applicable fish species, a fish lipid value of 0.020 for TL_3 and 0.015 for TL_4. EPA has reviewed this information and agrees that these values are appropriate state-specific

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		values to be used when calculating BAFs under ch. 7052. EPA therefore finds that these trophic level lipid fractions are consistent with Section 303(c) of the CWA and Federal regulations at 40 CFR 132.
	Subp. 4 Human health. A.	**Approved.** The revisions to this section reflect editorial and cross-referencing to be consistent with other changes, specifically the removal of the Tier II distinction for human health criteria as discussed below in Section III.C.4(o) for Minn. R. ch. 7052.0010, Subp. 41. Definition of Tier II. This item also list out chemicals where the Tier I methodology was used in the past. EPA therefore finds that these trophic level lipid fractions are consistent with Section 303(c) of the CWA and Federal regulations at 40 CFR 132.
	Subp. 4 Human health. B.	**Approved.** This new provision mainly provides a description of how the new methods in ch. 7050 will be used within ch. 7052. This is discussed in more detail below in Section C.4(r).
	Subp. 4 Human health. C. New provision to provide use of new methods for chemical mixtures in ch. 7050.0222 to apply to ch. 7052.	**Approved.** This addition of this new provision to allow for the use of new methods for determining risks associated with chemical mixtures is an enhancement over existing methods in ch. 7052 and will lead to an improvement in protection of the applicable designated uses. This is discussed in more detail below in Section C.4(s).
7052.0220. Reasonable Potentioa for Chemical-Specific WQBELs.	Subp. 2. Developing preliminary effluent limitations	**Approved.** Strikeout of the Tier II distinction. This is discussed in more detail in Section III.C.4(o) below.
	Subp. 4 Developing data for calculating Tier II aquatic life standards and criteria or noncancer human health-based standards or site-specific criteria.	**Approved.** Clarifying rule language regarding the removal of the Tier II distinction for human health standards and criteria. This is discussed in more detail in Section III.C.4(o) below.
7052.0230. Additivity	Subp. 2. Carcinogenic human health GLI pollutant additivity.	**Approved.** Non-substantive editorial change. EPA notes the appropriateness of this rule revision, and that it is consistent with Section 303(c) of the CWA and Federal regulations at 40 CFR 131.
	Subp. 3. Noncarcinogenic human health GLI pollutant additivity.	**Approved.** Clarifying rule language regarding the use of health risk index

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		endpoints for noncarcinogenic human health GLI pollutants to make consistent with Minn. R. ch. 7050.0219, subpart 7, item D. EPA notes the appropriateness of this rule revision, and that it is consistent with Section 303(c) of the CWA and Federal regulations at 40 CFR 131.

C. Elements of Minnesota's Rules Being Approved by EPA Under Section 303 of the CWA from Table 1 with Detailed Rationale

The methods used for deriving human health criteria include three main areas of risk assessment:

1. The toxicological profile of a pollutant;
2. Identification of the population protected and at what risk level; and
3. Evaluation of the exposure routes and rates representative of that population.

The submitted revised methodology includes new and revised elements in each of these three categories and are discussed below in more detail along with EPA's assessment. These revised elements are then further discussed as they are used within each of the new and revised methodology equations.

1. Revised toxicological parameters

The table below is taken from the MPCA's SONAR document (MPCA 2014b) summarizes all of the toxicological parameters that were changed in the revised methods. Following the table is EPA's approval rationale for each of these revised parameters.

Table 1 Proposed Toxicological Parameters for Developing Human Health-based Chronic Standards

Toxicological Parameter	Abbreviation	Values and Units	Agency Methodology	Data and Information
Noncancer and NonLinear Carcinogens (NLC): Reference Doses for Four Durations	RfD_{acute} $RfD_{short-term}$ $RfD_{subchronic}$ $RfD_{chronic}$	Pollutant-specific value mg/kg-d	MDH or MPCA based on amendments	EPA IRIS, OPP, scientifically peer-reviewed data, other government or industry reports and studies (Exhibit HH-6).
Health Risk Index Endpoint	Health Endpoint	No Units	MDH or MPCA based on amendments	Based on same studies used to develop the RfD (Exhibit HH-6).
Cancer Potency Slope Factor	CSF (previously q1*)	Pollutant-specific value $(mg/kg\text{-}d)^{-1}$	MDH or MPCA based on amendments	EPA with supporting information from the National Toxicology Program (NTP) and International Agency for Research on Cancer (IARC) (Exhibit HH-6).
Adjustment Factors for Cancer Potency Slope Factors	$ADAF_{<2}$ $ADAF_{2\ to\ <16}$ $ADAF_{16\ to\ 70}$ $AF_{lifetime}$	10 3 1 Pollutant-specific	MDH or MPCA based on amendments	ADAF established in EPA and MDH Guidance; $AF_{lifetime}$ based on chemical-specific data used to develop CSF and other supporting studies (Exhibit HH-6).
Cancer Risk Level	CR	10^{-5} or 1 in 100,000	MPCA Minn. R. chs. 7050 and 7052	Policy level used by MDH and EPA (Exhibit HH-1).

One of the major goals for these WQS revisions was to make the toxicological evaluations used for developing HH-WQS consistent with the methods used by the MDH. While the MDH reviews toxicological evaluations completed by the EPA's National Center for Environmental Assessment's Integrated Risk Information System

(IRIS) and Office of Pesticide Programs (OPP), differences in the MDH's toxicological methods mean State-specific evaluations are needed to ensure consistency between the toxicological values (RfD, CSF, and AF) developed by the MDH and EPA for use by the MPCA in HH-WQS. Important differences include the MDH's more extensive review and development of less than chronic RfD and broader application of the ADAF. The MDH fully describes their toxicological methodology in the HRL Rule, Minn. R. ch. 4717, and 2008/2009 SONAR (MDH 2008). These methods follow EPA guidance and resources (e.g., IRIS) with appropriate state-specific modifications including the use of less than chronic RfDs which follow other EPA guidance (USEPA 2002b; USEPA 2005b).

$RfD_{duration}$.

This term refers to the length of an exposure period. The EPA Technical Review Panel (USEPA 2002b) recommended evaluation of less-than-chronic exposure periods to ensure adequate protection during early life (i.e. the developmental period) and periods of high intake. As part of their recommendations, the EPA Technical Review Panel provided the following definitions for the various exposure time periods:

Acute - A period of 24 hours or less.

Short-term - A period greater than 24 hours and up to 30 days.

Subchronic - A period of greater than 30 days and up to approximately 10% of the life span in humans.

Chronic - A period of greater than approximately 10% of the life span in humans.

These exposure periods are used by the MDH and are equivalent to those in the MPCA's revised methods. The MDH develops muti-durational RfDs that the MPCA will utilize these where appropriate in the new methods. If acceptable data are available, RfDs are developed for up to four durations as listed above and in Table 1.

As cited above, the use of these exposure periods is consistent with EPA guidance and adds a more refined level of calculated risk to help ensure adequate protection during early life or periods of higher intake. The magnitude of the criterion value is a function of the RfD and the intake rate. In general, for a given chemical, the shorter-duration RfD values will be higher than longer-duration RfD values because the human body can usually tolerate a higher dose when the duration of the dose is short, even if that same dose would be harmful when it occurs over a longer duration. In most cases, therefore, the calculated criteria values decrease with increasing duration, e.g., acute criteria are greater than short-term criteria, short-term criteria are greater than subchronic criteria, and so on. However, when the shorter duration RfD is paired with a higher, shorter duration exposure rate, the final standard for these durations can be more stringent than the chronic. This has relevance to ensuring that a final CS or CC meets the narrative standard of providing protection from a lifetime of exposure.

Health Risk Index Endpoint.

The new methods include the use of Health Risk Index Endpoints (Health Endpoints), as used by the MDH (MDH 2008), into certain algorithms to evaluate mixtures of noncarcinogens. The MDH lists Health Endpoints for each RfD unless the available study did not identify a specific adverse effect. Health Endpoints identify the most sensitive target organs or systems (e.g., nervous) or developmental process affected by that pollutant. These endpoints are used to group chemicals to evaluate mixtures if more than one pollutant with the same adverse effect is measured in a sample or waterbody.

Following the EPA's guidelines for mixtures (EPA 1986b, 2000b), chemicals that share the same health risk endpoint are all evaluated together. For each chemical sharing a health risk endpoint, a hazard quotient is formed by comparing the concentration of the chemical to the duration-specific criterion for that chemical. The ratios are grouped by duration, summed within each health endpoint group, and compared to the multiple-chemical health risk index of one (e.g., see equation in 7050.0222, subp. 7(D) discussed below).

The equations above follow guidelines published by EPA in 1986 (EPA 1986b). The 1986 guidelines established a hierarchical approach. Data on the defined mixture of concern are preferred, followed by data on similar defined mixtures. If data on the specific mixture or a similar mixture are not available, the guidelines recommend applying an additive model, such as the equation above, to data on mixture components. Dose additive models are not the most biologically plausible approach for compounds that do not share the same mode of toxicological action. However, since the mechanism of action for most compounds is not well understood, it is assumed that dose addition will often be limited to similarities in toxicokinetics and toxicological characteristics. Most studies on toxicity report only descriptions of the effects. EPA issued supplementary guidance in 2000 (EPA 2000b). The supplement continues the hierarchical approach, but describes more detailed procedures.7 Both documents acknowledge that data on defined whole mixtures – whether the mixture of concern or a similar mixture – are limited. Thus, the additive model is usually the default. The additive model does not account for synergism, potentiation, antagonism, masking, or inhibition, or for the absence of contaminant chemical interactions; however, the model is a reasonable approach for evaluating the health risk of multiple chemicals. EPA also suggests that based on current information, additive assumptions are expected to yield generally neutral risk estimates (i.e., neither conservative nor lenient) and are plausible for component compounds that induce similar types of health effects.

In conformity with EPA recommendations, MDH has used the most specific data available to evaluate chemicals found together in groundwater. Given limited data, however, most HRLs are derived for individual chemicals. When multiple chemicals are present, MDH uses the shared health risk index approach described above as a default to derive a duration-specific health risk index for chemicals with shared health risk endpoints. MDH encourages risk managers to use more specific data when such data are available. However, in order to safeguard public health, approaches adopted for assessing risk from multiple chemicals should always err on the side of inclusion.

Cancer Potency Slope Factors and Adjustment Factors.

The new methods make use of $AF_{Lifetime}$ and ADAFs for addressing the higher risks of early-life exposure to linear carcinogens where data concerning early life stage susceptibility are lacking (MPCA 2014a). For linear carcinogens early-life exposure resulted in: 1) a higher risk of developing cancer; 2) cancer manifestation at an earlier age; and 3) higher incidence of cancer resulting from exposure in early life stages as compared to adult exposure. The MDH followed EPA guidance that determined that for some carcinogens, data were available to develop a chemical-specific $AF_{Lifetime}$. However, for many pollutants there are insufficient data to develop this factor and a default adjustment is necessary. EPA developed the ADAF of 10, 3, and 1 for the age groups of birth to less than 2 years of age (birth to <2), 2 to less than 16 years of age (2 to <16), and 17 to 70 years of age (17-70), respectively, for application with mutagenic chemicals (USEPA 2005b). As previously stated, one of the goals for the MPCA's revised methods was to obtain consistency in the State's risk assessment methods; therefore, the MPCA adopted the MDH's methods for ADAF application to ensure the HH-WQS are meeting its protection level goals for all age groups. Adjustment factors for cancer potency slope factors are further discussed below in Section III.C.4(a).

As cited above, the use of cancer slope adjustment factors is consistent with EPA risk assessment guidance and enhances the level of protection for early life-stage exposures to carcinogens.

The cancer risk level applicable to Minnesota's WQS of 1×10^{-5} is not being changed in this rulemaking.

2. Identification of population protected

It is rare to have epidemiologic studies or animal bioassays conducted in susceptible individuals. This information need can be determined by identifying the key events of the mode of action and then identifying risk factors. In assessing risks to children, EPA considers both effects manifest during childhood and early-life exposures that can contribute to effects at any time later in life. These cancer guidelines view childhood as a sequence of lifestages rather than viewing children as a subpopulation, the distinction being that a subpopulation refers to a portion of the population, whereas a lifestage is inclusive of the entire population (USEPA 2005a, 2005b).

Executive Order 13045 (April 21, 1997) requires that "each Federal Agency shall make it a high priority to identify and assess environmental health and safety risks that may disproportionately affect children, and shall ensure that their policies, programs, and standards address disproportionate risks that result from environmental health risks or safety risks." In assessing risks to children, EPA considers both effects manifest during childhood and early-life exposures that can contribute to effects at any time later in life.

EPA's 2000 methodology was developed to protect the majority of the general population from chronic adverse health effects. EPA has used a combination of median values, mean values, and percentile estimates for the parameter value defaults to calculate its national 304(a) criteria. EPA believes that its assumptions afford an overall level of protection targeted at the high end of the general population (i.e., the target population or the criteria-basis population). EPA also believes that this is reasonably conservative and appropriate to meet the goals of the CWA and the 304(a) criteria program. EPA considers that its target protection goal is satisfied if the population as a whole will be adequately protected by the human health criteria when the criteria are met in ambient water. However, EPA acknowledged in the 2000 methodology that in some cases specific consideration of toxicological and exposure assessments for infants and children are desirable although they are complex. Thus, if the State determines that a highly exposed population is at greater risk and would not be adequately protected by criteria based on the general population, and by the national 304(a) criteria in particular, EPA recommends that the State adopt more stringent criteria using alternative exposure assumptions.

3. Revised Exposure Parameters

The Minnesota method revisions include new intake rates that directly incorporate body weight, newer data, and consideration of different exposure profiles and rates by life state (e.g., infants and children tend to have higher exposures than adults when calculated on a body weight basis). The HH-WQS Technical Support Document (MPCA 2014a) provides the details and technical basis for the revised exposure parameters. Original sources consist of various EPA guidance documents and the MDH's Health Risk Limits Rule (MDH 2008).

The revised methods use the 70 kg default adult body weight which is consistent with EPA's 2000 guidance. Unlike EPA's criteria formulae however, the body weight factor does not appear in the Minnesota revised methods since it is incorporated and expressed within the exposure intake rates (DWIR, FCR, IWR). The intake rates are expressed on a per body weight basis to more easily show exposure differences by media and compare to toxicological values (RfDs and CSFs).

In 2015, EPA finalized revisions to human health water quality criteria national guidance for 94 pollutants that included an updated body weight of 80 kg. The new default body weight is the mean body weight for adults ages 21 and older from more recent National Health and Nutrition Examination Survey (NHANES) data. Revised default exposure inputs for Drinking Water Intake (2.4 L/day) and Fish Consumption (22 g/day) were also provided. The finalized EPA guidance came after Minnesota adopted these subject WQS rule revisions and were therefore not included in this review. Similarly, when EPA published the draft criteria update on August 13, 2014, the subject revisions to Minnesota WQS rules were already too far along in the rulemaking process to incorporate these changes. The MPCA recognizes the need to update these default exposure parameters and will be considering this in a future rulemaking.

The following table that summarizes the new exposure parameters was taken from the SONAR document (MPCA 2014b). A more detailed discussion of each parameter is presented below the table.

Table 2 Proposed Exposure Parameters for Developing Human Health-based Chronic Standards

Exposure Parameter	Abbreviation	Values and Units	Agency Methodology	Data and Information
Drinking Water Intake Rates	$DWIR_{acute}$ $DWIR_{short-term}$ $DWIR_{subchronic}$ $DWIR_{chronic}$ $DWIR_{0-<2}$ $DWIR_{2\ to\ <16}$ $DWIR_{16\ to\ 70}$ $DWIR_{lifetime}$	0.289 L/kg-d 0.289 L/kg-d 0.077 L/kg-d 0.043 L/kg-d 0.137 L/kg-d 0.047 L/kg-d 0.039 L/kg-d 0.043 L/kg-d or Pollutant-specific	MDH-HRL Rule (4717) drinking water Intake Rates (IR)	CSFII 1994 to 1996, 1998 on community water intake by, consumers only as evaluated by EPA; MDH time-weighted average 95th percentile values (Exhibit HH-6).
Incidental Water Intake Rate	IWR	0.0013 L/kg-d	MPCA	EPA, MDH, and ATSDR (Exhibit HH-1).
Fish Consumption Rates	FCR_{adult} $FCR_{child\ (1-5)}$ $FCR_{0\ to\ <2}$ $FCR_{2\ to\ <16}$	0.00043 kg/kg-d (default) (0.43 g/kg-d, derived from: 30 g of fish per day/70 kg BW) 0.00086 kg/kg-d 0.00086 kg/kg-d 0.00055 kg/kg-d	MPCA	Regional fish consumption surveys and other relevant national surveys used by EPA (Exhibits HH-1 and HH-8).
Bioaccumulation Factors	BAF_{TL3} (24%) BAF_{TL4} (76%)	Pollutant- and Use Class specific value L/kg	EPA (MPCA – fish lipid and organic carbon fraction values)	40 CFR 132, Appendix B and EPA 2000 HH-AWQC and TSDs specific to BAFs (Exhibits HH-3, HH-4); Fish lipid and organic carbon fraction reviews from Minnesota data (Exhibit HH-1).
Relative Source Contribution factor	RSC	Pollutant-specific value between 0.2 and 0.8 (for use of defaults: 0.2 and 0.5 when pollutant-specific value cannot be determined)	EPA	EPA 2000 HH AWQC: RSC Exposure Decision Tree (Exhibit HH-3).

Drinking Water Intake Rates (DWIR)

The DWIR data and analysis behind this revised exposure parameter came from the MDH's revisions to the HRL Rule (MDH 2008) which made use of the data sources provided in Table 1. MDH's research clearly indicated that use of one adult-based water intake rate may not be protective of children, especially for formula-fed infants, whom drink much more per body weight than adults. The MDH HRL rule used higher intake rates for drinking water based on the latest community drinking water data from EPA's Per Capita Water Ingestion report (EPA 2004b). The MDH applied a more protective 95th percentile intake rate from "consumers-only" data, resulting in intake rates higher than the previous 2 L per day for a 70 kg adult. In addition, higher intake rates were used for infants drinking formula mixed with tap water.

The MDH's HRL rule (MDH 2008) used EPA's analysis of data from the Continuing Survey of Food Intake by Individuals (CSFII) (USEPA 2004b, USEPA 2008). For the derivation on noncancer standards and criteria the following default-specific intake rates were used: acute or short term = 0.289 L/kg-day, based on the time-weighted average (TWA) of the 95th percentile intake from birth up to 3 months of age; subchronic = 0.077 L/kg-day, based on the TWA of 95th percentile intake from birth up to 8 years of age; and chronic = 0.043 L/kg-day, based on the TWA of the 95th percentile intake over a lifetime of approximately 70 years of age.

For linear carcinogens, EPA's approach for integrating age-dependent sensitivity adjustment factors and exposure information was followed. The default IRs corresponding to the ADAF age groups used in deriving cancer HRLs are based on the TWA of the 95th percentile intake rate for each age range. The values are 0.137 L/kg-day (birth up to 2 years of age), 0.047 L/kg-day (2 to up to 16 years of age), and 0.039 L/kg-day (16 years of age and older). When ADAFs are not applied, the same IR for the chronic noncancer duration, 0.043 L/kg-day is used, based on the TWA of the 95th percentile intake over a lifetime.

As cited above, the use of life-stage-specific drinking water intake rates is consistent with EPA risk assessment guidance and enhances the level of protection for early life-stage exposures to carcinogens.

Incidental Water intake Rate (IWR)

IWRs are used for HH-WQS as a component of the recreational designated use. A revised rate was needed to address the children's age groups most relevant for a chronic duration – defined as eight years, ages one through eight. A new rate is also reasonable because it reflects recently available data on actual incidental water intake for children during swimming. The MPCA based the revised IWI on EPA's 2008 Children's Exposure Factors Handbook and updated 2011 Exposure Factors Handbook that provide current and recommended incidental water exposure amounts and body weights for children. The previous rate was based on general estimates of ingesting a "mouthful of water.". The rate of 120 ml per day is used with estimates of swimming duration (1 hour per day) and frequency (77.4 days per year) based on Minnesota site-specific risk consultations completed by the MDH and the Center for Disease Control's (CDC) Agency for Toxic Substance and Disease Registry (ATSDR). The body weight used (20.1 kg) is the average for ages one through eight (MPCA 2014a). This equates to a IWR of 0.0013 L/kg-day (for an average body weitht of 20.1 kg for 1-8 years old). An IWR of 10 ml/day (0.00014 L/kg-day for a 70 kg adult) was used in the GLI (USEPA 1995c) and by the MPCA in ch. 7052 by reference. Given that the newly adopted IWR is about 10 times higher than the previous value, EPA finds that, all other factors being equal, the use of the new IWR will generate more stringent criteria protective of aquatic life and recreational uses as required under 40 CFR 131.11(a).

Fish Consumption Rates (FCR)

The MPCA's review of data on children's FCR used both published studies and EPA Guidance to develop new FCR for children (USEPA 2002a). EPA's 2002 publication, Estimated Per Capita Fish Consumption in the United States (USEPA 2002a), was the main source of information for comparing children and adult fish consumption rates on a body-weight basis. The age groups examined for differing rates centered on the EPA's Guidance on Selecting Age Groups for Monitoring and Assessing Childhood Exposures to Environmental Contaminants (USEPA 2005c). The adopted rules utilize children's FCRs for 0<2 years and 2 to < 16 years along with the cancer potency ADAFs as discussed above.

MPCA, with the assistance of a Toxics Technical Advisory Committee, determined that in Minnesota the importance and popularity of fishing warranted a higher level of protection and use of regional data on fishing habits. By focusing on regional, freshwater fish consumption surveys of adults, a FCR of 30 g/d was developed based on approximately the 80th percentile rate (80% of the population surveyed ate 30 g/d or less of freshwater fish) from this population of fish consumers, which equated to about a 90th percentile rate for the general population at that time. This rate was previously approved by EPA and was not changed in this rulemaking.

Since MPCA adopted the human health methods in 1990, additional survey data have been published on regional and national FCRs. Because EPA supports the efforts of states and tribes to maintain currency in their HH-WQS, many of the studies with relevance to Minnesota's FCR have been evaluated by EPA. MPCA has completed a limited reviewed of the ongoing use and application of the existing 30 g/d based on adults in light of the more recent data provided in these EPA evaluations. The reviewed centered on EPA published evaluations, primarily ,their recent republication of results from a fish consumption survey conducted in Minnesota and additional studies and guidance on application of national survey data for state and tribal risk assessments (USEPA 2013a, USEPA 2013b). The review focused on the relevance of this more current EPA information on the ongoing use of the 30 g/d as the default FCR.

To meet the key objectives of the method revisions to develop improvements for protecting infants, children, and other developmental life stages, the state conducted a comprehensive review of available survey data to examine fish consumption patterns and rates for children ages 1 to 18. The review examined fish consumption differences in children and adults and short-term rates. Identification of adverse effects that can occur after less-than-chronic durations of exposure, which form the basis for multiduration RfDs and new ADAF windows of higher cancer susceptibility, has important implications for FCRs used in HH-WQSs. MPCA has conducted this review by considering MDH's approach for developing new drinking water intake rates for infants and children based on less-than-chronic durations and examination of the timing of highest exposure (per body weight), within the context of differences in fish consumption profiles across developmental life stages.

EPA recognizes the limitations in the existing data and other variables that can effect fish consumption rates (especially for early life stages) and understands that the MPCA has begun to evaluate all available data to more strongly substantiate these FCRs or substantiate the basis for new FCRs. EPA further recognizes the MPCA's ability to consider site-specific or pollutant-specific data to determine alternative rates on a site-specific basis. In addition, the MPCA has acknowledged the need to update the general state-wide FCR applicable to adults of 30 g/day and with EPA assistance plans to do so in a future rulemaking.

Bioaccumulation Factors (BAF)

Minn. R. ch. 7052 currently incorporates by reference 40 CFR 132 Appendix B, originally developed as the 1995 304(a) *Great Lakes Water Quality Initiative Technical Support Document for the Procedure to Determine Bioaccumulation Factors*. The MPCA did not revise the methods currently in Minn. R. ch. 7052, which were used to develop WQS for the Lake Superior Basin. However, the MPCA did replace all of the BAF methods in Minn. R. 7050.0218, subp. 7, with new methods based on EPA's 2000 guidance (USEPA 2000a) in Minn. R. 7050.0219. These methods are almost identical to the GLI methods although a few adjustments were made to ensure broader applicability to waters outside the Great Lakes.

In general, EPA encourages States and authorized Tribes to make site-specific modifications to EPA's national BAFs provided such adjustments are scientifically defensible and adequately protect the designated use of the waterbody. Minnesota has used regional data in establishing factors to replace national defaults in BAF calculations. These factors included fish lipid content (discussed below) and particulate organic carbon (POC) and dissolved organic carbon (DOC) Separate values were determined for the state (inland lakes and streams) and for the Lake Superior basin (as part of the GLI). The BAF development methods and DOC and POC values of 2 mg/L and 0.04 mg/L, respectively, already in place in Minn. R. ch. 7052 and previously approved by EPA were not changed in this rulemaking. As part of this rulemaking, the MPCA reviewed POC and DOC data for use in the statewide methods (see Appendix A4 in the TSD document (MPCA 2014a)). Data on DOC from lake and stream monitoring studies, but not POC, was sufficient to develop a Minnesota-specific value of 7.5 mg/L. EPA reviewed the information provided in Appendix A4 and concurs that the datasets used and decisions made allow for a determination of this state-specific DOC value. Given the limited data for POC, the value applied to state BAFs is 0.5 mg/L (EPA's national default).

The MPCA previously evaluated the lipid composition of Lake Superior and inland fish communities to determine Minnesota-specific lipid values for use in developing Minnesota-specific BAFs for trophic levels 3 and 4. The BAF methods included fish lipid values specific to Minnesota's Class 2A trout waters (6%) and Class 2B cool-warm water fisheries (1.5%). The GLI methods included BAF methods that the MPCA adopted for use in Minn. R. ch. 7052 for the Lake Superior Basin. The GLI BAF methods, although essentially the same as those in these new rule revisioins, used a higher fish lipid value representative of Lake Superior Lake Trout of 8.5% (this replaced the default GLI values of 1.82% and 3.10% for TLs 3 and 4, respectively (USEPA 1995a)). These state-specific inputs were previously approved by EPA.

The MPCA examined fish lipid content as part of adopting these new BAF methods (see Appendix A5 in the TSD document (MPCA 2014a)). More Minnesota-specific data were available from the Interagency Fish Contaminant Monitoring Program (FCMP) database. These fish lipid data are the basis for the new Class 2B TL_3 fish lipid value of 2% and continued use of 1.5% for TL_4 BAFs. EPA reviewed the information provided in Appendix A5 and concurs that the datasets used and decisions made allow for a determination of trophic level-specific lipid values.

Relative Source Contribution (RSC) Factor

The newly adopted methods follow the RSC Exposure Decision Tree that was developed as part of the 2000 304(a) Methodology for Deriving Ambient Water Quality Criteria for the Protection of Human Health (USEPA 2000a). The Exposure Decision Tree refines and provides consistency for the development and application of a RSC. If there are sufficient data available to develop a chemical-specific RSC, it may be used to estimate the percentage of exposure a receptor would likely obtain from surface water compared to other sources of exposure, such as soil or air. The EPA recommends using no less than a minimum RSC of 0.2 (20% exposure from surface water) and no more than a maximum RSC of 0.8 (80% exposure from surface water). When data are not sufficient for a chemical-specific RSC, default values are used. The previous methods almost exclusively used a default RSC of 0.2. The new methods propose the use of two default values, 0.2 and 0.5 chosen based on chemical-specific properties and other sources of exposure (0.5 is used where there are no significant known or potential sources other than those related to the designated use). This distinction is consistent with the Exposure Decision Tree (USEPA 2000a).

4. Specific Rule Revisions with Detailed Rationale (from Table 1 – shaded rows)

(a) 7050.0218, subp. 3, item C: Definitions of "Adjustment factor lifetime" and item E: "Age-dependent adjustment factor".

Description of the State rule revision

7050.0218, subp. 3, item C. "Adjustment factor lifetime" or "$AF_{Lifetime}$" means the numeric multiplier used to modify the adult-based cancer slope factor for lifetime (70 years standard in risk characterization) exposure based on chemical-specific data.

7050.0218, subp. 3, item E. "Age-dependent adjustment factor" or "ADAF" means the default numeric modifiers to the cancer slope factor that account for the increased susceptibility to cancer from early-life exposures to linear carcinogens in the absence of chemical-specific data. For default use, there are three ADAF:

(1) $ADAF_{0<2}$ = 10, for birth up to two years of age;

(2) $ADAF_{2\ to <16}$ = 3, for two up to 16 years of age; and

(3) $ADAF_{16+}$ = 1, for 16 years of age and older.

Data and rationale submitted by State in support of rule revision

Minnesota's revised methods address the higher risks of early-life exposure to linear carcinogens through the use of Adjustment Factors ($AF_{Lifetime}$) and Age-dependent Adjustment Factors (ADAF). Based on EPA guidance (USEPA 2005b) and MDH rules (best described in the SONAR for the MDH's HRL rule (MDH 2008)), early life exposure results in: (1) a higher risk of developing cancer; (2) cancer manifestation at an earlier age; and (3) higher incidence of cancer resulting from exposure in early life stages as compared to adult exposure. EPA determined that for some carcinogens, data were available to develop a chemical-specific $AF_{Lifetime}$ and the MDH followed this approach. For other chemicals where chemical-specific $AF_{Lifetime}$ values cannot be determined, the default ADAFs are used. Increased protection to early-life stages for non-linear carcinogens is built into the enhanced process of RfD development discussed above in Section C.1 which considers all available information on adverse effects from exposure to a pollutant during developmental life stages.

Basis for EPA Action

The following definition is taken from EPA's Exposure Factors Handbook (USEPA 2011). "***Age dependent adjustment factor (ADAF)***—*In cases where age-related differences in toxicity occur, differences in both toxicity and exposure need to be integrated across all relevant age intervals, by the use of age dependent potency adjustment factors (ADAFs). This is a departure from the way cancer risks have historically been calculated based upon the premise* *that risk is proportional to the daily average of the long-term adult dose."* The age groups and default values listed in the definition are also provided in EPA's Child-Specific Exposures Factors Handbook (Table 1-3)(USEPA 2008).

The incorporation of these adjustment factors to account for the increased risk to carcinogens with early-life stage exposures is an enhancement to EPA's current methodology for deriving ambient water quality criteria (EPA 2000), following more recent EPA guidance (USEPA 2005b, 2008 and 2011), and is more protective of the human health designated uses. For these reasons, EPA considers the definitions and the justification provided to be consistent with Section 303(c) of the CWA and Federal regulations at 40 CFR 131.

EPA action

EPA approves Minnesota's newly adopted definitions for "Adjustment factor lifetime" and "Age-dependent adjustment factor" in Minn. R. ch. 7050.0218, subp. 3.

(b) 7050.0218, subp. 10. Applicable criteria or human health-based standard.

Description of the State rule revision

Subp. 10. Applicable criteria or human health-based standard. ~~The criterion for a pollutant includes: the CC, the MC, and the FAV.~~ The final criteria or chronic standard for human health for toxic pollutants for surface waters are must be the lowest of the applicable criteria or standards for human health derived under this part and part 7050.0219.

A. Applicable criteria or standards for human health by use for Class 2A, 2Bd, 2B, 2C, and 2D surface waters are listed for each applicable population protected (aquatic life, humans, and fish-eating wildlife). The applicable criteria or standards for human health must be the lowest of the ~~following~~ CC or CS as described in subitems (1) to (3):

(1) for aquatic life toxicity: a CC_{tox} and MC based on toxicity to aquatic organisms from subpart 4 or 5 or a CC_{tox} based on plant toxicity from subpart 4 or 5;

~~(2) a CC based on plant toxicity from subpart 4 or 5;~~

~~(3)~~ (2) for human health: a ~~CC_{df} or CC_f from subparts 6 and 7~~ CC or CS by medium (water or fish) as described in part 7050.0219, subpart 2, or a concentration that will prevent unacceptable taste or odor in water, fish, or other edible aquatic organisms from subpart 8; or

~~(4) a concentration that will prevent unacceptable taste or odor in water, fish, or other edible aquatic organisms from subpart 8; or~~

~~(5)~~ (3) when available, for fish-eating wildlife: a CC_w from subpart 9.

B. Applicable criteria for Class 7 waters ~~are~~ must be the lowest of the following:

[For text of subitems (1) and (2), see M.R.]

C. If the site-specific application of criteria developed in this subpart is used to establish an effluent limitation for national pollutant discharge elimination system and state disposal system permits or to establish the degree of remedial action cleanup activities, the provisions of part 7050.0222, subpart 7, items B to ~~E~~ G, apply.

D. The CS or CC and MS or MC must be averaged over the duration described in part 7050.0222, subpart 7, item C.

Data and rationale submitted by State in support of rule revision

The subpart 10 revisions continue the MPCA's policy and practice of adopting the most stringent criteria when multiple criteria are derived and apply to a given waterbody or designated use. The revisions reorganize and provide new language and cross-references to match revisions to other portions of ch. 7050. The process of adopting the most stringent applicable standards or criteria is summarized in the SONAR document (MPCA 2014b) and described in more detail in the TSD (MPCA 2014a).

Basis for EPA Action

These WQS revisions continue previously approved rule language that ensure the most protective criteria are applicable for particular designated uses. Following the procedures laid out in these provisions is consistent with the process described in EPA guidance (USEPA 1994) and will provide protection for all uses designated for a particular waterbody. As such, it will provide additional protection of the Class 2 designated uses and is consistent with Section 303(c) of the CWA and Federal regulations at 40 CFR 131.

EPA action

EPA approves the revised provisions in Minn. R. ch. 7050.0218, subp. 10.

(c) 7050.0219, subp. 6. Bioaccumulation factors

Description of the State rule revision

7050.0219, subp. 6. Bioaccumulation factors. This subpart describes the process and data for deriving bioaccumulation factors (BAF) used in the calculation of the human health-based chronic criteria (CC) or chronic standards (CS).

A. Information used for defining BAF must be consistent with the pollutant form used to derive the RfD or CSF. BAF development must also consider other forms that bioaccumulate in fish tissue. The preferred bioaccumulation data are available and reliable field and laboratory studies.

B. A general description of the steps and data used to determine final state or site BAF are listed in subitems (1) to (6) and described in detail in subparts 7 to 12.

(1) Categorize the pollutant based on certain properties into one of three broadly defined chemical categories: nonionic organic, ionic organic, or inorganic and organometallic chemicals as described in subpart 7.

(2) Define the methods for developing baseline BAF as described in subpart 8. A baseline BAF is the expression of the BAF based on the bioavailable or freely dissolved fraction of a pollutant in the ambient water and

normalized concentration of the pollutant within the organism.

(3) Determine the relevant procedure (1 to 6) for identifying the acceptable baseline BAF methods (maximum of four) and their hierarchy for developing individual or aquatic species-specific baseline BAF as described in subpart 9.

(4) Calculate species mean baseline BAF from acceptable individual baseline BAF as described in subpart 10.

(5) Determine final baseline BAF for TL_3 and TL_4 as described in subpart 11.

(6) Develop final state or site BAF for TL_3 and TL_4 based on default parameters by Class 2 subclass or site-specific data as described in subpart 12.

Data and rationale submitted by State in support of rule revision

Minnesota replaced all of their old BAF methods in ch. 7050 with updated methods consistent with EPA's 2000 Methodology which in turn are essentially identical to those applicable to Lake Superior and found in 40 CFR 132, Appendix B which Minnesota's rules in ch. 7052 incorporate by reference. As allowed by EPA guidance, the national defaults were replaced where possible with Minnesota-specific values derived using Minnesota data. Any change from national default values is discussed in Sections III.C.1-3 above or in the following sections below where they first occur.

Subpart 6 above describes the overall process used to derive BAFs. The following 6 subparts provide more detailed information on each of these steps.

The data and rationale for the State's rule revisions are described in detail on pages 3, 9 and 34 of the SONAR (MPCA 2014b) and examples of BAF algorithm usage can be located in sections D. "Exposure parameters and evaluation" (pages 34 – 36) and E. "Proposed methods: Noncancer and linear carcinogen algorithms" (pages 37 -46) of the SONAR. More details can also be found in the TSD, section IV.C. (MPCA 2014a).

Basis for EPA Action

As mentioned above, this subpart describes the state's overall process for deriving BAFs and is equivalent to the BAF derivation framework found in EPA's 2000 methodology (USEPA 2000, Section 5.3 and Figure 5.1). Specifically, the six steps listed in this subpart are consistent with EPA's 2000 guidance except for the state's use of only trophic level 3 and 4 where state-specific data in EPA's is used to derive state-specific values which is consistent with EPA's guidance provided in the TSD Volume 2 (EPA 2003b). This state-specific modification of trophic level fish consumption and lipid values was previously approved by EPA and is described in more detail above in Section C.3. As such, the use of these previously approved state-specific trophic level values is not a part of this review.

EPA therefore considers the decisions made and the justification provided to be consistent with the CWA, Federal regulations, and guidance. These BAF methods will be used by MPCA to develop criteria to protect MN's Class 2 water uses and since the BAF methods used are equivalent to those found in EPA guidance, EPA finds that, all other factors being equal, the new BAF methods will generate criteria protective of aquatic life and recreational uses as required under 40 CFR 131.11(a).

EPA action

EPA approves Minnesota's newly adopted standards for bioaccumulation factors in Minn. R. ch. 7050.0219, subp. 6.

(d) 7050.0219, subp. 7. Chemical categorization.

Description of State Rule Revision

Subp. 7. **Chemical categorization.** For BAF purposes, organic chemicals that haven no or negligible ionization at the pH range of ambient surface waters are categorized as nonionic organic chemicals; organic chemicals that undergo ionization at the pH range of ambient surface waters are categorized as ionic organic chemicals and further delineated for BAF development based on subpart 9, item C; organometallic chemicals and other chemicals or elements are categorized as organometallic and inorganic chemicals.

Data and rational submitted by State in Support of the Rule Revision

This subpart contains the initial chemical characterization step needed to derive appropriate BAFs as outlined in EPA's 2000 guidance (USEPA, 2000, Sec. 5.3). A simple explanation of how chemicals that need a derived BAF are categorized as ionic organic chemicals, nonionic organic chemicals, or organometallic and inorganic chemicals is provided. The chemical categorization process is summarized in the SONAR document (MPCA 2014b) and described in more detail in the TSD (MPCA 2014a).

Basis for EPA Action

EPA has reviewed the MPCA's categorization of chemicals used in the calculation of bioaccumulation factors and the supporting documentation provided in the SONAR and TSD documents and finds this categorization consistent with EPA guidance (USEPA 2000a). This chemical categorization will be used to derive BAFs that will be used by MPCA to develop criteria to protect

MN's Class 2 water uses and since this chemical categorization is equivalent to that found in EPA guidance, EPA finds that, all other factors being equal, the new methods will generate criteria protective of aquatic life and recreational uses as required under 40 CFR 131.11(a).

EPA Action

EPA approves Minnesota's newly adopted chemical categorization in Minn. R. ch. 7050.0218, subp. 7.

(e) 7050.0219, Subp. 8. Methods for baseline BAF.

Description of State Rule Revision

Subp. 8. Methods for baseline BAF. The four methods for developing baseline BAF in items A to D are listed in a hierarchy from most preferred to least preferred, except as noted in subpart 9: use of field-measured BAF studies (field BAF); use of field-measured BSAF studies (field BSAF); use of laboratory-measured BCF studies with food chain multipliers (lab BCF*FCM); and use of octanol-water partition coefficients with food chain multipliers (K_{ow}*FCM). Where relevant, differences in the baseline BAF methods are described by chemical categorization.

(See adopted rule for complete new text regarding the following 4 BAF methods)

A. Method 1: Field BAF.
B. Method 2: Field BSAF
C. Method 3: Lab BCF*FCM
D. Method 4: Kow*FCM.

Data and rational submitted by State in Support of the Rule Revision

Regarding baseline BAF methods, Minn. R. ch. 7052 currently incorporates by reference 40 CFR 132 Appendix B, originally developed as the 1995 304(a) Great Lakes Water Quality Initiative *Technical Support Document for the Procedure to Determine Bioaccumulation Factors*. The MPCA did not revise the BAF methods in ch. 7052, however all of the BAF methods in Minn. R. 7050.0218, subp. 7, were replaced with new methods based on methods found in EPA's 2000 methodology (USEPA 2000a) and TSD Volume 2 (USEPA 2003b). The incorporation of these new BAF methods is summarized in the SONAR document (MPCA 2014b) and described in more detail in the TSD (Sections II and IV.C) (MPCA 2014a).

Basis for EPA Action

As mentioned above, this subpart describes the four methods for developing baseline BAFs and is equivalent to the four methods found in EPA's 2000 methodology (USEPA 2000, Section 5.3 and Figure 5.1). Specifically, the six steps listed in this subpart are consistent with EPA's 2000 guidance except for the state's use of only trophic level 3 and 4 by replacing default values with state-specific data as discussed in EPA's TSD Volume 2 (EPA 2003b). This state-specific modification of trophic level fish consumption and lipid values was previously approved by EPA and is described in more detail above in Section C.3. above.

EPA therefore considers the decisions made and the justification provided to be consistent with the CWA, Federal regulations, and guidance. These baseline BAF methods will be used by MPCA to develop criteria to protect MN's Class 2 water uses and since the baseline BAF methods used are equivalent to those found in EPA guidance, EPA finds that, all other factors being equal, the new baseline BAF methods will generate criteria protective of aquatic life and recreational uses as required under 40 CFR 131.11(a).

EPA Action

EPA approves Minnesota's newly adopted methods for determining baseline BAFs in Minn. R. ch. 7050.0218, subp. 8.

(f) 7050.0219, Subp. 9. Hierarchy of acceptable baseline BAF methods.

Description of State Rule Revision

Subp. 9. Hierarchy of acceptable baseline BAF methods. Determine the hierarchy of acceptable baseline BAF methods available under subpart 8 for appropriate use based on the chemical categorization of the pollutant and other relevant properties as described under Procedures 1 to 6.

(See adopted rule for complete new text added to this subpart)

Data and rational submitted by State in Support of the Rule Revision

This subpart focuses on the implementation of the four BAF methods identified in subpart 8 above and explains the selection and use of each BAF method. The four baseline-BAF methods are defined and prioritized based on five main chemical characteristics: organic or inorganic compound, ionization in surface waters, octanolwater partition coefficients (K_{ow}), metabolism in aquatic organisms, and known biomagnification potential. These methods build on the available data and develop appropriate hierarchies of approaches, defined by six procedures, based on relevant and preferred data for all the chemical classes. The incorporation of these procedures and selection of the preferred new baseline BAF methods is summarized in the SONAR document (MPCA 2014b) and described in more detail in the TSD (Sections II and IV.C) (MPCA 2014a).

Basis for EPA Action

The use of chemical characteristics and the six procedures as described in this subpart is consistent with the Framework for Deriving a National BAF as described in EPA's 2000 methodology (USEPA 2000a). EPA therefore considers the decisions made and the justification provided to be consistent with the CWA, Federal regulations, and guidance. This hierarchy of acceptable BAF methods will be used by MPCA to develop criteria to protect MN's Class 2 water uses and since the selection of BAF methods used is equivalent to those found in EPA guidance, EPA finds that, all other factors being equal, the selection of the appropriate BAF methods will generate criteria protective of aquatic life and recreational uses as required under 40 CFR 131.11(a).

EPA Action

EPA approves Minnesota's newly adopted hierarchy of baseline BAF methods in Minn. R. ch. 7050.0219, subp. 9.

(g) 7050.0219, Subp. 10.Species mean baseline BAF.

Description of State Rule Revision

Subp. 10. Species mean baseline BAF. Calculate species and mean baseline BAF from acceptable individual baseline BAF.

A. For each appropriate baseline BAF method, calculate species-mean baseline BAF using the geometric mean.

B. Any baseline BAF with large differences between species (greater than ten percent) needs additional justification for use in a species-mean baseline BAF.

C. Evaluate data uncertainties for consideration in method hierarchy application for calculating trophic level baseline BAF.

Data and rational submitted by State in Support of the Rule Revision

The calculation of species-mean baseline BAFs is step 4 in the process of developing a final state or site BAF as summarized in Minn. R. ch. 7050.0219, subp 6. In situations where more than one acceptable baseline BAF is available for a given species, a species-mean baseline BAF is calculated as the geometric mean of all the individual baseline BAFs. More details were provided in the TSD for this rulemaking (MPCA 2014a).

Basis for EPA Action

The inclusion of the step to calculate a species-mean baseline BAF where there are more than one baseline BAF for a given species is consistent with EPA's 2000 guidance (USEPA 2000a).

EPA therefore considers the decisions made and the justification provided to be consistent with the CWA, Federal regulations, and guidance. This calculation of a species-mean baseline BAF is one of the steps in developing a state or site BAF that will be used by MPCA to develop criteria to protect MN's Class 2 water uses and since the calculation of a species-mean baseline BAF is equivalent to that found in EPA guidance, EPA finds that, all other factors being equal, the new step to calculate a species-mean baseline BAF will generate criteria protective of aquatic life and recreational uses as required under 40 CFR 131.11(a).

EPA Action

EPA approves Minnesota's newly adopted provision for calculating a species-mean baseline BAF Minn. R. ch. 7050.0219, subp. 10.

(h) 7050.0219, Subp. 11. Final baseline BAF by trophic level.

Description of State Rule Revision

Subp. 11. Final baseline BAF by trophic level. Determine the final baseline BAF by trophic level (TL):

A. Calculate geometric mean baseline BAF for TL3 and TL4 using available species-means for each baseline BAF method. For Class 2A water, preference is given for Salmonidae data and developed as a single representative TL4 baseline BAF for cold-water aquatic communities.

B. Combine species-means for methods that have equal preference in procedural hierarchies and have similarly reliable baseline BAF based on evaluation of data uncertainties for a final baseline BAF for TL3 where applicable, and final baseline BAF for TL4.

C. For some pollutants, TL3 and TL4 baseline BAF may be identical when not dependent on trophic level factors, such as lipid partitioning.

Data and rational submitted by State in Support of the Rule Revision

The determination of a final baseline BAF by trophic level is step 5 in the process of developing a final state or site BAF as summarized in Minn. R. ch. 7050.0219, subp 6. In situations where more than one acceptable species-mean baseline BAF is available for a given trophic level, a trophic-level-mean baseline BAF is calculated as the geometric mean of all the individual species-mean baseline BAFs. More details were provided in the TSD for this rulemaking (MPCA 2014a).

Basis for EPA Action

The inclusion of the step to calculate a trophic-level-mean baseline BAF where there are more than one species-mean baseline BAF for a given trophic level is consistent with EPA's 2000 guidance (USEPA 2000a).

EPA therefore considers the decisions made and the justification provided to be consistent with the CWA, Federal regulations, and guidance. This calculation of a final baseline BAF is one of the steps in developing a state or site BAF that will be used by MPCA to develop criteria to protect MN's Class 2 water uses and since the determination of a final baseline BAF is equivalent to that found in EPA guidance, EPA finds that, all other factors being equal, the new step to determine a final baseline BAF will generate criteria protective of aquatic life and recreational uses as required under 40 CFR 131.11(a).

EPA Action

EPA approves Minnesota's newly adopted provision for determining final baseline BAFs by trophic level in Minn. R. ch. 7050.0219, subp. 11.

(i) 7050.0219, Subp. 12.Final state or site BAF by trophic level.

Description of State Rule Revision

Subp. 12. Subp. 12. Final state or site BAF by trophic level. Calculate final state or site BAF for TL3 where applicable and TL4 for use in developing human health-based chronic criteria or standards.

A. For nonionic organic chemicals and ionic organic chemicals with no or negligible ionization as defined under subpart 7, for each TL3 and TL4, calculate a state or site BAF using the following equation:

$$\text{state or site BAF}_{(TL\ n)} = \left[\left(\text{final baseline BAF}_l^{fd}\right)_{TL\ n} \times (f_l)_{TL\ n} + 1\right] \times (f_{fd})$$

where: $(\text{final baseline BAF}_l^{fd})_{TL\ n}$ = final trophic-level-mean baseline BAF expressed on a freely dissolved and lipid-normalized basis for trophic level "n" (L/kg)
$(f_l)_{TL\ n}$ = lipid fraction of aquatic species consumed at trophic level "n" by Class 2 subclass: Class 2A = 0.06; Class 2Bd/2B/2C/2D = 0.02 for TL3 and 0.015 for TL4
f_{fd} = fraction of the total chemical in water that is freely dissolved in ambient waters

The default DOC and POC values for the state ambient Class 2 surface waters are 7.5 x 10^{-6} kg/L (7.5 mg/L) and 5 x 10^{-7} kg/L (0.5 mg/L), respectively. For a site BAF for use in site-specific criteria development, the DOC and POC values are from the site monitoring data, if available; in all other cases, the state defaults are used.

B. For inorganic and organometallic chemicals and ionic organic chemicals with ionization in natural waters, the baseline BAF^t_T using total chemical concentrations or bioavailable forms are directly applied as the state or site BAF:

$$\text{state BAF}_{(TL\ n)} \text{ or site BAF} = \text{final baseline BAF}_{(TL\ n)}$$

Data and rational submitted by State in Support of the Rule Revision

The determination of a final BAF for each trophic level is step 6 in the process of developing a final state or site BAF as summarized in Minn. R. ch. 7050.0219, subp 6. More details were provided in the TSD for this rulemaking (MPCA 2014a). The state-specific trophic level lipid fractions and DOC/POC values are discussed above in more detail in Section III.C.3.

Basis for EPA Action

This last step in determining a final state or site BAF is consistent with EPA's 2000 guidance (USEPA 2000a).

EPA therefore considers the decisions made and the justification provided to be consistent with the CWA, Federal regulations, and guidance. This is the final step in developing a state or site BAF that will be used by MPCA to develop criteria to protect MN's Class 2 water uses and since the determination of a final BAF is equivalent to that found in EPA guidance, EPA finds that, all other factors being equal, the new step to determine a final state or site BAF will generate criteria protective of aquatic life and recreational uses as required under 40 CFR 131.11(a).

EPA Action

EPA approves Minnesota's newly adopted provisions for deriving final state or site-specific BAFs by trophic levels in Minn. R. ch. 7050.0219, subp. 12.

(j) 7050.0219, Subpart 13. Algorithms for Class 2A or 2Bd surface waters.

This subpart describes human health-based criteria or standards for classes of surface waters designated for drinking water, fish consumption, and recreational use. To develop a final chronic criteria (CC_{dfr}) or standard (CS_{dfr}) applicable to surface waters designated Class 2A or 2Bd, items A to D must be evaluated for use based on the pollutant's toxicological profile: noncarcinogen or nonlinear carcinogen (NLC); developmental susceptibility; or linear carcinogen (C).

A. Algorithm for noncarcinogenic or NLC chemicals applicable to surface waters designated Class 2A or 2Bd

Description of the State rule revision

A. Algorithm for noncarcinogenic or NLC chemicals applicable to surface waters designated Class 2A or 2Bd to calculate: CC_{dfr} or CS_{dfr} =

$$\frac{RfD_{chronic}\ (mg/kg\text{-}d) \times RSC\ (no\ units) \times 1{,}000\ \mu g/mg}{\{DWIR_{chronic}\ (L/kg\text{-}d) + FCR_{adult}\ (kg/kg\text{-}d)[(0.24 \times BAF_{TL3}\ (L/kg)) + (0.76 \times BAF_{TL4}\ (L/kg))]\}}$$

where: CC_{dfr} or CS_{dfr} = drinking water plus fish consumption and recreation chronic criterion or standard in µg/L

$RfD_{chronic}$ = reference dose for chronic duration in mg/kg-day

RSC = relative source contribution factor

1,000 µg/mg = a factor used to convert milligram (mg) to microgram (µg); there are 1,000 micrograms per milligram

$DWIR_{chronic}$ = drinking water intake rate for the chronic duration based on a 95th percentile time-weighted average from MDH; rate may be chemical-specific with sufficient data or use the default rate of 0.043 L/kg-d

FCR_{adult} = fish consumption intake rate of 0.00043 kg/kg-d based on 0.030 kg/day of amount of fish assumed to be consumed per day and 70 kg adult body weight or rate may be chemical-specific with sufficient data

BAF_{TL3} = final BAF for TL_3 fish in L/kg; accounts for 24 percent of fish consumed

BAF_{TL4} = final BAF for TL_4 fish in L/kg; accounts for 76 percent of fish consumed; for Class 2A, the BAF_{TL4} is applied to 100 percent of the FCR

Data and rationale submitted by State in support of rule revision

This algorithm is used to develop HH-WQS for pollutants characterized for noncancer adverse effects. The basis for the algorithm is to ensure that exposure from surface water through drinking water, fish consumption, recreation and other sources will not exceed the RfD, the dose derived to be protective of adverse systemic toxic effects for a specific duration of exposure. Following EPA's 2000 guidance, the equation above does not include a factor for incidental ingestion of water from recreational uses. EPA determined that the averaged amount of incidental water intake is negligible and will not have any impact on the criteria values representative of both drinking water and fish consumption (USEPA 2000a).

Basis for EPA Action

The equation listed above is functionally equivalent to Equation 3-5 from EPA's 2000 guidance (USEPA 2000a) with the following state-specific modifications:

- $DWIR_{chronic}$. As discussed above in section III.C.3, this rate is based on a 95th percentile time-weighted average from MDH with either a chemical-specific value given sufficient data or a default rate of 0.043 L/kg-day (= 3 L/day for a 70 kg adult).
- FCR_{adult}. As discussed above in section III.C.3, this rate is the state's previously approved rate of 0.030 kg/day for a 70 kg adult and is converted for use in this equation as 0.00043 kg/kg-day.
- BAFs. As discussed above in section III.C.3, BAFs for TL_3 (24 percent) and TL_4 (76 percent) were previously approved and represent state-specific derived values.

EPA therefore considers the decisions made and the justification provided to be consistent with the CWA, Federal regulations, and guidance. This equation will be used by MPCA to develop criteria to protect MN's Class 2A and 2Bd water uses and since it is equivalent to Equation 3-5 from EPA's 2000 guidance (USEPA 2000a) with acceptable or previously approved state-specific exposure inputs, EPA finds that, all other factors being equal, this equation will generate criteria protective of aquatic life and drinking water uses as required under 40 CFR 131.11(a).

EPA Action

EPA approves the newly adopted algorithm for noncarcinogenic and NLC chemicals applicable to surface waters designated as Class 2A or 2Bd found in Minn. R. ch. 7050.0219, subp. 13, item A.

B. Supplemental algorithm for developmental susceptibility for noncarcinogenic or NLC chemicals applicable to surface waters designated Class 2A or 2Bd:

Description of the State rule revision

B. Supplemental algorithm for developmental susceptibility for noncarcinogenic or NLC chemicals applicable to surface waters designated Class 2A or 2Bd to calculate:

CC_{dev} or CS_{dev} =

$$\frac{RfD_{duration\_(acute,\ short\text{-}term,\ or\ subchronic)}\ (mg/kg\text{-}d) \times RSC\ (no\ units) \times 1{,}000\ \mu g/mg}{DWIR_{duration\_(acute,\ short\text{-}term,\ or\ subchronic)}\ (L/kg\text{-}d)}$$

where: CC_{dev} or CS_{dev} = developmental-based drinking water chronic criterion or standard in µg/L applied when shorter duration adverse effects and exposure parameters result in a more stringent chronic criterion or standard than calculated from item A

$RfD_{duration}$ = reference dose for acute, short-term, or subchronic duration in mg/kg-day

$DWIR_{duration}$ = drinking water intake rate for acute, short-term, or subchronic duration in L/kg-d; drinking water intake rate for the acute, short-term, and subchronic durations based on a 95th percentile time-weighted average from MDH; rate may be chemical-specific with sufficient data or use default rates of 0.289, 0.289, and 0.077 L/kg-d, respectively

Other variables as defined under item A

Data and rationale submitted by State in support of rule revision

As discussed in more detail elsewhere (MPCA 2014a, MPCA 2014b), the profile of a developmental toxicant is such that the prenatal and neonatal life stages may be uniquely susceptible to toxic insults from environmental pollutants. There are specific aspects to developmental toxicity profiles and less-than-chronic durations that require different considerations when applying those RfDs to the drinking water as compared to the fish consumption and incendental water pathways. For most pollutants where later developmental processes are not a target, drinking water exposure only for less-than-chronic durations is included in this new equation to ensure that the final CS_{dfr} or CS_{fr} is protective for shorter durations (i.e., the MPCA will determine standards using equation in Subp.13(A) above and also using this supplemental equation and the most stringent will be used).

Basis for EPA Action

The equation is modified from the equation discussed above (7050.0219, subp. 13(A)) by removing all fish consumption inputs and focusing on less-than-chronic exposures through drinking water only. For certain chemicals, less-than-chronic RfDs are available from the MDH and will be used in this supplemental equation to account for possibly higher risk from shorter duration exposure. In addition to the variables discussed above for the equation in Minn. R. ch. 7050.0219, Subp. 13(A) the following are state-specific modifications.

- $RfD_{duration}$. As discussed above in Section III.C.1, this is the Reference Dose for acute, short-term, or subchronic duration in mg/kg-day.
- $DWIR_{duration}$. As discussed above in Section III.C.3, the drinking water intake rate for acute, short-term, or subchronic duration in L/kg-d; drinking water intake rate for the acute, short-term, and subchronic durations based on a 95th percentile time-weighted average from MDH; rate may be chemical-specific with sufficient data or use default rates of 0.289, 0.289, and 0.077 L/kg-d, respectively.

Therefore, where this equation is utilized and resulting in more stringent criteria than that derived using the standard equation in Minn. R. ch. 7050.0219, Subp. 13(A), it will be more protective of the Class 2A and 2Bd designated uses. As such, it will provide additional protection of the Class 2 designated uses and is consistent with Section 303(c) of the CWA and Federal regulations at 40 CFR 131.

EPA Action

EPA approves the newly adopted supplemental algorithm for noncarcinogenic and NLC chemicals applicable to surface waters designated as Class 2A or 2Bd found in Minn. R. ch. 7050.0219, subp. 13, item B.

C. Algorithm for linear carcinogenic chemicals with lifetime adjustment factors applicable to surface waters designated Class 2A or 2Bd

Description of the State rule revision

C. Algorithm for linear carcinogenic chemicals with lifetime adjustment factors ($AF_{lifetime}$) applicable to surface waters designated Class 2A or 2Bd to calculate: CC_{dfr} or CS_{dfr} =

$$\frac{CR\ (1 \times 10^{-5})}{CSF\ (mg/kg\text{-}d)^{-1} \times AF_{Lifetime}} \times \frac{1000\ \mu g/mg}{\{DWIR_{Lifetime}\ (L/kg\text{-}d) + FCR_{adult}\ (kg/kg\text{-}d)\ [(0.24 \times BAF_{T3}\ (L/kg)) + (0.76 \times BAF_{T4}\ (L/kg))]\}}$$

where: CC_{dfr} or CS_{dfr} = drinking water plus fish consumption and recreation chronic criterion or standard in µg/L

CR = cancer risk level or an additional excess cancer risk equal to 1×10^{-5} (1 in 100,000)

CSF = cancer potency slope factor in $(mg/kg\text{-}d)^{-1}$

$AF_{Lifetime}$ = adjustment factor, lifetime (no units)

$DWIR_{lifetime}$ = drinking water intake rate for lifetime duration; drinking water intake rate for the lifetime duration based on a 95^{th} percentile time-weighted average from MDH; rate may be chemical-specific with sufficient data or use default rate of 0.043 L/kg-d

Other variables as defined under item A

Data and rationale submitted by State in support of rule revision

This algorithm is used to develop HH-WQS for pollutants characterized for carcinogenic adverse effects. The basis for the algorithm is to ensure that exposure from surface water through drinking water, fish consumption, and recreation will not exceed the state's risk level (1×10^{-5} or 1 in 100,000). The algorithms for evaluating linear carcinogens have expanded to address the use of Adjustment Factors ($AF_{Lifetime}$) for application with the CSF. These AFs enhance protection for higher cancer risk from early-life exposure as discussed in more detail in Sections III.C.1 and III.C.4(a) above.

Basis for EPA Action

The equation listed above is functionally equivalent to Equation 3-4 from EPA's 2000 guidance (USEPA 2000a) with the following state-specific modifications:

- $DWIR_{lifetime}$. As discussed above in Section III.C.3, this rate is based on a 95^{th} percentile time-weighted average from MDH with either a chemical-specific value given sufficient data or a default rate of 0.043 L/kg-day (= 3 L/day for a 70 kg adult).
- FCR_{adult}. As discussed above in Section III.C.3, this rate is the state's previously approved rate of 0.030 kg/day for a 70 kg adult and is converted for use in this equation as 0.00043 kg/kg-day.

- BAFs. As discussed above in Section III.C.3, BAFs for TL3 (24 percent) and TL4 (76 percent) were previously approved and represent state-specific derived values.
- $AF_{Lifetime}$. This factor is used when data are available to determine the additional excess risk associated with early life exposure to a pollutant. This factor would replace the default ADAF approach and could equal one if no additional risk is expected. As discussed above in Section III.B.4(a), the inclusion of $AF_{Lifetime}$ factors is consistent with EPA guidance (USEPA 2005b, 2008, 2011)

Therefore, where this equation is utilized and the resulting more stringent criteria than that derived using the standard equation in Minn. R. ch. 7050.0219, Subp. 13(C), it will be more more protective of the Class 2A and 2Bd designated uses. As such, it will provide additional protection of the Class 2 designated uses and is consistent with Section 303(c) of the CWA and Federal regulations at 40 CFR 131.

EPA therefore considers the decisions made and the justification provided to be consistent with the CWA, Federal regulations, and guidance. This equation will be used by MPCA to develop criteria to protect MN's Class 2A and 2Bd water uses and since it is equivalent to Equation 3-4 from EPA's 2000 guidance (USEPA 2000a) with acceptable or previously approved state-specific exposure inputs and use of adjustment factors, EPA finds that, all other factors being equal, this equation will generate criteria protective of aquatic life and drinking water uses as required under 40 CFR 131.11(a).

EPA Action

EPA approves the newly adopted algorithm for linear carcinogenic chemicals applicable to surface waters designated as Class 2A or 2Bd found in Minn. R. ch. 7050.0219, subp. 13, item C.

D. Algorithm for linear carcinogenic chemicals with age-dependent adjustment factors (ADAF) applicable to surface waters designated Class 2A or 2Bd

Description of the State rule revision

D. Algorithm for linear carcinogenic chemicals with age-dependent adjustment factors (ADAF) applicable to surface waters designated Class 2A or 2Bd to calculate:

CC_{dfr} or CS_{dfr} =

$$\frac{CR\,(1 \times 10^{-5}) \times 1000}{\left(\begin{array}{l}\{CSF \times ADAF_{<2} \times D_{<2} \times [DWIR_{<2} + FCR_{<2} \times (0.24BAF_{TL3} + 0.76BAF_{TL4})]\} + \\ \{CSF \times ADAF_{2\,to<16} \times D_{2\,to<16} \times [DWIR_{2\,to<16} + FCR_{2\,to<16} \times (0.24BAF_{TL3} + 0.76BAF_{TL4})]\} + \\ \{CSF \times ADAF_{16\,to\,70} \times D_{16\,to\,70} \times [DWIR_{16\,to\,70} + FCR_{Adult} \times (0.24BAF_{TL3} + 0.76BAF_{TL4})]\}\end{array}\right) \div 70\,yrs}$$

where: CC_{dfr} or CS_{dfr} = drinking water plus fish consumption and recreation chronic criterion or standard in µg/L

ADAF = age-dependent adjustment factor by age groups

D = duration corresponding to the three age groups: birth up to two years of age (two-year duration), two years of age up to 16 years of age (14-year duration), and 16 years of age up to 70 years of age (54-year duration)

DWIR = drinking water intake rate for age groups; drinking water intake rate for the lifetime duration based on a 95th percentile time-weighted average from MDH; rate may be chemical-specific with sufficient data or use default rates for:

$DWIR_{0<2}$ = 0.137 L/kg-d, birth up to two years of age

$DWIR_{2\,to<16}$ = 0.047 L/kg-d, two up to 16 years of age

$DWIR_{16\,to\,70}$ = 0.039 L/kg-d, 16 up to 70 years of age

FCR = fish consumption intake rate by age groups:

$FCR_{0<2}$ = 0.00086 kg/kg-d

$FCR_{2\,to<16}$ = 0.00055 kg/kg-d

$FCR_{16\,to\,70}$ = 0.00043 kg/kg-d

Data and rationale submitted by State in support of rule revision

The basis for the algorithm is to ensure that exposure from carcinogenic chemicals in surface water through drinking water, fish consumption, and recreation will not exceed the state's risk level (1×10^{-5} or 1 in 100,000). The algorithms for evaluating linear carcinogens have expanded to address the use of Age-Dependent Adjustment Factors (ADAF) for application with the CSF.. The algorithms that incorporate the new ADAF have to address exposure and cancer risk specifically for early life exposure using the age groups as discussed above

— birth to <2, 2 to <16, and 16 to 70 years of age — the MDH developed the appropriate drinking water IRs as discussed above in Section III.C.3.

The sum of the risks associated with each life-stage window is averaged over a lifetime duration of 70 years. The ADAFs of 10, 3 and 1 are based on EPA Supplemental Guidance (USEPA 2000b). The age-specific intake rates are time-weighted average (TWA) of the 95th percentile intake rates based on the intake rate data (see Section III.B.3). The duration in years for each age group is included in the algoritm and divided by the total lifetime averaging duration of 70 years.

Basis for EPA Action

The equation listed above is functionally equivalent to Equation 3-4 in EPA's 2000 guidance (USEPA 2000a) with the following modifications:

- ADAF – Use of Age-dependent Adjustment Factors to account for defenses in risk for different age groups. This is discussed in more detail above (see Section III.C.3 and III.C.4(a))
- DWIRs for various age groups. This is discussed in more detail above (see Section III.C.3)
- FCRs for various age groups. This is discussed in more detail above (see Section III.C.3)

The individual state-specific input factors as listed above were determined following EPA guidance as discussed above in Section III.C. Therefore, where this equation is utilized, with the higher exposures and toxicity for children included and all other factors being the same, it will be protective of the Class 2B, 2C or 2D designated uses is therefore consistent with Section 303(c) of the CWA and Federal regulations at 40 CFR 131.

EPA Action

EPA approves the newly adopted algorithm for linear carcinogenic chemicals applicable to surface waters designated as Class 2B, 2C or 2D found in Minn. R. ch. 7050.0219, subp. 13, item D.

(k) 7050.0219, Subpart 14. Algorithms for Class 2B, 2C, or2D surface waters.

This subpart describes human health-based criteria or standards for classes of surface waters designated for fish consumption and recreational use (nondrinking water use). To develop a final chronic criteria (CC_{fr}) or standard (CS_{fr}) applicable to surface waters designated Class 2B, 2C, or 2D, items A to C must be evaluated for use based on the pollutant's toxicological profile: noncarcinogen or nonlinear carcinogen (NLC) or linear carcinogen (C).

A. Algorithm for noncarcinogenic or NLC chemicals applicable to Class 2B, 2C, or 2D surface waters

Description of the State rule revision

A. Algorithm for noncarcinogenic or NLC chemicals applicable to Class 2B, 2C, or 2D surface waters to calculate: CC_{fr} or CS_{fr} =

$$\frac{RfD_{chronic}\ (mg/kg\text{-}d) \times RSC\ (no\ units) \times 1{,}000\ \mu g/mg}{\{IWR_{chronic}\ (L/kg\text{-}d) + FCR_{adult}\ (kg/kg\text{-}d)[(0.24 \times BAF_{TL3}\ (L/kg)) + (0.76 \times BAF_{TL4}\ (L/kg)]\}}$$

where: CC_{fr} or CS_{fr} = fish consumption and recreation chronic criterion or standard in µg/L

$IWR_{chronic}$ = 0.0013 L/kg-d; assumed incidental water intake rate based on minimum chronic duration

Other variables as defined under subpart 13

Data and rationale submitted by State in support of rule revision

This equation is a modification of the basic noncarcinogen and nonlinear carcinogen equation from EPA's 2000 guidance (USEPA 2000a) for waters designated for fish consumption and recreation. The IWR was determined based on EPA guidance and data as discussed above in Section III.C.3.

Basis for EPA Action

The equation listed above is functionally equivalent to Equation 3-5 from EPA's 2000 guidance with the following state-specific modifications:

- $IWR_{chronic}$. = 0.0013 L/kg-d; assumed incidental water intake rate based on minimum chronic duration. See Section III.C.3 for a more detailed discussion and consistency with EPA guidance.
- Other variables discussed above.

The individual state-specific input factors as listed above were determined following EPA guidance as discussed above in Section III.C. Therefore, where this equation is utilized with the newly determined IWR that is ten times larger than the current IWR, and all other factors being the same, more stringent criteria will be derived. As such, it will provide additional protection of the Class 2 designated fish consumption and recreation uses and is consistent with Section 303(c) of the CWA and Federal regulations at 40 CFR 131.

EPA Action

EPA approves the newly adopted algorithm for nonlinear carcinogenic chemicals applicable to surface waters designated as Class 2B, 2C or 2D found in Minn. R. ch. 7050.0219, subp. 14, item A.

<u>B. Algorithm for linear carcinogenic chemicals with lifetime adjustment factors applicable to surface waters designated Class 2B, 2C, or 2D</u>

B. Algorithm for linear carcinogenic chemicals with lifetime adjustment factors ($AF_{Lifetime}$) applicable to surface waters designated Class 2B, 2C, or 2D to calculate: CC_{fc} or CS_{fc} =

$$\frac{CR\,(1 \times 10^{-5})}{CSF\,(mg/kg\text{-}d)^{-1} \times AF_{Lifetime}} \times \frac{1000\ \mu g/mg}{IWR_{Lifetime}\,(L/kg\text{-}d) + FCR_{Lifetime}\,(kg/kg\text{-}d) \times [(0.24 \times BAF_{T3}\,(L/kg)) + (0.76 \times BAF_{T4}\,(L/kg))]}$$

where: CC_{fc} or CS_{fc} = fish consumption and recreation chronic criterion or standard in µg/L

Other variables as defined under item A and subpart 13

Data and rationale submitted by State in support of rule revision

This algorithm is used to develop HH-WQS for pollutants characterized for carcinogenic adverse effects. The basis for the algorithm is to ensure that exposure from surface water through fish consumption and recreation will not exceed the state's risk level (1×10^{-5} or 1 in 100,000). The algorithms for evaluating linear carcinogens have expanded to address the use of Adjustment Factors ($AF_{Lifetime}$) for application with the CSF. These AFs enhance protection for higher cancer risk from early-life exposure as discussed in more detail above in Section III.C.1 and III.C.4(a).

Basis for EPA Action

The equation listed above is functionally equivalent to Equation 3-4 from EPA's 2000 guidance with the following state-specific modifications:

- Use of lifetime adjustment factors and state-specific incidental water intake rate as previously discussed in Section III.C.3 and III.C.4(a). Also fish consumption rates and trophic level BAFs are used and are discussed above in Section III.C.3.
- Other factors were previously discussed.

The individual state-specific input factors as listed above were determined following EPA guidance as discussed above in Section III.C. Therefore, where this equation is utilized with the newly determined IWR that is ten times larger than the current IWR and the use of adjustment factors, and all other factors being the same, more stringent criteria will be derived. As such, it will provide additional protection of the Class 2B, 2C or 2D designated fish consumption and recreation uses and is consistent with Section 303(c) of the CWA and Federal regulations at 40 CFR 131.

EPA Action

EPA approves the newly adopted algorithm for linear carcinogenic chemicals with lifetime adjustment factors applicable to surface waters designated as Class 2B, 2C or 2D found in Minn. R. ch. 7050.0219, subp. 14, item B.

C. Algorithm for linear carcinogenic chemicals with age-dependent adjustment factors (ADAF) applicable to surface waters designated Class 2B, 2C, or 2D.

Description of the State rule revision

C. Algorithm for linear carcinogenic chemicals with age-dependent adjustment factors (ADAF) applicable to surface waters designated Class 2B, 2C, or 2D to calculate:

CC_{fr} or CS_{fr} =

$$\frac{CR\ (1 \times 10^{-5}) \times 1000}{\left(\begin{array}{l} \{CSF \times ADAF_{<2} \times D_{<2} \times [IWR + FCR_{<2} \times (0.24BAF_{TL3} + 0.76BAF_{TL4})]\} + \\ \{CSF \times ADAF_{2\ to <16} \times D_{2\ to <16} \times [IWR + FCR_{2\ to <16} \times (0.24BAF_{TL3} + 0.76BAF_{TL4})]\} + \\ \{CSF \times ADAF_{16\ to\ 70} \times D_{16\ to\ 70} \times [IWR + FCR_{Adult} \times (0.24BAF_{TL3} + 0.76BAF_{TL4})]\} \end{array} \right) \div 70\ yrs}$$

where: CC_{fr} or CS_{fr} = fish consumption and recreation chronic criterion or standard in µg/L

Other variables as defined under item A and subpart 13

Data and rationale submitted by State in support of rule revision

The basis for the algorithm is to ensure that exposure from surface water through fish consumption and recreation will not exceed the state's risk level (1×10^{-5} or 1 in 100,000). The algorithms for evaluating linear carcinogens have expanded to address the use of Age-Dependent Adjustment Factors (ADAF) for application with the CSF.. The algorithms that incorporate the new ADAF have to address exposure and cancer risk specifically for early life exposure using the age groups as discussed above — birth to <2, 2 to <16, and 16 to 70 years of age.

The sum of the risks associated with each life-stage window is averaged over a lifetime duration of 70 years. The ADAFs of 10, 3 and 1 are based on EPA

Supplemental Guidance (USEPA 2000b). The age-specific intake rates are time-weighted average (TWA) of the 95th percentile intake rates based on the intake rate data (see Section III.C.3). The duration in years for each age group is included in the algorithm and divided by the total lifetime averaging duration of 70 years.

The detailed basis for the fish-tissue equations in this subpart are discussed in the SONAR (MPCA 2014b) and TSD (MPCA 2014a).

Basis for EPA Action

The equation listed above is functionally equivalent to Equation 3-4 from EPA's 2000 guidance (USEPA 2000a) with the following state-specific modifications:

- Use of age-dependent adjustment factors and state-specific incidental water intake rate as previously discussed in Section III.C.3 and III.C.4(a). Also fish consumption rates and trophic level BAFs are used and are discussed above in Section III.C.3.

Therefore, where this equation is utilized, with the higher exposures and toxicity for children included and all other factors being the same, it will be protective of the Class 2B, 2C or 2D designated uses. As such, it will provide additional protection of the Class 2 designated uses and is consistent with Section 303(c) of the CWA and Federal regulations at 40 CFR 131.

EPA Action

EPA approves the newly adopted algorithm for linear carcinogenic chemicals with age-dependent adjustment factors applicable to surface waters designated as Class 2B, 2C or 2D found in Minn. R. ch. 7050.0219, subp. 14, item C.

(l) 7050.0219, Subpart 15. Algorithms for Class 2 fish tissue.

A. Algorithm for noncarcinogenic or NLC chemicals applicable to Class 2 surface waters

Description of the State rule revision

A. Algorithm for noncarcinogenic or NLC chemicals applicable to Class 2 surface waters to calculate: CC_{ft} or CS_{ft} =

$$\frac{RfD_{chronic}\ (mg/kg\text{-}d) \times RSC\ (no\ units)\ or\ -\ RSC\ (mg/kg\text{-}d)}{FCR_{adult}\ (kg/kg\text{-}d)}$$

where: CC_{ft} or CS_{ft} = fish tissue-based chronic criterion or standard in mg/kg

Other variables as defined under subpart 13

Data and rationale submitted by State in support of rule revision

With the exception of the fish-tissue mercury standard, which was adopted in 2008, Minn. R. chs. 7050 and 7052 currently have only water-based HH-WQS for highly bioaccumulative pollutants. The rule revisions include new algorithms as shown in this subpart to develop fish tissue-based CS_{ft} (or CC_{ft}) for toxic pollutants with final BAF greater than 1,000 (based on the BCC definition) to augment the water-based human health CS (or CC). Including fish tissue-based methods for CS_{ft} (and CC_{ft}) into WQS is needed to:

1. Enhance the usefulness of WQS by addressing the most relevant route– fish consumption – of human exposure to highly bioaccumulative surface water pollutants.
2. Reflect the EPA Guidance and recommendations for states to use fish-tissue data in their WQS program for developing HH-WQS.
3. Enable the MPCA to use more fish-tissue monitoring data to advance the process for assessing WQS.
4. Supplement, and eventually replace, the existing narrative standard in Minn. R. 7050.0150, subp. 7, based on the MDH FCA.

The detailed basis for the fish-tissue equations in this subpart are discussed in the SONAR (MPCA 2014b) and TSD (MPCA 2014a).

Basis for EPA Action

The equation listed above is equivalent to equations found in EPA's methyl mercury fish tissue guidance (USEPA 2001) and is essentially the same equation used in the EPA's 2000 Human Health Methodology (USEPA 2000a)

(Equation 3-5) to calculate a water quality criterion for noncarcinogenic chemicals, but is rearranged to solve for a protective concentration in fish tissue rather than in water. Thus, it does not include a BAF or drinking water intake value.

The proposed addition of fish tissue-based methods improves upon having water-based standards only. EPA's 2001 methyl mercury guidance speaks to the benefits of addressing fish pollutants with fish tissue-based criteria and monitoring data. Because a key aspect of HH-WQS is to keep pollutant concentrations in fish tissue below a level that can result in adverse health effects, the addition of CS_{ft} (or CC_{ft}) more directly addresses this goal and better protects fish consumers.

Therefore, where this equation is utilized it will provide additional protection of the Class 2 designated uses since it will supplement the already existing ambient water quality criteria. As such, it will provide additional protection of the Class 2 designated uses and is consistent with Section 303(c) of the CWA and Federal regulations at 40 CFR 131.

EPA Action

EPA approves the newly adopted algorithm for noncarcinogenic chemicals to calculate fish tissue chronic criteria or standards applicable to surface waters designated as Class 2 found in Minn. R. ch. 7050.0219, subp. 15, item A.

B. Algorithm for linear carcinogenic chemicals with lifetime adjustment factors ($AF_{lifetime}$) applicable to Class 2 surface waters

Description of the State rule revision

B. Algorithm for linear carcinogenic chemicals with lifetime adjustment factors ($AF_{lifetime}$) applicable to Class 2 surface waters to calculate: CC_{ft} or CS_{ft} =

$$\frac{CR\ (1 \times 10^{-5})}{CSF\ (mg/kg\text{-}d)^{-1} \times AF_{lifetime}\ (\text{no units})} \times \frac{1}{FCR_{Adult}\ (kg/kg\text{-}d)}$$

where: CC_{ft} or CS_{ft} = fish tissue-based chronic criterion or standard in mg/kg
Other variables as defined under subpart 13

Data and rationale submitted by State in support of rule revision

This formula is a modification of the basic linear carcinogen equation from EPA's 2000 guidance (USEPA 2000a) that incorporates the $AF_{Lifetime}$ as described in Section III.C.3 and III.C.4(a). The detailed basis for the fish-tissue equations in this subpart are discussed in the SONAR (MPCA 2014b) and TSD (MPCA 2014a).

Basis for EPA Action

This equation is the same equation used in the EPA's 2000 Human Health Methodology (Equation 3-4) to calculate a water quality criterion, but is rearranged to solve for a protective concentration in fish tissue rather than in water. Thus, it does not include a BAF or drinking water intake value. Also, state-specific variables are used as discussed above.

Therefore, where this equation is utilized it will provide additional protection of the Class 2 designated uses since it will supplement the already existing ambient water quality criteria. As such, it will provide additional protection of the Class 2 designated uses and is consistent with Section 303(c) of the CWA and Federal regulations at 40 CFR 131.

EPA Action

EPA approves the newly adopted algorithm for linear carcinogenic chemicals with lifetime adjustment factors to calculate fish tissue chronic criteria or standards applicable to surface waters designated as Class 2 found in Minn. R. ch. 7050.0219, subp. 15, item B.

<u>C. Algorithm for linear carcinogenic chemicals with age-dependent adjustment factors (ADAFs) applicable to Class 2 surface waters</u>

Description of the State rule revision

C. Algorithm for linear carcinogenic chemicals with age-dependent adjustment factors (ADAFs) applicable to Class 2 surface waters to calculate: CC_{ft} or CS_{ft} =

$$\frac{CR\ (1 \times 10^{-5})}{\left[\frac{(CSF \times ADAF_{<2} \times D_{<2} \times FCR_{<2}) + (CSF \times ADAF_{2-16} \times D_{2-16} \times FCR_{2-16}) + (CSF \times ADAF_{16-70} \times D_{16-70} \times FCR_{16-70})}{70\ \text{years}}\right]}$$

where: CC_{ft} or CS_{ft} = fish tissue-based chronic criterion or standard in mg/kg

Other variables as defined under subpart 13

Data and rationale submitted by State in support of rule revision

This formula is a modification of the basic linear carcinogen equation from EPA's 2000 guidance (USEPA 2000a) that incorporates the ADAFs and other age-dependent exposure variables as described in Section III.C.3 and III.C.4(a). The detailed basis for the fish-tissue equations in this subpart are discussed in the SONAR (MPCA 2014b) and TSD (MPCA 2014a).

Basis for EPA Action

This equation is essentially the same equation used in the EPA's 2000 Human Health Methodology (USEPA 2000a) (Equation 3-4) to calculate a water quality criterion, but is rearranged to solve for a protective concentration in fish tissue rather than in water. Thus, it does not include a BAF or drinking water intake value. The basic equation is also modified to account for the age-dependent exposure parameters (ADAFs, FCRs, Durations) that were previously discussed in Section III.C.3 and III.C.4(a).

Therefore, where this equation is utilized it will provide additional protection of the Class 2 designated uses since it will supplement the already existing ambient water quality criteria. As such, it will provide additional protection of the Class 2 designated uses and is consistent with Section 303(c) of the CWA and Federal regulations at 40 CFR 132.

EPA Action

EPA approves the newly adopted algorithm for linear carcinogenic chemicals with age-dependent adjustment factors to calculate fish tissue chronic criteria or standards applicable to surface waters designated as Class 2 found in Minn. R. ch. 7050.0219, subp. 15, item C.

(m) 7050.0222 Specific Water Quality Standards For Class 2 Waters Of The State; Aquatic Life And Recreation, subp. 7, item D.

Description of the State rule revision

Subp. 7. Additional standards; Class 2 waters.

D. Concentrations of noncarcinogenic or nonlinear carcinogenic (NLC) chemicals in water or fish tissue from point or nonpoint sources, singly or in mixtures, must be below levels expected to produce known adverse effects. [.....] To meet the protection objectives in part 7050.0217, the noncancer health risk index must not exceed a value of one.

$$\text{Noncancer health risk index by common health endpoint} = \frac{C_1}{CS_1 \text{ or } CC_1} + \frac{C_2}{CS_2 \text{ or } CC_2} + \ldots + \frac{C_n}{CS_n \text{ or } CC_n} \leq 1$$

where: C_n is the concentration of the first to the n^{th} chemical by common health endpoint and medium

$CS_1 \ldots CS_n$ is the drinking water plus fish consumption and recreation chronic standard (CS_{dfr} or CS_{dsr}), fish consumption and recreation chronic standard (CS_{fr}), or fish tissue chronic standard (CS_{ft}) for the first to n^{th} chemical by common health endpoint

$CC_1 \ldots CC_n$ is the drinking water plus fish consumption and recreation chronic criterion (CC_{dfr} or CC_{dsr}), fish consumption and recreation chronic criterion (CC_{fr}), or fish tissue chronic criterion (CC_{ft}) for the first to n^{th} chemical by common health endpoint

Data and rationale submitted by State in support of rule revision

This equation is a new approach for noncancer mixtures: an additivity analysis modeled on the MDH HRL rule (MDH 2008). The algorithm is based on summing up the ratio of each pollutant concentration measured in the surface water or in fish tissue to their respective CS with the same Health Endpoint. To ensure total exposure does not exceed the threshold for noncancer effects in the target organ, system, or process (development), the sum or Health Risk Index has to equal one or less to meet the HH-WQS.

Basis for EPA Action

Minnesota's rules currently include specific language on considering and limiting exposure to carcinogens in surface water. Minn. R. ch. 7052 also has general language for noncarcinogens. The carcinogen additive algorithm ensures that exposure to more than one carcinogen in surface waters does not exceed the cumulative incremental cancer risk level of 1 in 100,000 (Minn. R. 7050.0222, subp. 7, item D, and Minn. R. 7052.0230, subp. 2). For linear carcinogens, the additivity algorithm is as listed in Minn. R. 7050.0222, subp. 7.D, and Minn. R. 7052.0230, subp. 2. The additivity equation applies to chemicals that are linear carcinogens and have HH-WQS calculated with a CSF. The risk index level is slightly changed for consistency with the MDH. The index has to be equal to or less than one to meet HH-WQS. An index that exceeds one indicates the excess cancer risk level is greater than 1 in 100,000 and is in violation of the HH-WQS.

The addition of this equation for noncarcinogenic and non-linear carcinogic chemicals expands the already existing formula in Minnesota's rules for carcinogens. The use of this equation will provide additional protection for

Class 2 uses. As such, it is consistent with Section 303(c) of the CWA and Federal regulations at 40 CFR 131.

EPA Action

EPA approves the newly adopted algorithm for noncarcinogenic or non-linear carcinogenic chemicals to calculate health risk indices for single chemicals or in mixtures found in Minn. R. ch. 7050.0222, subp. 7, item D.

(n) 7050.0222 Specific Water Quality Standards For Class 2 Waters Of The State; Aquatic Life And Recreation, subp. 7, item E.

Description of the State rule revision

Subp. 7.E. Concentrations of carcinogenic chemicals from point or nonpoint sources, singly or in mixtures, ~~should~~ must not exceed ~~a~~ an incremental or additional excess risk level of one ~~chance~~in 100,000 (10^{-5}) in surface waters or fish tissue. […] To meet the protection objectives in part 7050.0217, the cancer health risk index must not exceed a value of one.

$$\text{Cancer health risk index} = \frac{C_1}{CS_1 \text{ or } CC_1} + \frac{C_2}{CS_2 \text{ or } CC_2} + \ldots + \frac{C_n}{CS_n \text{ or } CC_n} \leq 1$$

where: C_1 … C_n is the concentration of the first to the n^{th} carcinogen in water or fish tissue

CS_1 … CS_n is the drinking water plus fish consumption and recreation chronic standard (CS_{dfr}), fish consumption and recreation chronic standard (CS_{fr}), or fish tissue chronic standard (CS_{ft}) for the first to n^{th} carcinogenic chemical

CC_1 …. CC_n is the drinking water plus fish consumption and recreation chronic criterion (CC_{dfr}) fish consumption and recreation chronic criterion (CC_{fr}), or fish tissue chronic criterion (CC_{ft}) for the first to n^{th} carcinogenic chemical

Data and rationale submitted by State in support of rule revision

This is an existing provision with some updated language to better describe the process and formula used to determine if single pollutant cancer risk when added together for a mixture does not exceed the HH-WQS (see discussion immediately above). The formula was also changed to reflect that it can be used for either chronic standards or site-specific chronic criteria. A further explanation was added that this formula is applicable to both water and fish tissue criteria. A more detailed discussion of this provision can be found in the SONAR (MPCA 2014b) and TSD (MPCA 2014a).

Basis for EPA Action

This is an existing previously approved provision that has been modified based on terminology from the newly adopted methods and a clearer explanation of the additivity of the incremental chemical risk within mixtures. The applicability of fish tissue criteria was also added to the previously applicable water criteria. As such, it will provide additional protection of the Class 2 designated uses and is consistent with Section 303(c) of the CWA and Federal regulations at 40 CFR 131.

EPA Action

EPA approves the adopted revised algorithm for carcinogenic chemicals to calculate health risk indices for single chemicals or in mixtures found in Minn. R. ch. 7050.0222, subp. 7, item E.

<u>Minn. R. ch. 7052 (GLI) Rule Revisions</u>

GLI Methods. Minnesota's new human health methods for developing Class 2 CS or site-specific CC replaced those listed in Minn. R. 7050.0218 and in Minn. R. 7052.0110 as incorporated by reference from 40 CFR 132 Appendix C. The MDH toxicological evaluations are either consistent with the EPA GLI methods or improve upon these methods through the use of the most current guidance from the EPA on noncancer and cancer evaluations, as well as advancements in use of less-than-chronic duration toxicity information and Minnesota-specific policies to better protect a person from a lifetime of exposure. These enhancements and their acceptability is discussed earlier in this document.

For Site-Specific CC, which are developed for pollutants lacking promulgated CS, the minimum toxicological datasets may be less robust than that used to propose promulgating a CS, but must still meet minimum Tier II federal requirements and State-methods (i.e., consistent with the MDH health-based guidance) for their designated purpose (e.g., NPDES effluent limit).

Also, as allowed under 40 CFR 132.4(h), the use of any methodology acceptable under 40 CFR 131 can be used for developing water quality criteria or implementing narrative criteria under Part 132.

(o) Minn. R. ch. 7052.0010, subp. 41. Definition of Tier II.

Description of the State rule revision

Subp. 41. Tier II. "Tier II" means the methods referenced in part 7052.0110 for developing aquatic life ~~and human health~~ standards or criteria when there is not a set of data available that meets Tier I data requirements.

Data and rationale submitted by State in support of rule revision

The GLI criteria include methods for developing two types of human health criteria for use by states as the basis for HH-WQS, either Tier I: Human Noncancer Criterion (HNC) and Human Cancer Criterion (HCC) or Tier II: Human Noncancer Value (HNV) and Human Cancer Value (HCV). Both Tiers describe minimal datasets. However, the Tier I methods require a more robust dataset and specific suite of toxicological studies then the Tier II method. See 40 CFR 132, Appendix C.II. Minimum Data Requirements. The Tier II method requires a minimum of at least one acceptable 28-day short-term repeated dose study that provides a No Observed Adverse Effect Level (NOAEL), with some allowances for other studies if only a Lowest Observed Adverse Effect Level (LOAEL) is available. Tier I criteria also include minimum data requirements for BAFs, mainly the requirement for a field-measured BAF (see 40 CFR 132, Appendix C, II.C.1).

The GLI centered on having water quality criteria available for all of the Bioaccumulative Chemicals of Concern (BCC). Therefore, application of the Tier II method was necessary to help ensure that the EPA and Great Lakes States could develop numeric human health criteria or values (40 CFR 132). However, all the final GLI human health criteria previously adopted by the MPCA into Minn. R. 7050.0100 met Tier I minimum data requirements (MPCA 2014a). Therefore, in these amendments the reference to the Tier II methods for human health is being replaced by the revised methods that can address both robust and minimal datasets. Additionally, the MPCA contends that reliance on a past minimal dataset, as described in 40 CFR 132, Appendix C.II would not be appropriate for all pollutants, where more data may be needed to develop a defensible criterion or standard (MPCA 2014b).

Basis for EPA Action

EPA agrees with the rationale provided by the state and summarized above. The state's new methods will allow for the same capabilities as was the original intent of the GLI in distinguishing between Tier I and Tier II requirements. Therefore, this revision will better reconcile the methods in ch. 7050 with those in ch. 7052 and will not result in any lowering of protection for human health-related designated uses.

EPA Action

EPA approves the revisions made to the Tier II definition at Minn. R. ch. 7052.0010, subp. 41.

(p) Minn. R. ch. 7052.0100, subp. 1, item D. Incorporation of the state-wide human health methods in ch. 7050 into ch. 7052.

Description of the State rule revision

D. The Class 2A human health-based chronic standards listed in chapter 7050 are incorporated by reference as modified by the procedures in part 7052.0110, subpart 3.

Data and rationale submitted by State in support of rule revision

This provision incorporates the newly adopted state-wide human health methods in ch. 7050 into ch. 7052 with the exception that the BAF part of the method will use the Lake Superior-specific trophic level lipid values found in 7052.0110, subp. 3. A more detailed discussion of this provision can be found in the SONAR (MPCA 2014b) and TSD (MPCA 2014a).

Basis for EPA Action

EPA agrees with the rationale provided by the state and summarized above. As stated previously, EPA finds the new methods in ch. 7050 consistent with EPA guidance, the CWA and 40 CFR 131. As allowed under 40 CFR 132.4(h), the use of any methodology acceptable under 40 CFR 131 can be used for developing water quality criteria or implementing narrative criteria under Part 132. As previously discussed, the new methods in Minn. R. ch. 7050 are more protective than the existing methods and EPA has determined that they are protective of the Class 2 human health designated uses. The newly adopted methods are also equivalent to those under the GLI and adopted in Minn. R. ch. 7052 with the exception of some regional-specific data used for BAF determinations. As discussed above in Section III.C.3, the fish trophic level lipid values in part 7052.0110, subp. 3 will be used in place of those in part 7050.0219, subp. 6. EPA agrees that the use of the regional-specific values is appropriate and consistent with EPA guidance. As such, it will provide additional protection of the designated uses within the Lake Superior basin and is consistent with Section 303(c) of the CWA and Federal regulations at 40 CFR 132.

EPA Action

EPA approves the provision at Minn. R. ch. 7052.0100, subp. 1, item D.

(q) 7052.0100, subp. 1, item E. Adoption of *E. coli* Recreational Criteria for Lake Superior Basin.

Description of the State rule revision

Minnesota replaced its fecal coliform standards with *E. coli* standards in 2008 based on EPA's 1986 recommendations for bacteria criteria (*Ambient Water Quality Criteria for Bacteria – 1986* (EPA 440/5-84-002). The existing standards, which employed state-allowed adjustments based on state data and are consistent with the 1986 criteria, consist of a monthly geometric mean of not less than 5 samples of *E. coli* colony-forming units (cfu) per 100 ml, with 10% of the values not to exceed 1260 *E. coli* cfu/100 ml.

These new WQS rule amendments were adopted in response to EPA's publication of the "BEACH Act rule" in 2004 (40 CFR Part 131 *Water Quality Standards for Coastal and Great Lakes Recreation Waters*) that promulgated water quality criteria for bacteria at states with coastal recreation waters that had not adopted EPA's 1986 criteria.

Minnesota's rules are being revised to clarify which *E. coli* numeric WQS established under the BEACH Act rule apply within the Lake Superior basin and specifically apply to recreational coastal waters in Lake Superior. The BEACH Act rule criteria promulgated by EPA in 2004 are directly incorporated into Minn. R. ch. 7052. In addition to incorporating the specific *E. coli* standards that apply to Lake Superior, a definition of the Federal term "recreation season" was added and is the period from April 1 to October 31; the same timeframe as the existing state-wide *E. coli* WQS already in Minn. R. ch. 7050.

7052.0100 WATER QUALITY STANDARDS, Subpart 1, item E

Subpart 1. Applicability.

E. The *Escherichia (E.) coli* water quality standards in Code of Federal Regulations, title 40, section 131.41, Table (c)(1), that apply to coastal recreation waters are incorporated by reference as:

(1) *E. coli* bacteria must not exceed 126 organisms per 100 milliliters, as a geometric mean of not less than five samples representative of conditions during any calendar month; or

(2) *E. coli* bacteria must not exceed 235 organisms per 100 milliliters in more than ten percent of all the individual samples taken during any calendar month. The *E. coli* standard under this item applies only between April 1 and October 31.

Data and rationale submitted by State in support of rule revision

The data and rationale for the State's rule revisions are described in detail on pages 3, 28 and 29 of the SONAR (MPCA 2014b). This was a straightforward adoption of the criteria already in place through EPA's promulgation in 2004 with the goals of removing EPA's promulgation and also to comply with EPA's 2012 revised recreational criteria (USEPA 2012) within the Lake Superior basin.

Basis for EPA Action

On October 10, 2000, Congress passed the BEACH Act, an amendment to the Clean Water Act (CWA). The BEACH Act requires States and territories to adopt water quality standards for pathogens and pathogen indicators in coastal recreational waters that are as protective of human health as EPA's 1986 bacteria water quality criteria.

Section 303(i)(2)(A) of the BEACH Act also required EPA to promulgate water quality standards as protective of human health as EPA's 1986 bacteria criteria recommendations for States that did not have such standards . The States were required to adopt new or revised standards consistent with the BEACH Act provisions by April 10, 2004. On November 16, 2004, EPA published a final rulemaking (69 Fed. Reg. 67217 - 67243), which promulgated water quality standards for coastal recreational waters in all States that had not adopted such standards, including Minnesota.

EPA considers the following in order to make an approval determination and remove a State from the BEACH Act Rule: 1) Are the standards based on EPA's recommended indicators of *E. coli* and enterococci as pathogen indicators for freshwaters and enterococci for marine waters?; 2) Are the standards for *E. coli* and enterococci derived from a scientifically-defensible methodology that links them quantitatively to an acceptable risk level under CWA section 303(i)?; 3) Do the standards include appropriate single sample maximums for all coastal recreation waters?; and 4) Do the standards exempt fecal contamination from non-human sources? (67 FR 67217 67230-67233).

For the newly adopted standards in part 7052.0100, subp. 1, item E. Minnesota incorporated by reference the standards promulgated by EPA on April 10, 2004 under Section 303(i)(2)(A). As such, they meet the four requirements listed above. EPA has reviewed the MPCA's newly adopted *E. coli* standards and the supporting documentation provided in the SONAR document (MPCA 2014b) and considers the decisions made and the justification provided to be consistent with the CWA, Federal regulations, and guidance.

EPA acknowledges that this *E. coli* rule revision applies to waters in the Lake Superior basin as described in Minn. R. ch. 7052.0100, subp. 1. The state has indicated its intention to adopt EPA's 2012 Revised Recreational Water Quality Criteria during a future rulemaking that will apply at non-coastal waters state-wide. EPA has determined that the adopted rule revisions are protective of primary contact recreation and meet the requirements of EPA's 2012 revised criteria for waters within the Lake Superior basin. As such, they will not necessarily need to be revised as part of MPCA's planned rulemaking to adopt EPA's 2012 revised recreational criteria state-wide.

Finally, 40 CFR 131.41(d)(1) states that the state's adopted standards take precedence over EPA's promulgation once EPA determines that the state's adopted standards meet the requirements of the section 303(i) of the CWA.. EPA plans on removing the promulgation for Minnesota at some future time when it can be grouped with other state removals to conserve resources.

EPA action

EPA approves Minnesota's newly adopted standards for *E. coli* for the protection of the recreational use in waters within the Lake Superior basin including those coastal recreational waters specifically covered by section 303(i) of the CWA. With the approval of these water quality standards, these standards become the applicable water quality standards for CWA purposes as specified in the BEACH Act Rule (40 CFR 131.4l(d)) and under 40 CFR 131.21.

(r) Minn. R. ch. 7052.0110, subp. 4, item B. Applicability of new methods from parts 7050.0217 to 7050.0219.

Description of the State rule revision

B. Changes to the standards established for the pollutants in item A or additional human health-based chronic standards or site-specific chronic criteria must be based on the algorithms and methods in parts 7050.0217 to 7050.0219, with site-specific consideration as provided in part 7052.0270, except the bioaccumulation factor methods in part 7052.0110, subpart 3, must be used in place of those listed in part 7050.0219, subpart 6.

Data and rationale submitted by State in support of rule revision

This provision simply states that the newly adopted methods in part 7050 will be used within the Lake Superior basin, in part 7052, except that the BAF methods that include use of Lake Superior-specific trophic level lipid values must be used in place of the newly adopted state-wide methods in part 7050. A more detailed discussion of this provision can be found in the SONAR (MPCA 2014b) and TSD (MPCA 2014a).

Basis for EPA Action

EPA agrees with the rationale provided by the state and summarized above. As stated previously, EPA finds the new methods in ch. 7050 consistent with EPA guidance, the CWA and 40 CFR 131. The newly adopted methods are also equivalent to those under the GLI and adopted in Minn. R. ch. 7052 with the exception of some regional-specific data used for BAF determinations. As discussed above in Section III.C.3, the fish trophic level lipid values in part 7052.0110, subp. 3 will be used in place of those in part 7050.0219, subp. 6. EPA agrees that the use of the regional-specific values is appropriate and consistent with EPA guidance. As such, it will provide additional protection of the designated uses within the Lake Superior basin and is consistent with Section 303(c) of the CWA and Federal regulations at 40 CFR 132.

EPA Action

EPA approves the revisions made to Minn. R. ch. 7052.0110, Subp. 4, item B.

(s) Minn. R. ch. 7052.0110, subp. 4, item C. Applicability of new methods for chemical mixtures from ch. 7050.0222.

Description of the State rule revision

C. Concentrations of noncarcinogenic or nonlinear carcinogenic (NLC) chemicals in water or fish tissue from point or nonpoint sources, singly or in mixtures, must be below levels expected to produce known adverse effects. This is accomplished through the application of an additive noncancer health risk index using common health risk index endpoints or health endpoints as described in part 7050.0222, subpart 7, item D. Concentrations of carcinogenic chemicals from point or nonpoint sources, singly or in mixtures, must not exceed an incremental or additional excess risk level of one in 100,000 (10^{-5}) in surface waters. The combined risk from mixtures of linear carcinogens (C) is determined as described in part 7050.0222, subpart 7, item E.

Data and rationale submitted by State in support of rule revision

This provision supplements the existing protection to surface water users by including a new approach for noncancer mixtures: an additivity analysis modeled on the MDH HRL rule. The algorithm is based on summing up the ratio of each pollutant concentration measured in the surface water or in fish tissue to their respective CS with the same Health Endpoint. To ensure total exposure does not exceed the threshold for noncancer effects in the target organ, system, or process (development), the sum or Health Risk Index has to equal one or less to meet the HH-WQS.

Basis for EPA Action

EPA agrees with the rationale provided by the state and summarized above. This item adds the new capability of considering mixtures of noncarcinogenic and nonlinear carcinogenic chemicals so that the incremental or additional risk level of one in 100,000 is not exceeded. The inclusion of this additivity equation for noncarcinogenic and nonlinear carcinogens is a clear enhancement to Minnesota's rules. As such, it will provide additional protection of the Class 2 designated uses and is consistent with Section 303(c) of the CWA and Federal regulations at 40 CFR 132.

EPA Action

EPA approves the revisions made to Minn. R. ch. 7052.0110, subp. 4, item C.

IV. Endangered Species Act (ESA) Requirements

Section 7 of the Endangered Species Act (ESA) requires federal agencies to consult with the Unites States Fish and Wildlife Service (USFWS) to ensure that any federal action does not jeopardize the continued existence of any endangered or threatened species or adversely affect its critical habitat. Under 50 CFR §402.03, Section 7 applies to agency actions "in which there is discretionary agency action or control."

Human health ambient water quality criteria are developed based solely on data and scientific judgments about the relationship between pollutant concentrations and human exposure and health effects. These criteria are numeric values that describe ambient water concentrations that protect human health from the harmful effects of pollutants in ambient water. As such these criteria are adopted into state and tribal regulations to protect human health related designated uses such as the drinking water use. These criteria are not relevant to the ambient water concentrations needed to ensure protection of other, non-human health-related designated uses (e.g., aquatic life use). Rather, the State has an independent duty to adopt criteria based on those other uses, so as to ensure that all designated uses are fully protected. Ohio water quality standards include thallium criteria for the protection of aquatic life and these criteria are not affected by the subject rule revision. Accordingly, in determining whether to approve or disapprove these criteria under the CWA, EPA's discretion in making approval and disapproval decisions on new and revised standards explained at 40 CFR 131.5 is limited to determining whether the criteria ensure the protection of designated uses upon which the criteria are based (i.e., use by humans). Because consideration of effects of human health ambient water quality criteria on any listed species are not within EPA's discretion, EPA's action in this matter is not subject to the requirements of section 7(a)(2) of the ESA.

V Tribal Consultation

On May 4, 2011, EPA issued the "EPA Policy on Consultation and Coordination with Indian Tribes" to address Executive Order 13175, "Consultation and Coordination with Indian Tribal Governments." EPA's Tribal Consultation Policy states that "EPA's policy is to consult on a government-to-government basis with federally recognized tribes when EPA actions and decisions may affect tribal interests."

Multiple tribes (11) have resources in the state of Minnesota. In a letter dated March 12, 2015, EPA Region 5 extended an invitation to these 11 tribes to consult on Minnesota's proposed WQS for revisions to the methodology for deriving human health water quality criteria. A conference call to present the Minnesota rule revisions and take comments was held on March 31, 2015. Four tribes attended the call and all responded that they were only attending for information purposes and not to initiate formal consultation. Further, a comment period was established in the invitation letter ending on April 17, 2015. No written comments were received. Therefore, EPA concluded the tribal consultation since no tribal request for consultation were received by EPA's deadline.

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ATTACHMENT 3

ATTACHMENT 4

UNITED STATES ENVIRONMENTAL PROTECTION AGENCY
REGION 5
77 WEST JACKSON BOULEVARD
CHICAGO, IL 60604-3590

NOV 2 2 2017

REPLY TO THE ATTENTION OF:
WQ-16J

Honorable Laura Sue Schlatter
Office of Administrative Hearings
P.O. Box 64620
Saint Paul, MN, 55164-0620

Re: OAH Docket No. 80-9003-34519

Dear Honorable Schlatter:

On August 21, 2017, the Minnesota Pollution Control Agency (MPCA) published, "Proposed Permanent Rules Relating to Wild Rice Sulfate Standard and Wild Rice Water" (Minnesota Rules parts 7050.0130, 7050.0220, 7050.0224, 7050.0470, 7050.0471, 7053.0135, 7053.0205, and 7053.0406). Publication of the proposed rules was the culmination of years of effort by MPCA.

The U.S. Environmental Protection Agency reviewed the proposed rules. These proposed rules are a significant advance in the science of wild rice protection and EPA strongly supports MPCA's work. The proposed rules impact many aspects of Minnesota's Clean Water Act (CWA) programs as they relate to wild rice, including designated uses for surface waters of Minnesota, water quality criteria to protect these uses, site-specific modifications of uses and criteria, collection of water quality data necessary to implement the criteria, variances from water quality standards, and implementation of the water quality standards in National Pollutant Discharge Elimination System (NPDES) permits.

EPA's comments on the proposed rule are enclosed. These comments reflect EPA's preliminary review and do not constitute approval or disapproval decisions under either CWA sections 303(c) and 402, 33 U.S.C. §§ 1313(c) and 1342; nor are these comments a determination by the EPA Administrator under CWA section 303(c)(4)(B), 33 U.S.C. §1313(c)(4)(B), and 40 CFR § 131.22(b) that revised or new standards are necessary to meet the requirements of the CWA.

Thank you for the opportunity to review Minnesota's proposed rules. If you have any questions regarding the enclosed comments, please contact me or have your staff contact Katharine Marko of my staff. Ms. Marko may be reached at (312) 886-1473 or marko.katharine@epa.gov.

Sincerely,

Christopher Korleski
Director, Water Division

Enclosure

Enclosure 1, EPA Comments on Minnesota's "Proposed Permanent Rules Relating to Wild Rice Sulfate Standard and Wild Rice Water"

1. Minnesota's proposed rules

As part of this proposed rulemaking, Minnesota has made available for public comment a number of documents, including the proposed rules, two methodology documents being incorporated into the proposed rules by reference (*Sampling and Analytical Methods for Wild Rice Waters* and EPA's *Interim Economic Guidance for Water Quality Standards*), Minnesota's statement of need and reasonableness (SONAR), exhibits cited in the SONAR, attachments to the SONAR, records of the hearings held on the proposed rules, a document entitled *Final Draft: Analyzing Alternatives for Sulfate Treatment in Municipal Wastewater – Part 1*, and citations to five published research papers on wild rice and sulfates. EPA's review under the Clean Water Act (CWA) is limited to the water quality standards themselves, i.e., the proposed rules and the two documents specifically identified as being incorporated into the rules by reference. EPA views the other documents that Minnesota has published for public notice and comment as supporting documentation that supplements EPA's consideration of whether the proposed rules meet the requirements of the CWA (i.e., that states adopt the criteria necessary to protect the applicable designated use and that such criteria are based on sound science and protect the applicable designated use, consistent with the federal regulations at 40 CFR § 131.11(a)(1)).

To the extent that MPCA has incorporated by reference various procedures into its proposed rules, EPA has evaluated these procedures in light of a four-pronged inquiry to assist in determining whether a state or tribal provision is a water quality standard subject to EPA review and approval:

1. Is it a legally binding provision adopted or established pursuant to state or tribal law?
2. Does the provision address designated uses, water quality criteria (narrative or numeric) to protect designated uses, and/or antidegradation requirements for waters of the United States?
3. Does the provision express or establish the desired condition (e.g., designated uses, criteria) or instream level of protection (e.g., antidegradation requirements) for waters of the United States immediately or mandate how it will be expressed or established for such waters in the future?
4. Does the provision establish a new WQS or revise an existing WQS? A provision that establishes a new WQS or has the effect of changing an existing WQS would meet this consideration. In contrast, a provision that simply implements a WQS without revising it would not constitute a new or revised WQS.

(*What is a New or Revised Water Quality Standard Under CWA 303(c)(3)? Frequently Asked Questions*, EPA Publication No. 820F12017, October 2012.)

EPA reviewed all of the components of Minnesota's proposed rules, including the procedures identified in the rules as being incorporated by reference. In general, provisions of Minnesota's rules at Minn. R. § 7050 are potentially water quality standards and likely subject to EPA review and approval pursuant to CWA section 303(c), 33 U.S.C. § 1313(c). EPA views provisions of

Minnesota's rules at Minn. R. § 7053 as potential revisions to Minnesota's NPDES program and therefore likely subject to review pursuant to CWA section 402.

EPA discusses specific provisions of Minnesota's revised rules in detail below. Where we have determined that a procedure appears to be part of a new or revised water quality standard, we have reviewed and provided our comments. For those procedures which do not appear be part of a new or revised water quality standard, and thus would not be subject to EPA review and approval, we have, in some cases, nevertheless offered comments which we hope you will find helpful.

EPA's review of state-adopted water quality standards is described in 40 CFR § 131.5 and 131.6. EPA's review does not include approval of the SONAR or other documents that do not constitute water quality standards under the CWA.

2. EPA authority under the Clean Water Act (CWA) with respect to new and revised water quality standards (CWA section 303(c), 33 U.S.C. § 1313(c))

The federal regulations at 40 CFR § 131.3 define "water quality standards" as:

> Provisions of State or Federal law which consist of a designated use or uses for the waters of the United States and water quality criteria for such waters based upon such uses. Water quality standards are to protect the public health or welfare, enhance the quality of water and serve the purposes of the Act.

Consistent with CWA section 303(c)(2)(A), 33 U.S.C. § 1313(c)(2)(A), States and Tribes are required to submit new and revised water quality standards to EPA for review and approval:

> Whenever the State revises or adopts a new standard, such revised or new standard shall be submitted to the Administrator. Such revised or new water quality standard shall consist of the designated uses of the navigable waters involved and the water quality criteria for such waters based upon such uses. Such standards shall be such as to protect the public health or welfare, enhance the quality of water and serve the purposes of this Act. Such standards shall be established taking into consideration their use and value for public water supplies, propagation of fish and wildlife, recreational purposes, and agricultural, industrial, and other purposes, and also taking into consideration their use and value for navigation.

With respect to designated uses, EPA recognizes two distinct types of uses: 1) those specified in CWA section 101(a)(2), 33 U.S.C. § 1251(a)(2), including protection and propagation of fish, shellfish, and wildlife and recreation in and on the water; and 2) those uses specified in CWA section 303(c)(2), 33 U.S.C. § 1313(c)(2), but not in CWA section 101(a)(2), 33 U.S.C. § 1251(a)(2), i.e., agricultural, industrial and other purposes and navigation. The uses specified in CWA section 101(a)(2), 33 U.S.C. § 1251(a)(2), are presumed to be applicable to all waters unless it is demonstrated through a use attainability analysis (in accordance with 40 CFR § 131.10) that such a use is not attainable for a given surface water. Conversely, states and tribes are required to consider the "use and value" of waters for the non-101(a)(2) uses (in accordance with 40 CFR § 131.10(k)(3)).

States and tribes are required to submit any new and revised water quality standards to EPA for review and CWA section 303(c)(3), 33 U.S.C. § 1313(c)(3) requires that EPA review these submittals and approve the new or revised standards if they meet the requirements of the CWA or disapprove if they do not. Consistent with the federal regulations at 40 CFR § 131.21(c), new and revised water quality standards are not effective for CWA purposes until they are approved by EPA.

3. **EPA authority under the CWA with respect to new and revised provisions of a state's National Pollutant Discharge Elimination System (NPDES) discharge permit program (section 402 of the CWA)**

Proposed changes to Minn. R. § 7053 may be considered revisions to Minnesota's National Pollutant Discharge Elimination System (NPDES) program, subject to EPA approval, under 40 CFR § 123.62 if they are determined to be significant changes to the program. Program revisions that require EPA approval become effective upon approval of the revisions by EPA. While EPA has provided preliminary comments related to the implementation of the proposed standard in permitting (CWA section 402, 33 U.S.C. § 1342, and for purposes of making impaired water determinations under CWA section 303(d), 33 U.S.C. § 1313(d)) via a November 3, 2017 email from Chris Korleski to Rebecca Flood, EPA has included specific comments here to address those aspects of the proposed rules that appear to us to be minor revisions to the State's permitting regulations at Minn. R. § 7053.

4. **EPA Comments by Section:**

Minn. R. § 7050.0130, General Definitions

Provisions not discussed specifically below appear to be consistent with the applicable federal requirements. EPA offers the following comments on the provisions in Minn. R. § 7050.0130 that appear to be new or revised.

Minn. R. § 7050.0130, Subpart 2b. Cultivated Waters. EPA's understanding is that the surface waters to which the proposed rules apply are those waters identified specifically in the proposed rules at Minn. R. § 7050.0471 and that none of the waters identified as wild rice waters at Minn. R. § 7050.0471 include sub areas that meet the definition of "cultivated waters." Unless otherwise specified in rule, EPA considers the Class 4 D wild rice use (wild rice use) and criteria to be applicable to all waters identified in Minn. R. § 7050.0471.

Minn. R. § 7050.0130, Subpart 6c. Wild Rice Waters. The intent of the statement, "as defined by Laws 2011, First Special Session, chapter 2, article 4, section 32, paragraph (b)" is unclear. EPA's understanding of the proposed rules is that "wild rice waters" are all waters identified at Minn. R. § 7050.0471. To clarify the intent of the definition, EPA suggests the following revisions:

Wild rice waters. "Wild rice waters" means those water bodies that *are identified in part Minn. R. § 7050.0471 of Minnesota's water quality standards rules.* ~~contains natural beds of wild rice as defined by Laws 2011, First Special Session, chapter 2, article 4, section 32, paragraph (b) and are identified in part 7050.0471. Wild rice waters do not include cultivated wild rice waters.~~

Minn. R. § 7050.0220, Specific Water Quality Standards by Associated Use classes

Provisions not discussed specifically below appear to be consistent with the applicable federal requirements. EPA offers the following comments on the provisions in Minn. R. § 7050.0220 that appear to be new or revised.

Minn. R. § 7050.0220, Subp. 3a-6a. EPA notes that the tables in Minn. R. § 7050.0220 have not been updated to include Class 4D as a separate use. It appears that the tables in Minn. R. § 7050.0220 should be revised to recognize the Class 4D use created by Minn. R. § 7050.0224, Subp. 5, and possibly also the Class 4D [WR] use in Minn. R. § 7050.0224, Subp. 6. The statement in line 3.17 should appear under a column heading of 4D/IR as Minnesota did with its Eutrophication standards and others. This comment also applies to lines 4.12, 5.8 and 5.24.

MPCA proposes the following language throughout this section when referring to class 4D waters: "4D when applicable to a wild rice water listed in part 7050.0471." EPA's understanding is that 4D is always applicable to water bodies listed Minn. R. § 7050.0471 and so the phrase "when applicable to a wild rice water listed in part 7050.0471" is superfluous. To avoid confusion as to whether there might be instances when 4D would not be applicable to a wild rice water listed in Minn. R. § 7050.0471, EPA recommends that the language be revised to simply say "4D for water bodies listed in part 7050.0471."

Minn. R. § 7050.0224, Specific Water Quality Standards for Class 4 waters of the State: Agriculture and Wildlife

Provisions not discussed specifically below appear to be consistent with the applicable federal requirements. EPA offers the following comments on the provisions in Minn. R. § 7050.0224 that appear to be new or revised.

Minn. R. § 7050.0224, Subp 2. Class 4A waters. The proposed rules maintain the language, "the following standards shall be used as a guide…" (emphasis added). Minn. R. § 7050.0220 contains the same criteria (without this qualifying "used as a guide" language), which EPA understands to mean that these criteria are viewed as not-to-be-exceeded values. To clarify that the values in Subp. 2. are intended to be water quality criteria, the statement, "as a guide" should be deleted from Minn. R. § 7050.0224, Subp. 2.

Minn. R. § 7050.0224, Subp. 5. Class 4D waters; wild rice waters.

Minn. R. § 7050.0224, Subp. 5.A. The last sentence of Subp. 5.A. states, "The commissioner must maintain all numeric sulfate standards for wild rice waters on a public Web site." EPA commends MPCA's efforts to be transparent by maintaining a public website where all information relating the sulfate standard will be stored. We would like to confirm that this website will include:

- sulfate criteria values calculated via the equation stated at Minn. R. § 7050.0224 Subp. 5(B)(1),
- site-specific criteria generated via Subp. 5.B.(2) and Subp 5.C.,
- minor changes to WID numbers that do not affect the designated use of wild rice within the WID, and
- EPA-approved modifications to the areal extent of wild rice waters identified in Minn. R. § 7050.0471.

Please identify how frequently this website will be updated to ensure that the latest information will be available to permittees and stakeholders seeking to gain information on the status of sulfate criteria in a given waterbody. Up-to-date information on CWA-applicable criteria values will inform permit decisions as well as 303(d) assessments.

Minn. R. § 7050.0224, Subp. 5.B. EPA recommends that the first sentence be revised to include the term "water column" as follows:

> The annual average concentration of <u>*surface water*</u> sulfate in a wild rice water must not exceed the concentration established as the calculated sulfate standard under subitem (1) or alternate sulfate standard under subitem (2) more than one year out of every ten years.

Minn. R. § 7050.0224, Subp. 5.B.(1).

Minnesota's SONAR and TSD (exhibit 1 of the SONAR) describe the history of wild rice protection efforts and sulfate criteria in Minnesota, the background of Minnesota's proposed criterion, and the technical basis for the criterion. Since Minnesota's criterion is only proposed, EPA is providing only its preliminary technical evaluation of the proposed criterion. Based on the information provided by Minnesota as part of the public notice for these rules, the proposed criterion appears to be scientifically defensible and protective of the wild rice use. EPA's evaluation is based on the following:

- The proposed criterion is consistent with a long and abundant record of field work correlating wild rice presence and surface water sulfate concentrations;
- MPCA has demonstrated that porewater sulfide can be toxic to wild rice. Sulfate in the water column is converted to porewater sulfide in the presence of sulfate reducing bacteria (SRB). The rate of this conversion depends on the amount of total organic carbon (TOC) and total extractable iron (TEFe) in the sediments; TOC serves as an energy source for the SRB, while iron effectively binds to sulfide preventing it from becoming toxic to wild rice. In addition to MPCA's research, other studies have confirmed the toxicity of sulfide aquatic plants and how iron can bind to sulfide, rendering it non-toxic (Lamers et al., 2013; Van der Welle et al. 2007; Kinsman-Costello et al 2014); and
- The data presented in the SONAR and TSD provide sufficient support for Minnesota's conclusions regarding the role of iron in affecting the bioavailability of porewater sulfide.

MPCA's research has added greatly to the scientific understanding of the biology and chemistry of wild rice. MPCA's data and analyses further the understanding of the relationship between sulfate and wild rice growth, and appear to provide a sound scientific basis for the proposed water quality criterion to protect the wild rice designated use. The peer-reviewed journal articles generated by this effort underscore the scientific integrity of the research process that underlies the development of the proposed criterion. (Ng et al. 2017, Myrbo et al. 2017; Pollman et al. 2017; Myrbo et al. 2017 (2); and Pastor et al. 2017.)

The quantitative components of the criterion appear to be consistent with the available data presented in the SONAR and TSD. The wild rice protective porewater sulfide concentration of 120 µg/L appears to be a reasonable interpretation of the data and analyses upon which it is based. The equation for determining the concentration of sulfate necessary to ensure sulfide porewater concentrations do not exceed 120 µg/L relies on established statistical methods. The approach of adopting an equation as a water quality criterion is an accepted way of presenting a water quality criterion for a pollutant that is affected by other water quality parameters. EPA has a long history of equation-based criteria recommendations for metals based on hardness and EPA's most recent criterion recommendation for copper is based on a biotic ligand model that uses a suite of water quality parameters to determine the bioavailability and toxicity of copper at a given site. For these reasons, the proposed criterion appears to have a scientifically sound basis and to be protective of the wild rice use, consistent with the federal regulations at 40 CFR § 131.11.

The regulation at 40 CFR § 131.11(a) provides that States must adopt those criteria necessary to protect the designated use. MPCA's research and its supporting science indicate that sulfate can be a limiting factor to the growth and presence of wild rice through its conversion to sulfide in the porewater. This research indicates that a sulfate criterion is necessary for the protection of the wild rice use.

The sediment data used by MPCA to develop the sulfate criterion cover a specific range of concentrations of total extractable iron and total organic carbon present within Minnesota sediments. As a consequence, it is not possible to say with certainty that the relationships between sediment pore water sulfide and total organic carbon and total extractable iron used to calculate protective water column sulfate concentrations remain valid outside the range of the data used to develop the criterion. To ensure that calculations using the criterion equation at specific sites remain scientifically sound and protective of the use, EPA recommends that potential input parameter values be constrained to reflect the range of concentrations observed in the studies upon which the criterion is based. For MPCA's "Class B" dataset, the range for total organic carbon is 0.22 to 33.3%, and for total extractable iron in the sediments the range is 895-83,421 µg/g.

Minn. R. § 7050.0224, Subp. 5.B.(1)(a) – (c). Each of these proposed provisions address the collection of data; (a) and (b) cover collection of sediment organic carbon and iron respectively, and (c) covers the collection of sediment sulfide data.

Each provision requires the use of Minnesota's, *Sampling and Analytical Methods for Wild Rice Waters*, ("wild rice methods") in gathering the data. The wild rice methods are incorporated into the proposed rules by reference at Minn. R. § 7050.0224, Subp. E. EPA understands Minnesota's desire for consistency in collecting these important data. EPA is concerned that the methods, although detailed, are not sufficiently prescriptive to ensure that the collected data will adequately characterize the input parameters to the criterion equation so as to ensure that the wild rice use will always be protected (see also EPA's comments on Minn. R. § 7050.0224, Subp. E.). EPA recommends that MPCA modify the proposed rules to allow for flexibility in field and analytical methods in the event that modified or alternate approaches prove to be necessary because specific site conditions fall outside the range identified during development of the criterion. Minnesota's proposed rules could be revised to allow for this flexibility by modifying (a) – (c) as follows, combined with adopting EPA's recommendations regarding Minn. R. § 7050.0224, Subp. E.:

> (a) organic carbon is the amount of organic matter in dry sediment. The concentration is expressed as percentage of carbon, *consistent with the requirements of* ~~as determined using the method for organic carbon analysis in Sampling and Analytical Methods for Wild Rice Waters, which is incorporated by reference in~~ item E;

Minn. R. § 7050.0224, Subp. 5.B.(2). The provision of the proposed rules states:

> The commissioner may establish an alternate sulfate standard for a wild rice water when the ambient sulfate concentration is above the calculated sulfate standard and data demonstrates that sulfide concentrations in pore water are 120 micrograms per liter or less. Data must be gathered using the procedures specified in Sampling and Analytical Methods for Wild Rice Waters, which is incorporated by reference in item E. The alternate sulfate standard established must be either the annual average sulfate concentration in the ambient water or a level of sulfate the commissioner has determined will maintain the sulfide concentrations in pore water at or below 120 micrograms per liter.

EPA understands that the intent of this provision is to address unusual situations, such as upwelling of groundwater, that may result in site conditions that change the relationship between water column sulfate and porewater sulfide for reasons other than the effects due to iron and carbon that are accounted for in the criterion equation. EPA recognizes that site-specific conditions may affect the applicability of statewide water quality criteria. Accordingly, the federal rules at 40 CFR § 131.11(b) allow states to adopt water quality criteria that are modified to reflect site-specific conditions as long as such site-specific criteria would protect the designated use and are based on sound scientific rationale.

However, as specified at 40 CFR § 131.21, state water quality standards, including all site-specific water quality criteria, do not become effective for CWA purposes until they have been reviewed and approved by EPA under section 303(c) of the CWA. The only situation where states would not need to submit any new or revised water quality criteria to EPA for review and approval would be where states have adopted and EPA has approved a "performance-based" standard that relies on regulatory adoption of a process (i.e., a criterion derivation methodology) rather than a specific outcome (i.e., a concentration limit for a pollutant). As described in EPA's 2000 "Alaska Rule" (65 Fed. Reg. 24641), when such a performance-based approach is binding;

sufficiently detailed; and contains suitable safeguards to ensure predictable, repeatable outcomes, EPA's approval of such an approach can also serve as approval of the outcomes as well. If a state's approach is not sufficiently detailed or lacks appropriate safeguards to produce predictable outcomes, EPA review of a specific outcome remains necessary.

Minnesota's proposed provision at Minn. R. § 7050.0224, Subp. 5.B.(2) (excerpted above) does not specify a particular procedure by which an alternate standard would be calculated but allows such a standard to be set at any "level of sulfate the commissioner has determined will maintain the sulfide concentrations in pore water at or below 120 micrograms per liter." Chapter 2 of the TSD and section 6.E.10 of the SONAR describe a general empirical approach whereby an alternate standard may be set at either the ambient annual average sulfate concentration or at a level that is proportionally greater than the ambient level. While such an empirical approach could be potentially consistent with EPA's requirements for a "performance-based" standard, neither the proposed rule nor the supporting documentation specify how much sulfate and sulfide data would be required, whether that amount of data is sufficient to describe the empirical relationship between sulfate and sulfide in the specific surface water in question, or how MPCA would account for sample variability over time. Because this provision, as proposed, does not contain sufficient detail to ensure predictable, repeatable outcomes and it is unclear whether the process includes appropriate safeguards, EPA is unlikely to be able to approve this provision as a performance-based standard. One way to address this would be for MPCA to add sufficient detail to satisfy the requirements for performance-based standards, as described above. However, EPA believes that would be a significant undertaking that likely would not be achievable within the bounds of the current rulemaking process. Alternatively, MPCA could use this process to develop site-specific criteria, consistent with the federal CWA requirements for water quality criteria at 40 CFR § 131.11 and subject to EPA review and approval under CWA section 303(c), 33 U.S.C. § 1313(c), and 40 CFR §§ 131.20(c) and 131.21 (further discussed below).

We assume that until MPCA develops a performance-based standard, it would submit alternate standards to EPA for review and approval, just as the State would submit site-specific criteria for EPA review and approval. Therefore, EPA suggests the following sentence be added to the end of Minn. R. § 7050.0224 Subp. 5.B.(2):

> *Any alternate standard shall be duly adopted following an opportunity for public review and comment and a public hearing consistent with the requirements of 40 CFR § 25.5 and submitted to EPA consistent with section 303(c) of the Clean Water Act*

The federal regulations at 40 CFR § 25.5 specify that the public be given notice at least 45 days prior to a public hearing and that there be at least one public hearing to obtain public comment. EPA review is required to be completed within 60 days for approvals and 90 days for disapprovals. Consequently, the administrative process of adoption and submittal to EPA can be as little as four months if Minnesota is able to create a process for adoption that is comparable to the Federal requirements.

Minn. R. § 7050.0224, Subp. 5.C. The provision of the proposed rules states:

> The commissioner may establish a site-specific sulfate standard using the process in part 7050.0220, subpart 7, or 7052.0270 when the commissioner determines that the beneficial use is not harmed. This decision must be based on reliable and representative data characterizing the health and viability of the wild rice in the wild rice water.

Site-specific modifications of water quality standards previously approved by EPA are new or revised water quality standards subject to review and approval by EPA before they are effective for CWA purposes, consistent with CWA section 303(c)(2)(A), 33 U.S.C. § 1313(c)(2)(A) and federal regulations at 40 CFR §§ 131.20(c) and 131.21. Minnesota's water quality standards at Minn. R. § 7050.0270 acknowledge this requirement, whereas Minn. R. § 7050.0220 does not. To ensure clarity and conformity with the requirements of the CWA, EPA recommends adding the following sentence to Subp. 5.C.:

> *Any site-specific sulfate criterion shall be duly adopted following an opportunity for public review and comment and a public hearing consistent with the requirements of 40 CFR § 25.5 and submitted to EPA consistent with section 303(c) of the Clean Water Act.*

As was discussed above related to Minn. R. § 7050.0224, Subp. 5.B.(2), federal regulations at 40 CFR § 25.5 specify that the public be given notice at least 45 days prior to a public hearing and that there be at least one public hearing to obtain public comment. EPA review is required to be completed within 60 days for approvals and 90 days for disapprovals. Consequently, the administrative process of adoption and submittal to EPA can be as little as four months if State law allows creation of such a comparable process.

Minn. R. § 7050.0224, Subp. 5. D. The proposed rule states:

> Discharges of sulfate in sewage, industrial waste, or other wastes affecting class 4D waters must be controlled so that the numeric sulfate standard for wild rice is maintained at stream flows that are equal to or greater than 365Q10.

It is unclear whether Minnesota intends for water quality-based effluent limits (WQBELs) to apply when receiving water flows are less than 365Q10. Further, the proposed rules are silent on how discharges to lentic systems are addressed. The SONAR (page 99) states that isolated water bodies without inflows or outflows would have a one in ten-year flow of zero. This baseline flow calculation is acceptable to EPA.

Thus, EPA recommends proposed Minn. R. § 7050.0224 Subp. 5.D. be clarified, with the possible revised rule language below, which would address EPA's comments:

> Discharges of sulfate in sewage, industrial waste, or other wastes affecting class 4D lotic waters must be controlled so that the numeric sulfate standard for wild rice is maintained at stream flows that are equal to or greater than 365Q10, whereas the one-in-ten-year flow for isolated water bodies without inflows or outflows would be set at zero. Effluent

limits in NPDES permits that are developed to protect class 4D waters must be complied with regardless of stream flows.

Minn. R. 7050.0224, Subp. 5.E. This provision of Minnesota's proposed rules adopts the document, *Sampling and Analytical Methods for Wild Rice Waters*, (wild rice methods) by reference. EPA commends MPCA for detailing its intended methods for collecting data to calculate a numeric expression of its sulfate criterion. In other instances of state adoption of equation-based criteria requiring site-specific inputs to calculate protective criteria values at a site, EPA has encouraged states to document how the state will 1) determine the "site" to which the site-dependent criteria values apply, 2) consider spatial and temporal variability for each site when determining equation input data, and 3) reconcile outputs from the equation to ensure that the designated use is protected.

Although EPA encourages states to include these considerations in procedures concurrent with adoption of equation-based criteria, EPA is concerned that by adopting the document, *Sampling and Analytical Methods for Wild Rice Waters* (Minnesota Pollution Control Agency 2017) by reference, Minnesota may hamper its ability to respond to unforeseen technical issues that may arise as new sites are visited and for which application of the methods as written may lead to results that do not adequately protect the wild rice use as it occurs in a given wild rice water.

To memorialize the key overarching considerations captured in Minnesota's methods while preserving flexibility to respond to any operational issues that may arise with implementation of the proposed sulfate criterion, EPA has the following suggested modification to Minn. R. 7050.0224, Subp. 5. EPA's technical comments on the methods themselves are provided in appendix 1.

E. *Sampling and analytical methods to generate a numeric expression of the sulfate criterion for a specific wild rice water identified in 7050.0471*

(1) Definition of Terms:

(a) "wild rice waters" means the entire WID as identified in Minn. R. 7050.0471;

(b) "wild rice habitat" describes all areas where wild rice is growing or may grow within a WID;

(2) Requirements for generating a numeric expression of the sulfate criterion for a specific wild rice water identified in 7050.0471

(a) The entire wild rice water as identified in 7050.0471 must be evaluated to identify and document all areas of wild rice habitat

(b) Data must be collected in such a manner and of sufficient quantity to ensure that the values in the criterion equation at Minn. R. 7050.0224, Subp. 5.B.(1) for sediment total extractable iron and sediment total organic carbon are scientifically defensible and result in a numeric expression of the criterion that is protective of wild rice in all areas of wild rice habitat within the wild rice water

(c) The method for selecting sediment sample sites must be documented and must be appropriate for generating a representative sample of the wild rice water

(d) The methods for collecting, processing, and analyzing sediment samples must be fully documented, including all QA/QC conducted to ensure valid, reproducible results

(3) Requirements for determining the porewater sulfide for a specific wild rice water identified in 7050.0471

(a) The entire wild rice water as identified in 7050.0471 must be evaluated to identify and document areas of wild rice habitat

(b) Data must be collected in such a manner to ensure that the concentration of porewater sulfide reported for the wild rice water is scientifically defensible and result in a numeric expression of the criterion that is protective of wild rice in all areas of wild rice habitat within the wild rice water

(c) The method for selecting sediment sample sites must be documented and must be appropriate for generating a representative sample of the wild rice water

(d) The methods for collecting, processing, and analyzing sediment samples must be fully documented, including all QA/QC conducted to ensure valid, reproducible results

(4) The document, Sampling and Analytical Methods for Wild Rice Waters, Minnesota Pollution Control Agency (2017), provides the technical recommendations for gathering data required to generate a site-specific numeric expression of the sulfate criterion found at 7050.0224, Subp. 5 (B)(1) and for generating porewater sulfide data for a wild rice water.

7050.0471, Class 4D Surface Waters in Major Drainage Basins

Provisions not discussed specifically below appear to be consistent with the applicable federal requirements. EPA offers the following comments on the provisions in Minn. R. § 7050.0471 that appear to be new or revised.

Minn. R. § 7050.0471, Indian Country. Should MPCA submit these rules for EPA review and approval and should EPA approve them, our approval would apply only to those listed waterbodies that are not within Indian country, as defined in 18 U.S.C. section 1151. EPA does not intend to approve or disapprove WQS applying to waters within Indian country. The EPA, or authorized Indian tribes, as appropriate, will retain responsibilities for establishing WQS for waters within Indian country.

Minn. R. § 7050.0471, Subp. 2. Triennial Reviews. EPA supports the concept included in the proposed rules that new Class 4D wild rice waters may be added to Minn. R. § 7050.0471 through the State's CWA triennial review process. Providing additional detail about how that may be accomplished and the types of information that would be needed to support adding a water would facilitate future triennial reviews. Based on review of this subpart, EPA offers the following comments:

- Location – how will Minnesota accept location descriptions? Name of waterbody? GIS coordinates? General description of location? Are people required to use Minnesota's search tool to identify WIDs?
- The proposed rules provide a list of the types of "evidence" of the presence of a wild rice use that will be solicited as part of future triennial reviews for purposes of identifying additional Class 4D waters. The rule does not distinguish between the different types of evidence; however, the corresponding SONAR discussion (pages 59 – 64) indicates that some types of evidence of wild rice use are sufficient on their own to document a wild rice use while others must be in conjunction with other lines of evidence. Clarification of Minnesota's expectations would facilitate future application of this section of the proposed rule.
- The proposed rules say that some information may require additional documentation. For example, the rules state that "written or oral histories *that meet the criteria of validity, reliability, and consistency* [emphasis added];" may be used as evidence of a 4D use. What are the criteria of validity, reliability, and consistency? How will information be evaluated, by whom and who will provide this documentation?
- The SONAR (page 65) states that Minnesota will maintain a list of waters that have insufficient information to designate a Class 4D use. Will Minnesota indicate why the information presented was determined to be insufficient?

Minn. R. § 7050. 0471 Subp. 5 -9. Minnesota's proposed rules at Minn. R. § 7050.0471 establish a Class 4D wild rice water use for each of the surface waters identified by "Water Identification Number" (WID) in the subparts of Minn. R. § 7050.0471. EPA supports MPCA's efforts to clarify the beneficial use of wild rice and to identify approximately 1300 waters where the use applies. Consistent with the federal regulations at 40 CFR § 131.21, once approved by EPA, standards are applicable for CWA purposes for the waters as identified in Minn. R. § 7050.0471.

EPA understands that WIDs are used for purposes other than the designation of wild rice as a beneficial or designated use in Minnesota. As such, there will likely be a scenario where an individual WID number may need to be modified or split for purposes other than the absence of wild rice within a portion of the WID (i.e. differences in aquatic macroinvertebrate communities for purposed of assessment). It is our understanding that in the event a WID is subdivided, the original WID number is removed and replaced with new numbers (i.e., a riverine WID "001" would be changed to two WIDs with new assigned numbers "002" and "003"). EPA understands that MPCA wants to retain the ability to make these non-significant changes to WID numbers. However, EPA expects that these changes will be posted on the planned public website where MPCA will house information relating to the revised equation-based sulfate standard (see comment regarding Minn. R. § 7050.0224 Subp. 5.A.) and that the State will update these changes to WID numbers in rule via the triennial review process (Minn. R. § 7050.0471 Subp. 2.) EPA emphasizes that modifications to a WID number are only permissible as long as the designation of the WID as a wild rice water is not removed for the entirety of a WID or any subpart of a WID previously approved as a wild rice water.

Any modification to Minnesota's designated wild rice waters that would result in a removal of wild rice as a beneficial use would be a change to the applicable, EPA-approved designated use and would need to be adopted pursuant to state law and submitted to EPA for review under CWA section 303(c). To the extent that MPCA may choose to modify where the wild rice use applies, the state must document its consideration of the "use and value" of the water that supports the state's decision to remove the wild rice use from the affected surface water in accordance with 40 CFR § 131.10(a).

When considering the use and value of a surface water, EPA recommends that states take into account a suite of facts including, but not limited to:

- Relevant descriptive information (e.g., identification of the use that is under consideration for removal, location of the water body/waterbody segment, overview of land use patterns, summary of available water quality data and/or stream surveys, physical information, information from public/comments and/or public meetings, anecdotal information, etc.);
- Attainability information (i.e., the 40 CFR § 131.10(g) factors) if applicable; and
- Value and/or benefits (including environmental, social, cultural and/or economic value/benefits) associated with either retaining or removing the use.

Minn. R. § 7053.0406, Requirements for Facilities Discharging to Wild Rice Waters

Provisions not discussed specifically below appear to be consistent with the applicable federal requirements. EPA offers the following comments on the provisions in Minn. R. § 7053.0406 that appear to be new or revised. EPA also offers specific technical comments on the implementation of the proposed rules in appendix 2.

Minn. R. § 7053.0460, Subp. 1. Minnesota's proposed rules at Minn. R. § 7053.0406 Subp. 1 appear to allow for modification of where in a WID the Class 4D wild rice designated use applies (see comment Minn. R. § 7050.0471 Subp. 5-9, above):

> No effluent limit required based on site-specific conditions. If the commissioner determines that, based on the location of the discharge in the wild rice water or site-specific hydraulic or substrate conditions, the effluent will not affect the class 4D wild rice beneficial use in the wild rice water, the commissioner must not establish a water-quality-based effluent limitation for the class 4D sulfate in that discharge

MPCA is proposing language that would allow the MPCA Commissioner to determine that an effluent discharge will not affect the Class 4D wild rice beneficial use based on the location of the discharge and site-specific hydraulic or substrate conditions. Such a determination would prohibit the MPCA Commissioner from establishing a water-quality based effluent limit (WQBEL) for sulfate for the discharge of concern. The SONAR (page 106) states that MPCA anticipates this provision will be used for "situations where the location of the discharge point will ensure there is no reasonable potential for an impact on the wild rice beneficial use."

Federal regulations at 40 CFR § 122.44(d)(1)(vii)(A) specify that all WQBELs in an NPDES permit must derive from and comply with all applicable water quality standards. WQBELs must be developed for all pollutants that have the reasonable potential to cause or contribute to an excursion above any applicable WQS, in accordance with 40 CFR § 122.44(d)(1)(i). EPA interprets Minn. R. § 7053.0406 Subpart 1 to be inconsistent with 40 CFR §§ 122.44(d)(1)(vii)(A) and 40 CFR 122.44(d)(1)(i), insofar as that the provision establishes a process whereby the MPCA Commissioner may determine that no sulfate WQBEL is necessary to protect the wild rice beneficial use, absent an evaluation of reasonable potential. Application of Minn. R. 7053.0406 Subpart 1 would therefore result in NPDES permits that are not in compliance with the applicable wild rice use and associated criteria on designated wild rice waters.

Minn. R. § 7053.0460, Subp. 2. Variances. As discussed in section 6.I of the SONAR, this provision is intended to address situations where meeting a WQBEL derived from the proposed sulfate standard would be economically infeasible. This would be consistent with the CWA and Minnesota's recently federally approved variance rules at Minn. R. § 7050.0190, both of which allow the state to grant a water quality standards variance where it is currently infeasible to meet a water quality standard for one of the six factors found in Minnesota's state rules at Minn. R. 7050.0190, Subpart 4, Item A.

In 2015, EPA published a new regulation on water quality standards variances (80 Fed. Reg. 51020 -51051 (August 21, 2015)). The preamble to these regulations reviews the role that water quality standards variances can play in managing the transition to new, more stringent water quality criteria that are determined to be necessary to protect the uses of surface waters. The preamble states: [Water quality standards] variances are customized [water quality standards] that identify the highest attainable condition applicable throughout the [water quality standards] variance term." (80 Fed. Reg. 51035.) Water quality standards variances are defined by EPA at 40 CFR § 131.3 (o) as, "a time-limited designated use and criterion for a specified pollutant(s), permittee(s), and/or water body or waterbody segment(s) that reflects the highest attainable condition applicable throughout the specified time period.

Because water quality standards variances have the effect of temporarily changing uses and criteria, they are themselves new water quality standards that must be adopted subject to public participation and comment and submitted to EPA for review and approval. Consistent with the federal regulations at 40 CFR § 131.14, a water quality standards variance has two key components: 1) a demonstration that attaining the unvaried water quality standards is not feasible, and 2) a description of the "highest attainable condition" and the steps necessary to achieve the highest attainable condition. The federal regulations at 40 CFR §§ 131.14(b)(ii)(A)(1 - 3) define the "highest attainable condition" as:

> (*1*) The highest attainable interim criterion; or
>
> (*2*) The interim effluent condition that reflects the greatest pollutant reduction achievable; or
>
> (*3*) If no additional feasible pollutant control technology can be identified, the interim criterion or interim effluent condition that reflects the greatest pollutant reduction achievable with the pollutant control technologies installed at the time the State adopts

the WQS variance, and the adoption and implementation of a Pollutant Minimization Program.

EPA notes that the situation Minnesota faces with adoption of its revised sulfate criterion for wild rice is not unlike what occurred when states in the Great Lakes region adopted more stringent water quality criteria to comply with the requirements of EPA's Great Lakes regulations at 40 CFR § 132, which were published by EPA in 1995. Many Great Lakes dischargers operate under variances, especially for mercury. EPA's experience has been that variances can be an effective tool for managing the transition to more stringent water quality criteria and achieving feasible progress. While EPA's review of any specific water quality standards variance is dependent on the specific information supporting the variance, EPA Region 5 has extensive experience working with states to develop water quality standards variances and would be happy to work with MPCA to ensure that any potential water quality standards variance from the sulfate standard would be consistent with federal variance rules at 40 CFR § 131.14.

The proposed rules at Minn. R. § 7053.0406, Subp. 2 reference the state's variance rules at Minn. R. § 7053.0195. During the rulemaking for Minnesota's revisions to its variance rules, MPCA stated that "[p]roposed variance provisions in Minn. R. 7053 are expressly limited to variances from state discharge restrictions and minimum treatment requirements that are explicitly included in this chapter. The MPCA acknowledges that variances from WQS must proceed under chapter Minn. R. 7050 or 7052" (MPCA, Final Response and Proposed Amendments to *Minnesota Rules*, Chapters 7050, 7052, and 7053 Governing Water Quality Variances, p. 6). Therefore, it is unclear how Minn. R. § 7053.0195 would apply to a variance from the sulfate water quality standards to protect the wild rice use. EPA recommends that MPCA reword this subpart to clarify when the state's three variance rules (Minn. R. §§ 7050.1910, 7052.0280 and 7053.0195) would apply to a variance from the sulfate standard.

One possible way this might be accomplished follows:

Subp. 2. **Variances.**

A. A permit applicant may apply for a variance from the sulfate *water quality* standard for wild rice ~~*and associated water quality based effluent limit (WQBEL)*~~, as specified in parts 7000.7000, 7050.0190 *and* 7052.0280, ~~and 7053.0195~~ as applicable.

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Appendix 1- EPA Technical comments on Minnesota's *Sampling and Analytical Methods for Wild Rice Waters*

Comments on Sediment Characterization Procedures

1. *Page 3, Background*- In the first sentence of this section, MPCA states that they have "developed these procedures to ensure that samples taken for the purposes of establishing the sulfate standard to protect wild rice (Minn. R. § 7050.0224) are accurate." EPA recommends that MPCA revise this language to state that "the Minnesota Pollution Control Agency has developed these procedures to ensure that samples taken for the purpose of calculating a quantitative expression of the sulfate standard to protect wild rice (Minn. R. § 7050.0224) are scientifically defensible and protective of the Class 4D wild rice use." EPA also recommends that MPCA add a goal statement about the intent of the porewater sampling procedure found in the section entitled "Porewater sampling and analytical method for the determination of sulfide" on pp. 12-13) as it relates to revised provisions in the rule such as the alternate criteria (Minn. R. § 7050.0224 Subp. 5.B.2) and site-specific criteria (Minn. R. § 7050.0224 Subp. C.)

2. *Page 3, Identify Areas of Wild Rice Habitat*- EPA is concerned that this section does not provide enough detail as to how a WID will be assessed for wild rice habitat. MPCA states that the first step to the sediment sampling procedure for wild rice should be to "identify areas within a wild rice water where wild rice is growing or may grow. The entire wild rice water must be evaluated to determine areas of wild rice habitat." EPA asks that MPCA clarify when wild rice waters (i.e., WIDs) will be assessed for areas of wild rice habitat relative to when they will be sampled to characterize for sediment total organic carbon (TOC), total extractable iron (TEFe) and/or porewater sulfide (i.e., will these be separate events? What will be the acceptable time frame between these two events?). Please indicate how WIDs will be accurately surveyed for depth as well as substrate and hydraulic conditions since this information appears to be required (Minn. R. § 7053.0406 Subp. 1) for sediment characterization and rule implementation.

   Additionally, it is EPA's understanding that aerial photography is not an effective means of identifying where beds of wild rice may exist. Wild rice is a grass species and there are several other species that are very similar in appearance. As a result, it is not possible to accurately assess where wild rice is growing via remote imagery. If MPCA intends to incorporate the use of aerial photography anywhere in this procedure, then EPA recommends that the methods by which these images will be verified by on-the-ground assessments prior the characterization of these areas for TOC, TEFe and porewater sulfide.

3. *Page 4, Selection of Sediment Sample Areas*- MPCA states that "if the wild rice water contains areas with wild rice habitat identifier #1, all of the sediment sample areas must be in #1 areas." However, the previous draft of the sediment sampling protocol that was made available to MPCA's Technical Advisory Committee for wild rice on February 15, 2017 stated that the sampling effort should "select sample sites on the above descriptors (habitat identifiers 1-5 (similar to the identifiers currently listed in the July 2017 version of this

document) as prioritized or in combination to best represent the conditions in the wild rice water at the time of sampling" (emphasis added). EPA is concerned that sampling solely in habitats where there is evidence of wild rice being present may bias the sampling; especially in the case of porewater sulfide sampling where MPCA has stated that research has demonstrated the presence of sulfide can lower the concentration of porewater sulfide within a bed of wild rice (Myrbo et al., 2017). In the interest of developing a protective sulfate concentration across an entire WID, EPA recommends that MPCA take a broader approach when conducting sediment characterization sampling within WIDs and use a combination of habitats that most accurately reflect conditions at the site in order to develop a protective sulfate concentration that is most protective of the entire range of habitats observed within a WID.

As an alternate approach, where there is evidence of habitat that has previously supported or could potentially support wild rice, MPCA could conduct some preliminary "screening" sampling in order to make a determination as to whether those areas could still support wild rice. If that is the case, then these areas should be included as at least one of the five transects to be sampled when the TOC and TEFe are characterized for the development of a sulfate criterion for that WID.

This procedure also specifies that the number of habitat areas sampled is limited to five; however, it is not clear how those five will be selected when more than five exist. In other words, what criteria will be chosen to determine which wild rice beds are to be sampled when more than five beds occur across a WID? EPA recommends that MPCA specify the criteria for how wild rice beds are to be chosen for sampling when more than five beds are present across a WID. Such criteria should ensure that the data are collected in such a manner to ensure that the calculated sulfate criterion using that data is protective of wild rice in all areas of wild rice habitat in the WID.

Further, MPCA states that "if there are fewer than five separate areas with habitat identifier #1, the largest areas must be divided to establish five sediment samples." EPA recommends that MPCA attempt to define a minimum acceptable size for a wild rice bed if more than one transect will be placed in the same wild rice bed. Additionally, where less than five separate areas of wild rice are present, MPCA progresses through the hierarchy as identified in Section 1, of this procedure to habitat areas 2, 3, 4, 5 and 6 which represent other areas that could potentially support wild rice within a WID.

4. *Page 5, Identifying Sampling Transects*- MPCA states that transects must be "a straight line across the sediment sample area" and "perpendicular to the shore, unless the area is an island of habitat that is far away from any shore." EPA recommends that MPCA add more detail to this section including but not limited to:

    - Specify the areas within a habitat where transects are to be placed (i.e., an approximation of center or a section of the wild rice bed where density appears to be high).
    - Minimum and maximum allowable distances between transects.
    - Minimum and maximum allowable lengths of transects.
    - Minimum and maximum allowable distances between sampling points along a transect.

This procedure also states: "Identify the approximate location of each transect with each sediment sample area on the map or aerial photograph of the water." MPCA provides no further clarification on how the position of a transect should be identified and recorded. EPA recommends that the information collected on each transect should include but not be limited to:

- GPS coordinates on the start and end of the transect with specified accuracy parameters on the instrument being used to collect these coordinates.
- A description of where the transect is located relative to landmarks on shore.
- The heading and/or length of the transect.
- Photographs of specific orientations relative to the transect (i.e., pointing towards shore at the beginning of the transect).

5. *Page 5, Sediment Sample Collection and Processing (1)*- EPA recommends that MPCA provide more information on how to handle samples of varying consistency; in particular, samples that are of a "slurry" consistency where it may be difficult to obtain an intact sediment core.

   EPA recommends that MPCA define the diameter of the corer that will be required to conduct the sediment sampling. According to page 85 of the TSD, a 70 mm or (7 cm) polycarbonate core tube was used for the pilot test of the sediment sampling procedures and the porewater sulfide procedure also specifies a 7 cm diameter core barrel be used (Section 2). Barring any major problems discovered with this size core during the pilot testing, EPA recommends that MPCA specify this as the core size for all future sampling unless site conditions require a core of a different diameter. If that becomes the case, then an alternate core diameter should also be identified in these procedures.

6. *Page 5, Sediment Sample Collection and Processing (2)*- As it appears that sediment sampling locations will be used as a reference point for additional sampling for porewater sulfide sampling locations (as specified in Section 1 of the porewater sulfide procedure) EPA strongly recommends that MPCA collect GPS coordinates for each sediment sample point and define minimum/maximum allowable distances between each point. Once a minimum allowable distance is defined, then MPCA should define the acceptable accuracy of GPS instruments used to identify sampling locations to ensure sufficient geographical information is collected such that these sites can be resampled.

7. *Page 5, Sediment Sample Collection and Processing (6)*- EPA requests that MPCA specify the procedure for how sediments will be composited for each transect. MPCA should provide specific information as to how large rocks and other debris will be removed from the sample in a uniformly consistent manner.

8. *Page 5, Sediment Sample Collection and Processing* (7)- EPA recommends that MPCA specify the type of container that the sediment subsample will be transferred into, as well as how these samples will be transported back to laboratory prior to analysis.

9. *Page 5, Sediment Sample Collection and Processing*- EPA requests that MPCA specify the procedures that are to be used to ensure that the sampling equipment will be cleaned

sufficiently between sediment sample cores, transects and wild rice waters to ensure that no cross-contamination of sediment samples during sampling.

Comments on Analytical Methods

10. *Analytical Methods*- As written, the Sampling and Analytical Methods document incorporated by reference at Minn. R. § 7050.0224 Subp. 5.E "describes the methods for the preparation and analysis of sediment samples" for total extractable iron (TEFe) (pp. 8-9) and total organic carbon (TOC) (pp. 10-11). However, the document does not appear to restrict preparation and analysis of sediment samples to those methods described in the document. If MPCA intends to require that sediment samples be prepared and analyzed using the methods described in the document, EPA recommends that the document explicitly restrict analysis of the sediment samples to specific methods cited in the document.

11. *Analytical Methods*- The analytical methods for the determination of TEFe and TOC do not appear to require a specific published method. As an example, the TOC method cites a specific method but only requires that the sample by analyzed using a "Standard Operating Procedure based on EPA Method 9060A", which suggests that the method could be modified. If MPCA will be allowing flexibility in the specific analytical method used to analyze sediment samples, MPCA should define how it will determine whether analytical results will be acceptable or not by specifying the required data quality objectives (DQOs). Such DQOs may include minimum detection limits, acceptable ranges of calibration, training and certification requirements for laboratory staff, and precision and accuracy requirements.

12. *Analytical Methods*- EPA would like clarification on where the measures of acceptable performance as described here were derived from for the TEFe, TOC and porewater sulfide methods. In particular, where were the acceptance criteria for the Laboratory Control Sample (LCS), Matrix Spike (MS) and Relative Percent Difference (RPD) derived from?

13. *Analytical Methods*- Both the sediment sampling procedure and the analytical methods for TOC, TEFe and porewater sulfide do not specify requirements for collecting QA/QC samples in the field, such as blanks and duplicates. We recommend that MPCA specifically state which field QA/QC samples should be collected while in the field as well as the requirements for analyzing these field QA/QC samples in the analytical methods for TOC, TEFe and porewater sulfide in the "Acceptable Performance" section of each method.

14. *Analytical Methods*- At several points in both the sediment sampling and analytical methods MPCA says to "manually remove large materials such as rocks, shells, and sticks." However, manually removing debris is not likely to be done in a consistent manner, which will likely lead to increased variability among samples and a potential source of error. EPA recommends that MPCA consider sieving sediment samples for TOC and TEFe prior to analysis.

15. *Analytical Methods*- The methods stated in sections 2(a) and 2(b) of both the TOC and TEFe procedures appear to have been derived from EPA standard methods on sample preparation techniques. Page 523 (Section 9.2 of EPA standard method 6020A) of MPCA's document "Minnesota Wild Rice Sulfate Standard 2013 Field Survey- Quality Assurance Plan" states: "Refer to a 3000 series method (Method 3005, 3010, 3015, 3031, 3040, 3050, 3051, or 3052)

for appropriate QC procedures to ensure the proper operation of the various sample preparation techniques." EPA recommends that MPCA cite and explicitly incorporate which sample preparation procedures are being used for both the TEFe and TOC analytical procedures. Citing and using EPA standard methods provides certainty and transparency and EPA encourages MPCA to do this to the extent possible.

16. *Page 8, Analytical Method for Determination of Total Extractable Iron (TEFe) in Sediment (3)*- Page 85 of the TSD states that in the pilot study done for sediment characterization in June 2015 "analysis of TEFe followed Balogh et al. (2009) as modified by the Minnesota Department of Health (MDH, 2016). EPA notes that the procedures listed in the methods for Balogh et al. (2009) do not include an analysis of iron. EPA requests that MPCA clarify on where the method the analytical method for TEFe was derived from and how it compares to the method that was used to analyze TEFe for samples collected from the field study (as described in the document "Minnesota Wild Rice Sulfate Standard 2013 Field Survey – Quality Assurance Project Plan).

17. *Page 10, Analytical Method for the Determination of Total Organic Carbon in Sediment (3)*- This method cites EPA (SW-846) Method 9060A for analysis of TOC in sediments. However, Section 3.2 of Method 9060A states that it is "applicable only to homogeneous samples which can be injected into the apparatus reproducibly by means of a microliter-type syringe or pipet. The openings of the syringe or pipet limit the maximum size of particle which may be included in the sample." It is not clear how dried sediment will be successfully injected. Please clarify and specify any additional sample preparation or extraction methods that may be needed to perform Method 9060A so that future use of your methodology will be consistent.

18. *Page 10, Analytical Method for the Determination of Total Organic Carbon in Sediment (4)*- EPA asks that MPCA provide clarification on where the QA/QC procedures stated set forth in this section originated from, as they do not appear to match the QA/QC recommendations as stated in sections 7.0 and 8.0 of Method 9060A. The MPCA procedure says to "analyze every sample in duplicate. The relative percent difference (RPD) must be ≤ 30%." However, Method 9060A explicitly states in Section 7.6 that "quadruplicate analysis is required. Report both the average and the range." EPA asks that MPCA clarify why the collection of duplicate samples versus the Method 9060A recommendation of quadruplicate samples is appropriate and scientifically defensible.

19. *Page 12, Porewater sampling and analytical method for the determination of sulfide*- As this method is currently written, it only appears to be triggered in the event that an alternate standard is needed. Are there any other circumstances under which MPCA intends to sample for porewater sulfide? If so, please state them.

20. *Page 12, Porewater sampling and analytical method for the determination of sulfide (1)*- MPCA's method states: "Before conducting an analysis to determine the alternate standard, sediment in the water must have been sampled as described in the Sediment Sampling Procedure for Wild Rice Waters." EPA recommends that MPCA define a minimum and/or

maximum allowable time period between when the sediment sampling and porewater sampling can occur.

21. *Page 12, Porewater sampling and analytical method for the determination of sulfide (1)-* MPCA's methods states: "Using the same locational data used for the previous sediment sampling, take ten sediment cores for porewater analysis as close as possible to the sediment sampling points within each of the five previously established transects..." If MPCA is intending to revisit sediment sampling locations, that GPS location information needs to be collected at each sediment sampling point, see comment 8.

22. Page 12, *Porewater sampling and analytical method for the determination of sulfide (1)-* MPCA should clarify why 10 samples of porewater are reasonable and needed to determine that sulfide is "consistently" less than 120 µg/L.

23. *Page 12, Porewater sampling and analytical method for the determination of sulfide (2)-* MPCA's procedure specifies that a sediment core for porewater sulfide should be collected at a depth of 15-50 cm. EPA asks that MPCA clarify to what extent the core depth influences the results of the analysis of sediment porewater for sulfide. In particular, please explain why the core for the TEFe and TOC sampling is taken at 10 cm depth, while the core for porewater sulfide is collected at the deeper depth of 15-50 cm.

24. *Page 12, Porewater sampling and analytical method for the determination of sulfide (3)-* When extracting the porewater, the procedures specifies that a 10 cm filter be inserted into the top of the sample, but it does not specify how far down into the sample the filter should be inserted. Given that sediment concentrations vary within a sediment profile; EPA strongly recommends that MPCA define the depth of filter insertion into the porewater sulfide in this procedure.

25. *Page 13, Porewater sampling and analytical method for the determination of sulfide (3)-* This procedure specifies that 15-50 mL of porewater be collected in each sample. Please specify how the volume of the sample will be determined and what to do in the event that a sample of 15 mL cannot be obtained.

References

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Appendix 2: NPDES Implementation Considerations Pertaining to MPCA's Wild Rice Sulfate Criteria

MPCA's procedures for conducting reasonable potential analyses and calculating WQBELs to protect class 4D wild rice waters are not contained in Minnesota's proposed rules, but are discussed in the SONAR accompanying those rules. EPA is offering the following comments and recommendations on the NPDES permit procedures included in the SONAR to assist MPCA as it moves from the criteria adoption stage to the criteria implementation stage. While we have not had time to fully explore these issues in conjunction with MPCA staff, we hope that these comments will help to further that dialogue.

Implementing MPCA's wild rice criteria will require intensive data collection in order to calculate sulfate water quality criteria applicable to each of the listed wild rice waters. EPA is concerned that MPCA may lack sufficient current data to conduct reasonable potential determinations and calculate WQBELs consistent with 40 CFR 122.44(d)(1). To address this concern, EPA recommends that when MPCA is developing its monitoring strategy and schedules, that it consider the need to ensure that enough data are collected sufficiently in advance of permit issuance to enable MPCA to calculate the applicable water quality criteria. Specifically, EPA would recommend that the monitoring strategy prioritize data collection in wild rice waters: (1) with near-field dischargers; (2) that are effluent-dominated; or (3) are affected by dischargers with expired or soon-to-be-expiring NPDES permits. If needed, EPA suggests that MPCA consider strategies for protecting designated uses during the time period between the effective date of the criterion and the collection of sufficient data to implement the wild rice sulfate criterion.

We also provide the following additional recommendations for MPCA's consideration as it moves forward to finalize the proposed water quality criteria rule.

Recommendations:

1. The SONAR requires "sufficient" data (page 104) in order to perform reasonable potential determinations. As MPCA works to implement the proposed wild rice criterion, EPA recommends that MPCA clarify what constitutes sufficient data, including the number of data points and the necessary quality of the data (e.g., specifying analytical methods to be used, including data quality objectives).

2. The implementation procedures state that WQBEL determinations will be dependent upon staff levels and workload. However, such factors do not change the requirement (40 CFR 122.44(d)(1)(ii)) that MPCA conduct reasonable potential determinations and calculate WQBELs for sulfate when issuing NPDES permits. EPA recommends that MPCA clarify the SONAR to address this comment.

3. Neither MPCA's proposed rules or supporting documents contain detailed procedures on how reasonable potential determinations will be made-- although, the SONAR (page 98) contains a general steady-state mass balance equation that can be used to calculate WQBELs. MPCA uses procedures to make reasonable potential determinations and to calculate WQBELs for many pollutants that are consistent with EPA's 1985 Technical

Support Document for Water Quality-based Toxics Control (EPA-440/4-85-032) (1985 TSD). EPA recommends that MPCA consider making reasonable potential determinations and WQBEL calculations for the wild rice sulfate criterion using these existing MPCA procedures that are based on the 1985 TSD, and that this be clarified in guidance.

4. The SONAR and Appendix 4 of the SONAR commit MPCA to making reasonable potential determinations and to calculating WQBELs for wastewater treatment plants/facilities. We recommend the development of guidance (and clarification of the SONAR as appropriate) to make clear that reasonable potential determinations and WQBELs calculations must be performed for all point sources (40 CFR 122.44(d)), not only for wastewater treatment facilities, that discharge directly to and upstream from wild rice waters.

5. MPCA proposes to express WQBELs as 12-month-moving total mass limits, with concentration-based limits being used, if warranted. As MPCA moves forward to implement the proposed wild rice sulfate criterion, EPA recommends that MPCA include limits in its NPDES permits consistent with 40 CFR 122.45(d) and (e) or provide a rationale why limits consistent with 40 CFR 122.45(d) are impracticable. In addition, EPA recommends that MPCA use actual or average/dry weather design effluent flows to calculate mass-based limits instead of wet weather flows or maximum design flows since the use of wet weather flows or maximum design flows in such calculations could result in increased loadings of sulfate that could cause or contribute to exceedances of the wild rice sulfate criterion. Lastly, EPA recommends that MPCA describe more specifically how mass-based limits will be calculated and applied in permits, including how violations of mass limits will be determined.

6. MPCA uses calculated "background" concentrations in reasonable potential determinations and calculating WQBELs – and MPCA defines background in the SONAR (page 103) as the quality of water without facility impacts. EPA suggests that MPCA use measured in-stream sulfate concentration data collected upstream of the discharge in making reasonable potential and WQBEL determinations, consistent with Chapter 6 of EPA's NPDES Permit Writers Manual to ensure the available assimilative capacity is applied in the calculation of WQBELs. Therefore, EPA recommends MPCA update the SONAR or develop further guidance to clarify the need for the use of an upstream sample that accounts for loadings from all point and nonpoint sources to ensure that the discharge at issue would not cause a water quality violation in the immediate or downstream waters, consistent with 40 CFR 122.44(d).

Minnesota Pollution Control Agency

Sampling and Analytical Methods for Wild Rice Waters

March 2018

Environmental Analysis and Outcomes Division

The analytical methods and sampling procedures provided in this document are incorporated by reference in Minn. R. pt. 7050.0224. They apply to the analysis and sampling of sediment for purposes of implementing the sulfate water quality standard applicable to wild rice waters.

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Background

The Minnesota Pollution Control Agency developed this procedure to ensure that samples taken for the purposes of calculating the numeric expression of the sulfate standard to protect wild rice (Minn. R. 7050.0224) are scientifically defensible and protective of the Class 4D wild rice use. The numeric expression of the sulfate standard is derived from the output of an equation that calculates a sulfate concentration necessary to maintain sulfide concentrations in sediment porewater less than or equal to 0.120 mg/L. The standard is derived using measured concentrations of total organic carbon (TOC) and total extractable iron (TEFe) in a sediment sample to calculate a protective sulfate concentration for each sediment sample. Due to natural processes, TOC and TEFe concentrations vary in the sediment of aquatic ecosystems, which means that the analysis of multiple sediment samples will produce a range of calculated sulfate concentrations that could serve as the numeric expression of the standard.

In order to protect the majority of wild rice habitat in a wild rice water, the numeric sulfate standard for a wild rice water is defined as the 20th percentile of at least 15 protective sulfate concentrations calculated from sediment samples randomly selected from the wild rice habitat. Sediment is only sampled from areas of wild rice habitat, since wild rice does not grow at all locations within a wild rice water.

This document establishes the methodology that must be used to collect sediment samples from wild rice habitat in wild rice waters, analyze the samples, apply the equation, and determine the numeric sulfate standard.

The terms used in this document have the following meanings.

- Wild rice water is the entire WID identifying a Class 4D wild rice water as shown in Minn. R. 7050.0471.
- Wild Rice Habitat (WRH) are the area(s) of the wild rice water that (1) support or have supported wild rice, or (2) are identified as likely to support wild rice. Once the referencing period has ended, WRH has been delineated, and sediment samples have been taken, the WRH areas defined for a wild rice water do not change. The MPCA will post on its website maps for each wild rice water that has had WRH delineated.
- Each Candidate Sample Site (CSS) is a point randomly selected from within the WRH, identified by its spatial coordinate. At least 100 CSS points must be identified for each wild rice water prior to obtaining sediment samples that will be analyzed for the determination of a numeric sulfate standard. Sediment samples must be taken from at least 15 of the candidate sample sites.
- Referencing period identifies the time within which desktop review and on-site reconnaissance occurs in preparation for the final delineation of WRH and sampling of sediment. The referencing period ends when the first complete set of sediment samples is collected.
- The numeric sulfate standard of a wild rice water is defined as the 20th percentile of the 15 or more protective calculated sulfate concentrations.

Section 1. Sediment sampling procedure for wild rice waters

A. Identifying wild rice habitat areas

Before sediments are sampled, WRH must be delineated within the wild rice water. The entire wild rice water (WID) must be evaluated to determine WRH. The process of identifying WRH in a wild rice water must be completed in two steps: (1) a desktop review of available information prior to any field reconnaissance, and (2) a pre-sampling field reconnaissance of the wild rice water. The intent of these two steps is to produce a map of WRH within the wild rice water. The map produced from this survey must be in a format that is compatible with performing a random selection of candidate sample sites as described in part B.

Delineation of Areas of Potential WRH

Step 1. Desktop review: On a map or aerial photograph of the wild rice water, outline the areas of potential WRH based on the following information:

- Areas where existing information identifies the past location of wild rice plants. Examples of acceptable information are annotated maps, documented plant surveys, sampling events, or historical records from which the areas containing wild rice plants can be determined.
- Areas where satellite or aerial photographs indicate the past presence of floating-leaved or emergent plants.

Step 2. Pre-sampling field reconnaissance:

After conducting the desktop review, the map of potential WRH must be compared to direct observation by conducting a field survey during the growing season of wild rice. This field survey must be done at a time when wild rice plants can be effectively identified; the best time period is when the growth of wild rice is at least at the tiller stage (July through September).

Areas identified as potential WRH in the desktop review must be examined in the field for evidence of wild rice plants. The survey must include visual observation of all areas of potential WRH. The wild rice water must also be surveyed for evidence of wild rice plants outside of the areas identified in the desktop review. Available information must also be gathered about possible phenomena that may have reduced that year's wild rice population, such as unusually high water levels. If the available information show a likelihood that the year's wild rice population has been significantly impacted by such phenomena, the referencing period must be extended by performing additional field reconnaissance in a following year.

Information on each area of potential WRH must be recorded, including which hierarchy level each site falls into, as described here:

Level 1 – Areas that Support or Have Supported Wild Rice

#1a. Areas where wild rice is observed growing or where there is evidence of recent growth, such as rooted wild rice plants that have been grazed, or wild rice plant residue from previous year's growth.

#1b. Areas that have supported wild rice in the past, as identified from evidence included in the desktop review.

Level 2 – Areas Likely to Support Wild Rice

#2a. Areas with either floating-leaved plants or emergent plants where water depth is less than 120 cm. Examples of floating-leaved or emergent plants whose presence approximates the conditions for wild rice growth are yellow or white waterlilies (*Nuphar variegata* and *Nymphaea odorata*), pondweeds (*Potamogeton* species), watershield (*Brasenia schreberi*), pickerelweed (*Pontederia cordata*), and arrowhead (*Sagittaria latifolia*). WRH does not include areas dominated by species that form dense monocultures that exclude wild rice, such as cattails

(*Typha* species), phragmites (*Phragmites australis*), purple loosestrife (*Lythrum salicaria*), and reed canary grass (*Phalaris arundinacea*).

#2b. Areas where water depth is between 30 and 120 cm.

Delineating Final WRH

If any Level 1 area is identified, then the entirety of the Level 1 areas (both 1a and 1b) represent the final WRH for that wild rice water. If no Level 1 area is identified, then any Level 2a areas are the WRH. If no Level 2a areas are identified, then the Level 2b areas are the WRH. The map of the final delineated WRH must be used to define at least 100 random candidate sample sites, as described below in Part B.

B. Selecting sediment core sample sites

All sediment sampling must occur within the delineated WRH. Using the map of the delineated WRH within the wild rice water, identify the randomly located 100 candidate sample sites as potential locations for sediment sampling. Each candidate sample site must be geo-referenced, specifying latitude and longitude to 5 decimal places.

The CSS sites may be identified by laying a grid over the WRH and randomly locating potential sites where the gridlines overlap, or through the use of geographic information system (GIS) software that randomly selects points within the WRH layer.

Once at least 100 points of the CSS are randomly established within the WRH, the CSS points must be tabulated and randomly numbered. Sort the sites by the random numbers and number them in order from 1 to 100.

The candidate sample sites must be selected in order as sites for the collection of sediment samples for analysis. At least the first 15 samples must be collected. Additional samples may be collected, moving sequentially through the random number list, to ensure that sufficient samples are available in case the analysis of some samples fail the QA/QC procedures specified in Sections 2 and 3 of this document. At least 15 pairs of acceptable total organic carbon (TOC) and total extractable iron (TEFe) concentrations must be available from laboratory analysis in order to calculate the numeric expression of the standard, as specified in part 4 of this document.

A map showing WRH and the sites selected for sampling must be submitted to the MPCA and placed on the website that houses information on the Class 4D wild rice waters.

C. Conducting Sediment Sampling

The selected sample locations may be visited in any order and at any time during the open water season. Sampling can take place the same year as the WRH was delineated, or at a later date. For instance, sediment can be collected early the following summer, before emergent wild rice becomes dense. Sampling before the wild rice population is dense has the potential advantage of allowing navigation across the wild rice water without damaging emergent plants.

A global positioning system (GPS) receiver must be used to locate the position of the site in the field, and accuracy of the receiver must be at least 3 meters. Sediment must be collected in a place with overlying water that is within 3 meters of the predetermined location.

At each of the selected sampling points, use the following methods to collect a sediment core sample:

1. Each sediment sample is the top 10 centimeters of a sediment core after the overlying water has been removed.
2. Place the sediment sample into a clean container that is clearly labeled with an identification number associated with the table of random numbers, water body, collection date, latitude, and longitude.
3. Store the samples on ice in the field and keep the samples at ≤ 6° C until delivered to an analytical lab for analysis.

D. Data Reporting

Document and report to the MPCA the following information about the sediment sampling:

1. Name and WID of the wild rice water
2. Name of person responsible for desktop review, and summary of findings.
3. Reconnaissance date and names of field crew.
4. Sediment sampling date(s) and names of field crew.
5. Description of coring device and diameter of coring tube.

6. The map or aerial photograph of the wild rice water, marked with the areas of wild rice habitat delineated in part A, steps 1 and 2, and the location of the final sample points determined in part B.
7. A table of the CSS that gives the latitude and longitude of at least the first 100 randomly selected sites and identifies the final sample sites;

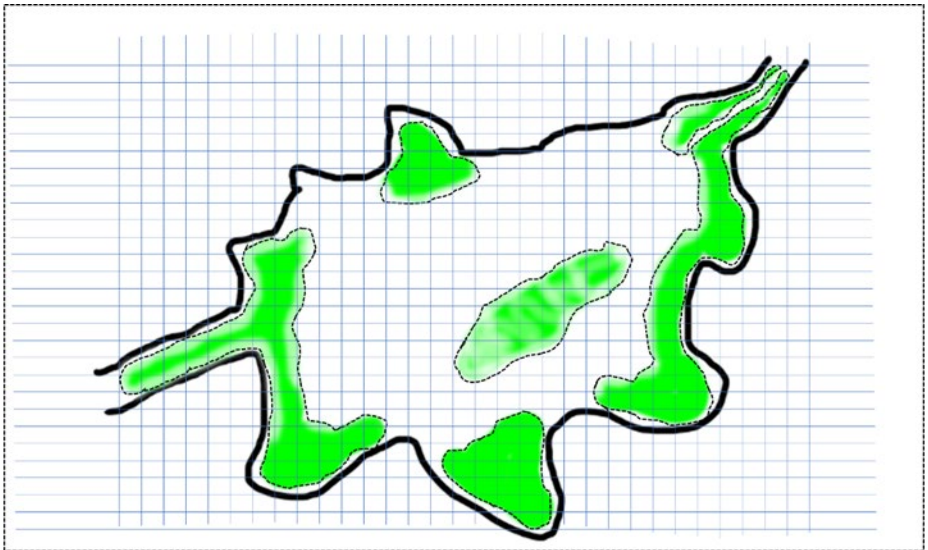

Figure 1. Example of grid overlay on a base map of a wild rice water with areas of wild rice habitat delineated. Potential sampling points are the grid intersections within areas of wild rice habitat. Alternatively, random sites within wild rice habitat can be randomly selected by GIS software.

Section 2. Analytical method for the determination of total extractable iron in sediment

This document describes the methods for the preparation and analysis of sediment samples for total extractable iron (TEFe) for analysis by Inductively Coupled Plasma-Atomic Emission Spectrometry Spectroscopy.

1. Prior to analysis, store the samples at ≤ 6° C to minimize biological activity. Samples must be analyzed within 180 days of collection date.
2. Dry and prepare the sample using either procedure 2a or 2b:

   2a.

   - Manually remove large materials such as rocks, shells, and sticks, and add a description of removed materials to the lab report.
   - Dry the sample in an oven at 50° C until constant weight is achieved.
   - Manually break the dried sample into pieces.
   - Pulverize the dry sample using a mill.

   2b.

   - Freeze-dry the sample.
   - Homogenize the sample using a stainless steel spatula.
   - Manually remove r~~emaining~~ large materials such as rocks, shells, and sticks, and add a description of removed materials to the lab report.

3. After the sample has been prepared, digest a small aliquot of the sample (0.25 +/- 0.02 grams) and all necessary QA/QC samples by adding 25 mL of 0.5 N hydrochloric acid to all digestion tubes. Digest samples (and all necessary QA/QC samples) on a hot block at 80-85° C or in a water bath at 80-85° C. Once samples reach 80° C, digest samples for 30 additional minutes. After 30 minutes, remove samples immediately and cool to room temperature, and bring to a constant volume. Immediately either centrifuge the tubes at 1000 rpm for 10 minutes or filter using a 0.45 µm PES-type filter. Remove an aliquot and dilute with reagent water to known volume for iron analysis. Determine iron in the diluted aliquot using Inductively Coupled Plasma-Atomic Emission Spectrometry. Report the results in mg/kg (dry weight).
4. Acceptable performance must be demonstrated on an ongoing basis. With every digestion batch, the laboratory must perform the following:

   - Low Background: At the beginning of each batch, analyze a blank (BLK) to determine reagent or laboratory contamination. The background level of the BLK must be below the report level before samples are analyzed.
   - Accuracy: With every batch of 20 samples processed as a group, analyze a Laboratory Control Sample (LCS). The LCS should be prepared at concentrations similar to those expected in the field samples and ideally at the same concentration used to prepare the matrix spike (MS). The acceptance criteria for recovery of the analyte in the LCS is 80 – 120%.

- Matrix spike. A MS must be prepared and analyzed with each batch of 20 samples processed as a group, or a minimum of 10% of the field samples analyzed, whichever is greater. The same solution used to fortify the LCS is used to fortify the MS. The acceptance criteria for recovery of the analyte in the MS is 80 – 120%.

- Precision: Analyze a Laboratory Duplicate (DUP) with each batch of field samples processed as a group, or 10% of the field samples analyzed, whichever is greater. The acceptance criteria for the relative percent difference (RPD) is ≤ 20%.

  RPD is a measure of precision, calculated as: RPD = (X1 – X2)/Xave x 100, where X1 and X2 are the concentrations of duplicates. Xave is the average of the two concentrations, calculated as: Xave = (X1 + X2)/2.

Section 3.Analytical method for the determination of total organic carbon in sediment

This document describes the methods for the preparation and analysis of sediment samples for the analysis of Total Organic Carbon (TOC) by Non-Dispersive Infrared Detection.

1. Prior to analysis, store the samples at ≤ 6° C to minimize biological activity. Samples must be analyzed within 28 days of collection date.
2. Dry and prepare the sample using either procedure 2a or 2b:

   2a.

   - Manually remove large materials such as rocks, shells, and sticks, and add a description of removed materials to the lab report.
   - Dry the sediment sample in an oven at 50° C until constant weight is achieved.
   - Manually break the dried sample into pieces.
   - Pulverize the remaining dry sediment using a mill.

   2b.

   - Freeze-dry the sample.
   - Homogenize the material using a stainless steel spatula,
   - Remove remaining large materials such as rocks, shells and sticks, and add a description of removed materials to the lab report .
3. After the sample has been prepared:

- Treat an aliquot of the homogenized sample with a 5% solution of H_3PO_4 to remove any inorganic carbon.
- Either air-dry or oven-dry (at 105°C) the sample until constant weight is achieved.
- Analyze the sample (and all necessary QA/QC samples) for Total Organic Carbon content using a Standard Operating Procedure based on EPA Method 9060A.
- Analyze all environmental samples in duplicate.
- Report the results in mg C/kg dry sediment, and as percent C in dry sediment.

4. Acceptable performance must be determined for every digestion batch by performing the following activities:
   - Low Background: At the beginning of each batch, analyze a blank (BLK) to determine reagent or laboratory contamination. The background level of the BLK must be below the report level before analyzing samples.
   - Accuracy: With every batch of 20 samples processed, analyze a Laboratory Control Sample (LCS). The LCS must prepared at the same concentrations as the field samples and at the same concentration used to prepare the matrix spike (MS). The acceptance criteria for recovery of the analyte in the LCS is 70 – 130%.

- Matrix spike: Prepare and analyze a MS with every 20 samples processed as a group, or a minimum of 10% of the field samples analyzed, whichever is greater. The same solution used to fortify the LCS is used to fortify the MS. The acceptance criteria for recovery of the analyte in the MS is 70 – 130%.
- Precision: Analyze a Laboratory Duplicate or a MS duplicate with every 20 samples processed as a group, or 10% of the field samples analyzed, whichever is greater. The acceptance criteria for the relative percent difference (RPD) is ≤ 30%.

  Analyze every environmental sample in duplicate. The RPD between duplicates must be ≤ 30%.

  RPD is a measure of precision, calculated as: RPD = (X1 – X2)/Xave x 100, where X1 and X2 are the concentrations of duplicates. Xave is the average of the two concentrations, calculated as: Xave = (X1 + X2)/2.

Section 4. Calculating the numeric sulfate standard using the equation.

A protective sulfate concentration (mg/L) is computed based on each sediment sample using the following equation:

$$MBLR120\ Sulfate = 0.0000854 \times \frac{TEFe^{1.637}}{TOC^{1.041}}$$

If any sample has an organic carbon concentration that is lower than 0.20 percent carbon, then the concentration of 0.20 percent carbon must be substituted for the lower concentration. If any sample has an iron concentration greater than 83,421 micrograms/gram, then the concentration of 83,421 micrograms/gram must be substituted for the higher concentration.

The numeric expression of the sulfate standard is the 20^{th} percentile of all calculated sulfate concentrations resulting from the application of the equation to each pair of organic carbon and iron concentrations (including any substituted concentrations).

There are several different ways to calculate percentiles; for this purpose, 20^{th} percentile can be calculated through the use of the Microsoft Excel function PERCENTILE.INC, or through the following procedure:

1. Sort all calculated sulfate concentrations, ranked from low to high (e.g., 1^{st}, 2^{nd}, 3^{rd}, 4^{th}, etc.).
2. Calculate values for x and y in the following expression: x.y=0.2(N-1)+1 (N is the total number of calculated sulfate concentrations; if there are 15 samples, x.y = 3.8).
3. Calculate the 20^{th} percentile as x^{th} sulfate concentration plus [0.y times (value of x^{th}+1 sulfate concentration minus the value of x^{th} sulfate concentration)]. For instance, if there were 15 samples, the 20^{th} percentile sulfate concentration would be:

   [value of 3^{rd} + 0.8(value of 4^{th} – value of 3^{rd})].

At least 15 pairs of TOC and TEFe concentrations must be used to calculate the numeric expression of the sulfate standard. All acceptable (based on Sections 2 and 3) concentrations of TOC and TEFe must be used to calculate the numeric expression of the sulfate standard, even if those concentrations were gathered from different sampling events.

If the numeric sulfate concentration is above 335 mg/L sulfate, then the numeric expression of the sulfate standard for the wild rice water from which the sediment samples were taken is 335 mg/L. If the numeric sulfate concentration is below 0.5 mg/L sulfate, then the numeric expression of the sulfate standard for the wild rice water from which the sediment samples were taken is 0.5 mg/L.

Attachment 6: Technical Discussion of Proposed Equation Related Changes to the Rule.

Revision to the Equation

The MPCA is proposing to revise proposed Minn. R. 7050.0224, Subp. 5, B (1). The proposed revision is to change the equation that serves as the standard to protect wild rice from adverse impacts of sulfate.

Upwelling Groundwater – Second Creek

During the comment and hearing process, the MPCA heard several comments that sulfate in surface water may not be controlling sulfate availability to the bacteria in the sediment that convert sulfate to sulfide. In particular, it was suggested that sulfide in sediment porewater where wild rice grows may be controlled by the sulfate content of upwelling groundwater rather than the sulfate content of the surface water.

Pollman et al., 2017[1] (Response Exhibit N.4) showed that there is a significant and quantifiable impact of sulfate in surface water on porewater sulfide in Minnesota waterbodies. Since discharged sulfate would increase sulfate concentrations in surface water, it is therefore reasonable to conclude that discharged sulfate has the potential to affect wild rice via increased porewater sulfide. However, the Technical Support Document[2] ("TSD") did consider the potential effects of upwelling groundwater in some detail. It noted that waterbodies with upwelling groundwater could be favorable sites for wild rice growth, and that such sites would not conform to the conceptual model underlying the proposed equation (TSD, pp. 23-24). Groundwater upwelling is discussed in the TSD as a likely reason for some of the observed false positives in the MPCA data set (false positives are waterbodies for which the equation predicts that sulfide should exceed 120 micrograms per liter, but the sulfide is less than 120).

On further review of the concerns about the equation, the MPCA determined that it would be appropriate to reconsider the standard without the inclusion of data from Second Creek – the single site where groundwater upwelling is fully documented. The MPCA does not believe this is a substantial change because there is no change to the fundamental relationships that define the equation-based standard, and the proposed change is a logical outgrowth of the comments received during the public comment period.

MPCA developed the equation in the 2017 proposal using data from all 108 different waterbodies that had been sampled during the MPCA-sponsored 2011-2013 field survey. The use of all of the waterbodies assumed that most of the sites conformed to the conceptual model that porewater sulfide is derived from sulfate that moves downward into the sediment from the overlying surface water. MPCA staff were aware that it was possible that at some study sites groundwater may have been moving upward into the overlying water, which would have not been consistent with the assumption that surface water was the source of sulfate. The equation would not be materially affected if sulfate concentrations were similar between groundwater and surface water, but the equation would potentially be made inaccurate if the concentrations were significantly different. All sites were used because it was not possible to collect or find data that would reveal groundwater flow at each site.

The MPCA identified four waterbodies, out of the 108 waterbodies sampled, that were potentially affected by upwelling groundwater low in sulfate compared to surface water sulfate concentrations

[1] See MPCA Post-Hearing Response to Public Comments, November 22, 2017, Exhibit N.4
[2] See SONAR, Exhibit S-1

(TSD, Table 2-1, p. 72). The only evidence of this possibility was that the four waterbodies did not conform to the equation; based on the equation, porewater sulfide was expected to be above 120 µg/L, but observed concentrations were below 120 µg/L (i.e., these sites had a preponderance of false positive predictions). The lack of conformance could be the result of (a) upward groundwater movement, as suggested, (b) random deviation, or (c) inhibition of sulfide production caused by variables not quantified by the MPCA model.

If it had been known that upward groundwater movement was responsible for the observed level of sulfide being lower than predicted than the equation (false positives), the MPCA would have had a defensible rationale for excluding such sites from the development of the equation. This would have enhanced the accuracy of the predictions. However, given the lack of specific knowledge as to the mechanism producing the false positive predictions, MPCA did not exclude any of these four sites from the development of the equation. If MPCA had excluded any of the false positive sites without any knowledge of the specific mechanism, MPCA would justifiably have been vulnerable to criticism for increasing the accuracy of the equation by arbitrarily excluding sites that happened to not conform to the hypothesis.

The state of knowledge of waterbodies included in the MPCA equation changed upon the publication of a detailed study of Second Creek, which was one of the four sites identified by the MPCA as possibly affected by upwelling groundwater because sulfide levels were much lower than predicted,. The four waterbodies were:

Waterbody	Identifier	Observed Sulfate (mg/L)
Second Creek	S007-220	838
Ox Hide Creek	31-0106-00-203	25.9
Turtle River (North Dakota)	S007-662	198
Big Swan Lake	77-0023-00-207	5.5

On August 21, 2017, the day that the Notice of Hearing for the wild rice sulfate rule was published in the State Register, a journal posted online a peer-reviewed paper by Dr. Crystal Ng and her team containing their findings on a 2015 study of the relationship between groundwater and surface water in the area where wild rice grows in Second Creek (Ng et al. 2017[3]). Dr. Ng is a professor in the Earth Sciences Department at the University of Minnesota-Twin Cities. Dr. Ng studied Second Creek at the suggestion of MPCA staff, given that MPCA staff were aware of the site's lack of conformance to the conceptual model for sulfide development. Dr. Ng obtained financial support for the study from the University's Water Resources Center. The MPCA arranged for the installation of local groundwater monitoring wells that Dr. Ng needed for the study, but the MPCA was otherwise not involved in the study or preparation of the published paper.

Ng et al. (2017) concluded that under usual conditions groundwater upwells in Second Creek in the area that wild rice grows, and that the groundwater has much lower sulfate concentrations than the surface water. The upwelling, combined with the mismatch between groundwater and surface water sulfate

[3] See Hearing Exhibit L.2, Ng et al., 2017

concentrations, is evidence that it is inappropriate to include Second Creek in the dataset used to develop the equation. The site does not match the conceptual model that the equation is designed to capture.

The Second Creek data point therefore had inappropriate influence on the coefficients of the equation. This influence was likely particularly strong, considering that Second Creek had the highest sulfate concentration observed, at 838 mg/L.

After removing Second Creek from the dataset, MPCA staff updated the equation and observed the effect on the resulting numeric expression of the sulfate standard. The MPCA retained the other three waterbodies in the dataset due to a continued lack of information about why these sites have lower porewater sulfide than expected.

The original equation, developed using multiple binary logistic regression (MBLR) for the prediction of a porewater sulfide concentration of 120 µg/L, was:

$$MBLR120\ Sulfate = 0.0000121 \times \frac{TEFe^{1.956}}{TOC^{1.197}}$$

The revised equation, using the same methodology but excluding Second Creek, is:

$$MBLR120\ Sulfate = 0.0000854 \times \frac{TEFe^{1.637}}{TOC^{1.041}}$$

The revised equation produces numeric expressions of the standard (sulfate values) that are highly correlated with those from the original equation (R^2=0.99 [4]). However, the revised equation reduces the spread of the sulfate concentrations, resulting in sulfate concentrations that are higher at very low concentrations and progressively lower the higher they were.

The difference at the very low concentrations is minor in absolute terms; for instance, the lowest concentration increased from 0.4 mg/L under the original equation to 0.5 mg/L under the revised equation. On the other hand, sulfate values above 4.0 mg/L decreased progressively more the higher they were; the maximum decreased from 1,821 mg/L to 790 mg/L, a 57% decrease. This significant decrease of high values is understandable, given that the Second Creek data (the highest sulfate value in the whole data set, 838 mg/L, coupled with a low porewater sulfide concentration of 45 µg/L) exerted strong influence on the equation when it was included in the dataset. The effect of that single data point was to cause the equation to underestimate the effect of elevated sulfate. The sulfate concentration in Second Creek (838 mg/L) was more than twice as high as the next-highest concentration in the 108-waterbody dataset (335 mg/L, observed in Lady Slipper Lake in southwestern Minnesota, a region naturally high in sulfate). Lady Slipper Lake had a very high porewater sulfide concentration of 1,680 µg/L, which is consistent with the MPCA conceptual model, given that its sulfate concentration is over ten times greater than the calculated numeric expression of the standard, which is a sulfate value of 30 mg/L.

The MPCA finds that this change to the standard follows the science and data analysis that was used to develop the proposed standard, and is therefore reasonable. It is also a direct outgrowth of comments raising concerns about upwelling groundwater.

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[4] A correlation coefficient or R^2 value of 0.99 indicates that the original and revised equations agree with each other as to which predictions should be relatively low and which relatively high, but not necessarily of the same magnitude. An R^2 value of 1 indicates perfect correlation.

<u>Bounding the Equation</u>

The MPCA noted in its rebuttal response that it agreed with commenter concerns about the fact that the equation is of unknown validity outside of the range of data used to develop it. As noted in the rebuttal response,

> "The MPCA believes it is appropriate to respond to this concern by setting constraints on the implementation of the equation that would ensure that the equation is protective. The MPCA is proposing that input values of carbon cannot be lower than the minimum value in the range of data used to develop the equation, because carbon enhances sulfide production. The MPCA is proposing that input values of iron cannot be higher than the maximum value in the range of data used to develop the equation because iron removes sulfide from porewater.
>
> The MPCA is proposing that output values of sulfate cannot be higher than the maximum value in the range of data used to develop the equation, 838 mg/L."[5]

The MPCA continues to believe that such bounding on the sulfate output is reasonable, and the ALJ agreed in finding 298 of her report. The proposed change to the equation based on the removal of the data from Second Creek results in a different upper bound to the sulfate values calculated as the numeric expression of the standard. Although a sulfate value of 790 mg/L was *calculated* for a waterbody in the dataset, the MPCA is proposing to bound the calculated sulfate concentrations at the highest *observed* sulfate concentration in the dataset that produces the equation. When the 838 mg/L value from Second Creek is not used to develop the equation, the upper sulfate bound would be 335 mg/L, which was observed in Lady Slipper Lake. The MPCA proposes to utilize the Lady Slipper Lake data point as the highest sulfate concentration used in the development of the equation because its relationship between sulfate and sulfide conform to the expectations of the conceptual model.

The MPCA is proposing to add rule language that notes that the numeric expression of the standard/calculated sulfate standard may not be below 0.5 mg/L and may not be above 335 mg/L sulfate. In Finding 298, the ALJ indicated that doing so was needed and reasonable.

The MPCA is also proposing to bound the iron and carbon inputs to the equation. In Finding 299, the ALJ notes that unspecified bounds on carbon or iron are not reasonable; the MPCA always intended to specify these numeric values but was not able to do so in the time constraints of the rebuttal period. The finding implies that specific numeric values would be acceptable.

In order to be protective of wild rice, the MPCA is proposing to set a minimum value for carbon and a maximum value for iron as inputs to the equation. The MPCA is only proposing to bound the inputs on the sides that would result in a higher calculated sulfate value as the numeric expression of the standard. The MPCA is proposing that calculations of the numeric expression of the standard should use any iron concentrations that are lower than the minimum in the field data set (895 µg/g), and any TOC concentrations that are greater than the maximum value in the field data set (33.3%). Doing so will calculate lower sulfate standards than the use of the minimum and maximum (respectively), but doing so will ensure protection of unusual waterbodies that don't fit in the broad ranges found in the MPCA field survey.

The removal of the Second Creek data does not change the minimum carbon or maximum iron input values for the equation. Those values are 0.20 percent carbon (TOC) and 83,431 micrograms/gram iron (TEFe). If any composite sample has an organic carbon value that is lower than 0.20 percent carbon,

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[5] MPCA Rebuttal Response to Public Comments, December 1, 2017, pp 3-4

then the value of 0.20 percent carbon would be substituted for the lower value in performing the calculation. If any composite sample has an iron value greater than 83,421 micrograms/gram, then the value of 83,421 micrograms/gram would be substituted in doing the calculation.

The MPCA is proposing to implement these bounds through the addition of language in the incorporated by reference document "Sampling and Analytical Methods for Wild Rice Waters". The MPCA is proposing to remove subitems (a) – (d) from proposed Minn. R. 7050.0224, subp. 5, B (1) and to place these requirements in the methods document. This will result in a new section of the Sampling and Analytical Methods for Wild Rice Waters that covers how to calculate the numeric expression of the sulfate standard using the equation. That section will include the information about the inputs and how they are expressed, and include language about how to bound the input values. The methods document will also include the upper sulfate bound, but the MPCA felt it was also appropriate to put the maximum calculated sulfate value directly in the rule for clarity.

Sediment Sampling Methods

The MPCA is also proposing changes to the way that sediment sampling is conducted to derive the numeric expression of the standard based on the sediment's iron and carbon content. The MPCA does not believe that this is a substantial change because the rule continues to require sediment sampling and analysis to determine iron and carbon levels. The changes are responsive to concerns raised during the public comment period about how wild rice habitat will be located within wild rice waters, the need for more specificity in selecting wild rice beds for sampling, and concerns about how the MPCA might deal with additional sampling and the resulting data.

As originally proposed, sediment sampling would be conducted in five identified representative areas of wild rice habitat, with five samples collected on a transect across each area. One composite sample would be produced from each transect by mixing the sediment from the five equally spaced sampling locations. Then a potential sulfate concentration would be calculated from each of the five composite sediment samples. MPCA proposed that the lowest sulfate concentration of the five would be adopted as the numeric expression of the sulfate standard for that wild rice water.

Concerns about this proposal included:

- The difficulty and potential subjectivity of identifying five areas of wild rice habitat and ensuring they are representative of the wild rice water (especially if there are more than five areas where wild rice is growing).
- How to orient the transect within the area (e.g. orthogonal to the shore, or parallel to the shore).
- How to identify the numeric expression of the sulfate standard if MPCA or other entities sampled more than five transects.

The MPCA re-examined the original proposal, keeping in mind the following goals:

- To produce a reproducible calculated numeric expression of the sulfate standard that is protective of wild rice.
- To reduce or remove the subjectivity in selecting sampling sites.
- To ensure that the samples (and resulting numeric expression of the standard) accurately represent all the sediment within the wild rice habitat of the wild rice water
- To accommodate the analysis of additional samples.

- To be practical, in terms of the time spent obtaining the sediment samples and the money spent analyzing the samples.

Based on these goals, the MPCA is proposing to move to a stratified random sampling methodology, in which the areas of wild rice habitat within each WID designated as a Class 4D wild rice water are delineated and then randomly sampled.

The U.S. Environmental Protection Agency (EPA) has published guidance on how to choose a sampling design for environmental data collection.[6] The guidance differentiates between probability-based designs, where sample sites are randomly chosen, and judgmental sampling designs, where subjective expert judgment is employed to choose sample sites. Judgmental sampling can be easier to implement than a probability-based design. Although often requiring more work and more steps, a great advantage of probability-based designs is that they allow statistical inferences to be made about the system being sampled. In other words, random design ensures that you can draw conclusions about the whole system or whole population based on the sample population. Because the goal is to objectively characterize the range of calculated protective sulfate concentrations, a probability-based approach better meets the MPCA's goals than to a judgmental approach.

The first step in the process now described in the sampling and analytical methods incorporated by reference is to delineate the areas of wild rice habitat within the wild rice water. Potential wild rice habitat is defined at two key levels: 1) areas where there is observed evidence of present or past support of wild rice growth; 2) areas that are likely to support wild rice. These levels are further subdivided as follows:

Level 1 – Areas that Support or Have Supported Wild Rice

#1a. Areas where wild rice is observed growing or where there is evidence of recent growth, such as rooted wild rice plants that have been grazed, or wild rice plant residue from previous year's growth.

#1b. Areas that have supported wild rice in the past, as identified from evidence included in the desktop review.

Level 2 – Areas Likely to Support Wild Rice

#2a. Areas with either floating-leaved plants or emergent plants where water depth is less than 120 cm. Examples of floating-leaved or emergent plants whose presence approximates the conditions for wild rice growth are yellow or white waterlilies (*Nuphar variegata* and *Nymphaea odorata*), pondweeds (*Potamogeton* species), watershield (*Brasenia schreberi*), pickerelweed (*Pontederia cordata*), and arrowhead (*Sagittaria latifolia*). WRH does not include areas dominated by species that form dense monocultures that exclude wild rice, such as cattails (*Typha* species), phragmites *(Phragmites australis*), purple loosestrife (*Lythrum salicaria*), and reed canary grass (*Phalaris arundinacea*).

#2b. Areas where water depth is between 30 and 120 cm.

[6] See Guidance on Choosing a Sampling Design for Environmental Data Collection. 2002. (https://www.epa.gov/sites/production/files/2015-06/documents/g5s-final.pdf*)*

Those doing sampling will start with a desktop review of available data that will help determine the location of potential wild rice habitat within the wild rice water. Desktop review could include information such as aerial photos, past plant surveys, historical records, satellite bathymetry, and similar.

The next step will be on-site field surveys to delineate the areas of wild rice habitat. This field survey needs to occur at a time when wild rice can be easily identified. Field crews would travel the wild rice water and document areas of potential wild rice habitat in the three categories described above. That would produce a map of potential wild rice habitat.

If there are Level 1 areas – those where wild rice has been observed in the past (based on the desktop review) or is observed during the field reconnaissance, those areas become the final delineated wild rice habitat. If areas of specific wild rice growth cannot be identified, the delineated habitat is defined moving down the hierarchy – first to areas where similar aquatic plants grow and then to water of appropriate depth.

Once documented, the wild rice habitat would not change, and the MPCA envisions that we would make maps of the wild rice habitat within each wild rice water available on the website. All sediment sampling, whether by the MPCA or others, must be done within the delineated area of wild rice habitat.

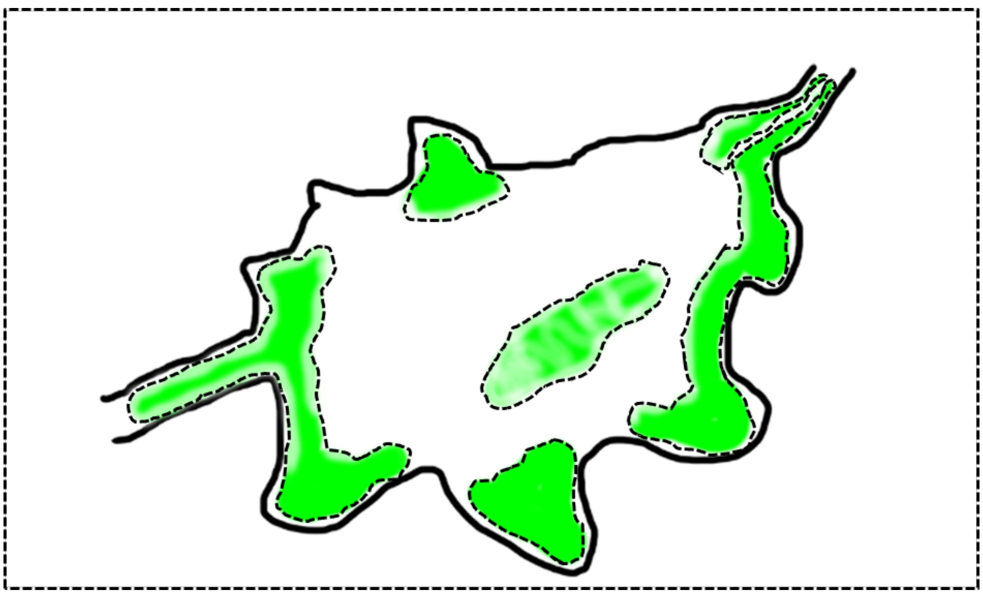

Figure 1. Example of wild rice habitat (green areas) identified in a wild rice water.

Next, 100 random locations would be identified within the wild rice habitat – either using a grid based system or a GIS tool that generates random locations within the wild rice habitat. The first 15 randomly selected sites would be selected for sampling and analysis to develop the numeric expression of the sulfate standard based on the equation. One sediment core would be taken at each site. (More than 15 samples could be taken if desired, in case of errors during analysis.) That sediment core could then be taken at any time, such as the following spring or early summer before wild rice is dense. Sediment cores would not need to all be taken on the same day, but should be completed in a single summer.

The MPCA originally proposed using composite samples largely in order to reduce the analytical costs. As noted in the SONAR, composite samples provide a way to integrate the conditions in the sediment where wild rice grows. Because of this property, the use of composite samples makes more sense with a sampling design that involves transects or similar closely spaced samples – when the samples are intended to approximate a similar area. Composite samples also tend to even out the differences between extreme values, which is appropriate when characterizing a relatively homogenous area. With a random sampling design, sediment samples may be taken from very diverse locations and it is important to preserve the differences among the locations.

Therefore, the MPCA finds it appropriate to move to analysis of individual samples rather than composite samples, because analyzing individual samples offers more clarity, accuracy, and precision regarding the level of protection being calculated.

Although this revision to the procedure specifies an initial field survey that was not in the proposed version, MPCA's monitoring staff have indicated that an initial field reconnaissance would already have been necessary. Therefore, the changes do not increase field costs. Splitting the field work into a habitat survey and sampling will enable crews to focus more specifically on each task. Analyzing 15 cores will increase analytical costs compared to analyzing five composites, but reduces field time compared to collecting 25 cores.

Analysis to Develop the Numeric Expression of the Standard

The MPCA is also proposing to move from using the lowest sulfate value to a percentile approach to determining the numeric expression of the standard. The MPCA is proposing to use the 20th percentile value. The MPCA believes this is a logical outgrowth of the comments, as several commenters suggested different approaches rather than the lowest sulfate value.

The MPCA is now proposing to use a percentile approach. The percentile approach works well with the random sampling design and analysis of individual sediment cores – each individual core may be more different from another core, but the percentile approach evens out the variability. In addition, as more data is collected the calculation will converge on the "true" values that exist in the sediment.

The choice of the percentile is interrelated with the number of samples that are needed to characterize the sediment. The MPCA examined the relationship between percentile and number of samples analyzed by mimicking the random sampling of a wild rice water and calculating numeric expressions of the sulfate standards from various percentiles (10th, 20th, and 30th) based on various numbers of samples analyzed for iron and TOC (5, 10, 15, 20, or 25 samples). This was done through analysis of the pilot sediment sampling project described in the TSD, in which six different wild rice waters were each sampled for 25 sediment cores and each core was analyzed for iron and TOC. A larger, synthetic, data set of 100 samples was created using the data from each of the six wild rice waters. A synthetic data set of 100 protective sulfate concentrations was created for each wild rice water with the same mean and standard deviation (original data sets were transformed when necessary to achieve a normal distribution prior to calculating mean and standard deviation). Then the synthetic data sets were randomly sampled 10,000 times to create average standard deviations and associated normalized measures of variation (coefficient of variation, CV). The CV values were then averaged in order to characterize the effect of given percentiles and number of samples analyzed.

These calculations were done so that the consequences of choosing particular percentiles and number of samples to analyze would be clear. Use of a percentile to identify a numeric sulfate standard would allow additional data to be collected without affecting the theoretical standard being identified. But, the certainty around that percentile calculation is affected by both the percentile level being used, and the number of samples being analyzed.

The MPCA is proposing to use the 20th percentile value. The 10th percentile estimates of sulfate concentrations have significantly more variation (i.e., less certainty) than either the 20th or 30th percentile estimates (Figure 2). Once the number of samples exceeds 5, the benefit of using the 20th percentile, compared to the 10th percentile, is roughly twice the benefit of using the 30th percentile rather than the 20th percentile. In other words, there are diminishing benefits to the use of percentiles greater than 20th.

The benefit (reduction in CV) of increasing the number of samples analyzed is greatest when increasing from 5 to 10 samples. There are diminishing benefits when more than 15 samples are analyzed.

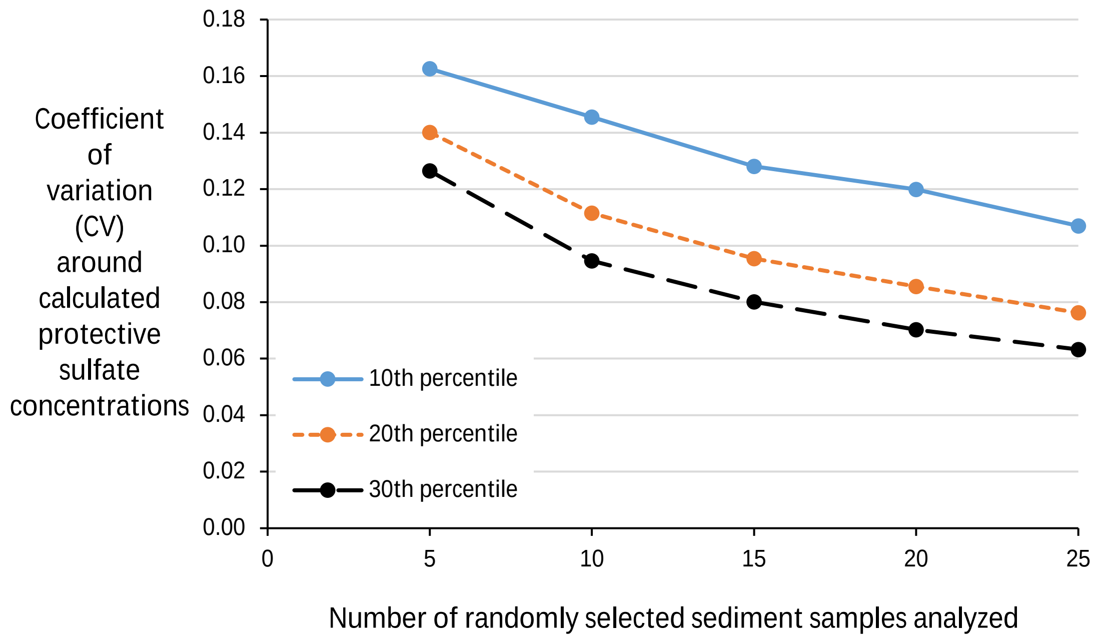

Figure 2. Relationship between percentile and number of sediment samples analyzed.

The previously proposed lowest sulfate value is more susceptible to variability. As noted above, the use of composite samples would even out some variability – somewhat compensating for the increase in variability from using the lowest value. In the SONAR, pg 89, the MPCA discussed the relationship between using the lower calculated sulfate value from composite samples and a percentile value derived from analysis of individual cores. At the six waterbodies where pilot sediment sampling was conducted, the lowest calculated value was always between the 10^{th} and 30^{th} percentile.

Therefore, the MPCA concludes that it is reasonable to identify a numeric sulfate standard for a wild rice water as the 20^{th} percentile sulfate concentration after sampling and analyzing at least 15 sediment samples. The outcome of this calculation will be similar to the outcome produced by the originally proposed rule, but the sampling design is more clear and the outcome will be much more consistent.

The analysis indicates that the analysis of additional sediment samples is unlikely to substantially change a numeric expression of the sulfate standard calculated as the 20^{th} percentile of 15 samples. The 20^{th} percentile has a 95% confidence interval of ± 5%; so one would expect the “true value” of the numeric expression of the sulfate standard to be ± 5% of the calculated value.

All data collected in a wild rice water would be used to set the numeric expression of the standard for that wild rice water. If MPCA has already collected and analyzed 15 (or more) values, then the next 15 (or more) values would be added to the calculation. Moving to a percentile approach will provide greater stability in the numeric expression of the standard – as more data is collected, the numeric expression will converge on the "true" value. This will reduce the likelihood of major changes in the calculated numeric expression of the standard.

Attachment 7: List of Proposed Rule Changes

1. Line 1.11 (7050.0130, subp. 2b) The reasonableness of deleting the definition of "cultivated wild rice water" is addressed on page 2 of Part II of MPCA's Rebuttal Response dated December 1, 2017. This change was approved at Finding 318a. of the Report of the Chief Administrative Law (Report).

    ~~*Subp. 2b. **Cultivated wild rice water**. "Cultivated wild rice water", means a contained area where water levels are artificially manipulated for producing wild rice.*~~

2. Line 2.3 (7050.0220, subp.6c) The reasonableness of removing the last sentence of this definition is addressed on page 3 of Part II of MPCA's Rebuttal Response dated December 1, 2017. This change was approved at Finding 318b. of the Report.

    *Subp. 6c.**Wild Rice Waters.** "Wild rice waters" means those water bodies that contain natural beds of wild rice as defined by Laws 2011, First Special Session chapter 2, article 4 section 32, paragraph (b) and are identified in part 7050.0471.* (~~Wild rice waters do not include cultivated wild rice waters.~~)

3. Lines 2.19, 2.22, 3.2, 3.4, 3.8, 21.3, 38.22, and 50.21 (7050.0220, subps. 1 to 6a) The reasonableness of changing this phrase is discussed on pages 2-3 of Part II of MPCA's Rebuttal Response dated December 1, 2017. These changes were approved at Finding 318c. of the Report.

    Example: (*1) cold water sport fish (trout waters), also protected for drinking water classes 1B; 2A; 3A or 3B; 4D ~~when applicable to a wild rice~~ for water bodies listed in part 7050.0471; and 5 (subpart 3a);*

    .

4. Lines 3.11, 4.1, 4.15, 5.16 6.6, 6.22, 7.14, 21.6, 21.19, 22.10, 23.8, 24.1, 24.17, 25.8, 39.5, 39.18, 40.21, 41.16, 51.1, 51.16, and 52.7 (7050.0130, subp. 3a- 6a) The columns listing the use classes are expanded to include a new Class 4D. The reasonableness of adding this additional column is addressed on page 2-3 of Part II of MPCA's Rebuttal Response dated December 1, 2017. These changes were approved at Finding 318d. of the Report.

5. Line 54.11 (7050.0224, subp. 5, item A) The first sentence is modified to reflect the changes made to remove the requirements for alternate and site-specific standards in items B and C. This change is needed to provide consistency with the proposed change to line 54.21 (7050.0224, subp. 5, item B, subitem (1)) discussed in item 8 below. It is reasonable to make small changes in phrasing to provide consistent reference to the proposed standard.

    A. The ~~standards~~ standard in ~~items~~ item B ~~and C apply~~ applies to wild rice waters identified in part 7050.0471 to protect the use of the grain of wild rice as a food source for wildlife and humans.....

6. Line 54.13 (7050.0224, subp. 5, item A) the second and third sentences in item A are amended to more accurately characterize the sulfate standard by distinguishing between the standard and the numeric expression of the standard. This change is needed to provide consistency with the proposed change to line 54.21 (7050.0224, subp. 5, item B, subitem (1)) discussed in item 8 below. It is reasonable to make small changes in phrasing to provide consistent reference to the proposed standard.

    A. *... The ~~numeric~~ sulfate standard for wild rice is designed to maintain sulfide concentrations in pore water at 120 micrograms per liter or less. The commissioner must maintain all numeric expressions of the sulfate ~~standards~~ standard for wild rice waters on a public website.*

7. Line 54.17 (7050.0224, subp.5, item B). The first sentence in item B is amended in three ways. The clarification that adds "surface water" was approved at Finding 318e. of the Report.
    Changing the phrase "calculated sulfate standard" to "numeric expression of the sulfate standard," and the reasonableness of removing the references to the alternate and site-specific sulfate standard are needed to provide consistency with the proposed change to line 54.21 (7050.0224, subp. 5, item B, subitem (1)) discussed

in item 8 below. It is reasonable to make changes in phrasing to provide consistent reference to the proposed standard.

> *B. The annual average concentration of sulfate in the surface water of a wild rice water must not exceed the concentration established as the ~~calculated~~ numeric expression of the sulfate standard ~~under subitem (1) or alternate sulfate standard under subitem (2)~~ more than one year out of every ten years.*

8. Line 54.21 (7050.0224, subp. 5, item B, subitem (1)) is amended to change the references to the "calculated sulfate standard" to "numeric expression of the sulfate standard" and revise the equation for calculating the sulfate standard. The reasonableness of these changes is provided in Technical Discussion of Proposed Equation Related Changes to the Rule, Attachment 4 to the MPCA's Request for Review by the Chief Administrative Law Judge dated March 27, 2018 (Request for Review).

> *~~(1)~~ The ~~calculated~~ numeric expression of the sulfate standard, expressed as milligrams of sulfate ion per liter (mg SO_4^{2-}/L), is determined by the following equation:*

> *~~Calculated~~ Numeric expression of the sulfate standard = ~~0.000012~~ 0.0000854 x iron ~~1.923~~ 1.637*
>
> *----------------------------*
>
> *Organic carbon ~~1.197~~1.041*

$$\text{Numeric expression of the sulfate standard} = 0.0000854 \times \frac{\text{iron}^{1.637}}{\text{Organic carbon}^{1.041}}$$

> *~~Where:~~ The numeric expression of the sulfate standard is the sulfate value resulting from applying the equation to the sampling data, as described in Sampling and Analytical Methods for Wild Rice Waters, except that:*
>
> *(1) if the sulfate value resulting from applying the equation to the sampling data is less than 0.5 mg/L, then the numeric expression of the sulfate standard is 0.5 mg/L; and*
>
> *(2) if the sulfate value resulting from applying the equation to the sampling data is greater than 335 mg/L, then the numeric expression of the sulfate standard is 335 mg/L.*

9. Line 55.10 (7050.0224, subp. 5, item B, subitem (1) (a) through (d) are deleted to conform to the disapproval at Finding 299 of the Report.

> *~~(a) organic carbon is the amount of organic matter in dry sediment. The concentration is expressed as percentage of carbon, as determined using the method for organic carbon analysis in Sampling and Analytical Methods for Wild Rice Waters, which is incorporated by reference in item E;~~*
>
> *~~(b) iron is the amount of extractable iron in dry sediment. The concentration is expressed as micrograms of iron per gram of dry sediment, as determined using the method for extractable iron in Sampling and Analytical Methods for Wild Rice Waters;~~*
>
> *~~(c) sediment samples are collected using the procedures established in Sampling and Analytical Methods for Wild Rice Waters; and~~*
>
> *~~(d) the calculated sulfate standard is the lowest sulfate value resulting from the application of the equation to each pair of organic carbon and iron values collected and analyzed in accordance with units (a) to (c).~~*

10. Line 55.23 (7050.0224, subp. 5, item B, subitem (2) is deleted to conform to the disapproval at Finding 313 of the Report.

> *~~The commissioner may establish an alternate sulfate standard for a wild rice water when the ambient sulfate concentration is above the calculated sulfate standard and data demonstrates that sulfide concentrations in pore water are 120 micrograms per liter or less. Data must be gathered using the procedures specified in Sampling and Analytical Methods for Wild Rice Waters, which is incorporated by reference in item E. The alternate sulfate standard established must be either the annual average sulfate concentration in the ambient water or a level of sulfate the commissioner has determined will maintain the sulfide concentrations in pore water at or below 120 micrograms per liter.~~*

11. Line 56.6 (7050.0224, subp. 5, item C) is deleted to conform to the disapproval at Finding 287 a. of the Report.

~~*C.The commissioner may establish a site-specific standard using the process in part 7050.0220, subpart 7, or 7052.0270 when the commissioner determines that the beneficial use is not harmed. This decision must be based on reliable and representative data characterizing the health and viability of the wild rice in the wild rice water.*~~

12. Line 56.10 (7050.0224, subp. 5, item D) Item D is renumbered to reflect the deletion of item C. The change of the term "numeric sulfate standard" to "numeric expression of the sulfate standard" is needed to provide consistency with the proposed change to line 54.21 (7050.0224, subp. 5, item B, subitem (1)) discussed in item 8 below. It is reasonable to make changes in phrasing to provide consistent reference to the proposed standard.

    ~~D.~~C. Discharges of sulfate in sewage, industrial waste, or other wastes affecting Class 4D waters must be controlled so that the numeric expression of the sulfate standard for wild rice is maintained at stream flows that are equal to or greater than $365Q_{10}$.

13. Line 56.14 (7050.0224, subp.5, item E) Item E is renumbered to reflect the deletion of item C and modified to change the date of the incorporated document from 2017, when the rules were proposed, to 2018, the date when the revised version of the document will be adopted. This item was previously disapproved in Conclusion of Law 4.b. of the Report. The grounds for disapproval have been addressed in the sampling discussion of the Request for Review.

    ~~E~~D. Sampling and Analytical Methods for Wild Rice Waters, Minnesota Pollution Control Agency (~~2017~~2018), is incorporated by reference. The document is not subject to frequent change and is available on the agency's Web site at www.pca.state.mn.us/regulations/minnesota-rulemaking and through the Minitex interlibrary loan system.

14. Line 58.22 (7050.0471, subp. 2). This subpart is modified to add a clarifying phrase to the title and to make clarifying changes to address how wild rice waters will be addressed through the triennial review. The reasonableness of these clarifications is addressed in Part II of MPCA's Rebuttal Response dated December 1, 2017. These changes were mentioned in footnote #391 of Finding 266 of the Report as "fairly minor proposed changes."

    *Subp. 2. **Triennial review and future listing of wild rice waters.** As part of each triennial review of water-quality standards conducted under Code of Federal Regulations, title 40, section 131.20, the commissioner must solicit evidence that supports identifying additional wild rice waters in rule. ~~The~~ Identifying additional wild rice waters in rule must be based on evidence ~~must demonstrate~~ that supports a demonstration that the wild rice beneficial use exists or has existed on or after November 28, 1975, in the water body, such as by showing a history of human harvest or use of the grain as food for wildlife or by showing that a cumulative total of at least two acres of wild rice are present. Acceptable types of evidence include:*

    A to D [unchanged]

15. Line 64.13 (7050.0471, subp. 3, item C, subitem (14)) This item is modified to change the water identification number of the Embarrass River that is being identified as a wild rice water. The reasonableness of this change is addressed in Part II of MPCA's Rebuttal Response dated December 1, 2017. This change was not directly addressed in the Report.

    (14) Embarrass River St. Louis ~~04010201-577~~ 04010201-A99 Stream

16. Lines 65.26 and 66.5 (7050.0471, subp. 3 item C, subitems 42 and 49). Mud Lake and Round Lake are being removed from the list of wild rice waters for the reasons discussed in Part III of MPCA's Rebuttal Response dated December 1, 2017. This change was not directly addressed in the Report.

    ~~*(43) Mud Lake St. Louis 69-0652-00 Lake*~~

    ~~*(4)9 Round Lake St. Louis 69-0649-00 Lake*~~

17. Lines 60.18, 61.19, 62.25, 63.5, 63.21, 63.26, 64.3, 64.24, 65.14, 65.15, 66.1, 66.4, 66.14, 66.15, 67.4, 67.5 and 113.5 (7050.0471, subpart 3, items A and B and subpart 8, item B, subpart 23). These waters are being renumbered or removed from the list of wild rice waters for the reasons discussed in Part IV of the MPCA's November 22, 2017 Response to Comments. These changes were approved by the ALJ at Findings 318.f (changes to subpart 3) and 318.h (changes to subpart 8).

Subpart 3, item A

~~*(14)*~~	~~*Cuffs Lake*~~	~~*Cook*~~	~~*16-0006-00*~~	~~*Lake*~~
~~*(35)*~~	~~*Mt. Maud Wetland*~~	~~*Cook*~~	~~*16-0914-00*~~	~~*Wetland*~~
~~*(54)*~~	~~*Teal Lake*~~	~~*Cook*~~	~~*16-003-00*~~	~~*Lake*~~
~~*(60)*~~	~~*Unnamed stream (Grand Portage*~~	~~*Cook-*~~	~~*04010101-757*~~	~~*Stream*~~

Subpart 3, item C

~~*(4)*~~	~~*Bang Lake*~~	~~*Carlton*~~	~~*09-0046-00*~~	~~*Lake*~~
~~*(9)*~~	~~*Cedar Lake*~~	~~*Carlton*~~	~~*09-0031-00*~~	~~*Lake*~~
~~*(12)*~~	~~*Dead Fish Lake*~~	~~*Carlton*~~	~~*09-0051-00*~~	~~*Lake*~~
~~*(23)*~~	~~*Hardwood Lake*~~	~~*Carlton*~~	~~*09-0030-00*~~	~~*Lake*~~
~~*(30)*~~	~~*Jaskari Lake*~~	~~*Carlton*~~	~~*090050-00*~~	~~*Lake*~~
~~*(35)*~~	~~*Martin Lake*~~	~~*St. Louis*~~	~~*69-0768-00*~~	~~*Lake*~~
~~*(30*~~	~~*Miller Lake*~~	~~*Carlton*~~	~~*09-0053-00*~~	~~*Lake*~~
~~*(46)*~~	~~*Perch Lake*~~	~~*Carlton*~~	~~*09-0036-00*~~	~~*Lake*~~
~~*(48)*~~	~~*Rice Portage Lake*~~	~~*Carlton*~~	~~*09-0037-00*~~	~~*Lake*~~
~~*9540*~~	~~*Side Lake*~~	~~*St. Louis*~~	~~*69-0699-00*~~	~~*Lake*~~
~~*(55)*~~	~~*Simian Lake*~~	~~*St. Louis*~~	~~*69-0619-00*~~	~~*Lake*~~
~~*(65)*~~	~~*Twin Lake*~~	~~*St. Louis*~~	~~*69-0695-00*~~	~~*Lake*~~
~~*(66)*~~	~~*Unnamed lake (FDL1)*~~	~~*Carlton*~~	~~*09-0178-00*~~	~~*Lake*~~
~~*(67)*~~	~~*Unnamed lake (FDL2)*~~	~~*St. Louis*~~	~~*69-1454-00*~~	~~*Lake*~~

Subpart 8, item B,

~~(23)~~	~~Wild Rice Lake~~	~~Carlton~~	~~09-0023-00~~	~~Lake~~

18. Lines 91.19, 93.2, 93.4, and 93.5 (7050.0471, subp. 6, item C, subitems (40), (76), (78), and (79). The identification numbers of these wild rice waters are changed to more accurately identify the part of each stream where wild rice is located. The reasonableness of these changes is provided Part IV of the MPCA's November 22, 2017 Response to Comments. These changes were approved at Finding 318.g. (changes to subpart 6).

(40)	*Moose River*	*Aitkin*	~~*07010103-524*~~	*07010103-749*	*Stream*
(76)	*Swan River*	*Itasca*	~~*07010101-506*~~	*07010103-753*	*Stream*
(78)	*Tamarack River*	*Aitkin*	*07010103-758*		*Stream*
(79)	*Tamarack River*	*Aitkin*	~~*07010103-521*~~	*07010103-757*	*Stream*

19. Line 117.6 (7053.0406, subp. 1). Subpart 1, which established conditions for the commissioner to make a determination that no effluent limit is required, is deleted. The reasonableness of deleting this subpart is addressed in Part IV of the MPCA's November 22, 2017 Response to Comments. This change was approved at Finding 318.i. of the Report.

~~Subpart 1. **No effluent limit required based on site-specific conditions.** If the commissioner determines that, based on the location of the discharge in the wild rice water or site-specific hydraulic or substrate conditions, the effluent will not affect the class 4D wild rice beneficial use in the wild rice water, the commissioner must not establish a water-quality based effluent limitation for the class 4D sulfate in that discharge.~~

20. Line 117.11 (7053.0406, subp. 2,item A) Item A is modified to delete the reference to the water quality based effluent limit. The reasonableness of this change is addressed in Part IV of the MPCA's November 22, 2017 Response to Comments. This change was approved at Finding 318.j. of the Report.

    ~~*Subpart 2 Variances*~~

    A. A permit applicant may apply for a variance from the sulfate standard for wild rice ~~and associated water-quality based effluent limit (WQBEL),~~ as specified in parts 7000.7000, 7050.0190, 7052.0280, and 7053.0195, as applicable

21. Line 117.15 (7053.0406, subp. 2, item B). Item B, which incorporated the *Interim Economic Guidance for Water Quality Standards* by reference is deleted. The reasonableness of deleting this incorporation by reference is addressed in Part IV of the MPCA's November 22, 2017 Response to Comments. This change was approved at Finding 318.k. of the Report.

    ~~*B. The commissioner must base the determination of widespread economic and social effect on the procedures established in Interim Economic Guidance for Water Quality Standards, EPA-823-B-95-002 (March 1995) and as subsequently amended), which is incorporated by reference, is not subject to frequent change,and is available at https://www.epa.gov/wqs-tech/economic-guidance-water-quality-standards.*~~

22. Incorporation by reference. The document incorporated by reference in 7050.0224, subp. 5, item D (line 56.13) has been modified from the document as proposed. The revisions to *Sampling and Analytical Methods for Wild Rice Waters* are provided as Attachment 5 to the Request for Review. The reasonableness of these changes is provided in the Technical Discussion of Proposed Equation Related Changes to the Rule, Attachment 4 to the Request for Review.

Pollution Control Agency

Adopted Permanent Rules Relating to Wild Rice Sulfate Standard and Wild Rice Waters

7050.0130 GENERAL DEFINITIONS.

[For text of subps 1 and 2, see M.R.]

Subp. 2a. **Annual average ten-year low flow or $365Q_{10}$.** "Annual average ten-year low flow" or "$365Q_{10}$" means the lowest average 365-day flow with a once in ten-year recurrence interval. A $365Q_{10}$ is derived using the same methods used to derive a $7Q_{10}$, and the guidelines regarding period of record for flow data and estimating a $7Q_{10}$ apply equally to determining a $365Q_{10}$, as described in subpart 3.

~~Subp. 2b.~~ ~~**Cultivated wild rice water.**~~ ~~"Cultivated wild rice water" means a contained area where water levels are artificially manipulated for producing wild rice.~~

Subp. ~~2c~~ 2b. **Existing use.** "Existing use" has the meaning given in part 7050.0255, subpart 15.

[For text of subps 3 to 6, see M.R.]

Subp. 6a. **Water identification number or WID.** "Water identification number" or "WID" means a unique identifier used by the agency to identify a surface water. For rivers and streams, a WID is an eight-digit hydrologic unit code, followed by three digits that further define the reach of water being identified. For lakes, wetlands, and reservoirs, a WID is a two-digit county identification code, followed by a four-digit unique lake number, followed by a two-digit basin identification code. For purposes of part 7050.0224, a WID identifies a specific water body or reach of a river or stream.

Subp. 6b. **Wild rice.** "Wild rice" means plants of the species *Zizania palustris* or *Zizania aquatica*.

Subp. 6c. **Wild rice waters.** "Wild rice waters" means those water bodies that contain natural beds of wild rice as defined by Laws 2011, First Special Session chapter 2, article 4, section 32, paragraph (b), and are identified in part 7050.0471. ~~Wild rice waters do not include cultivated wild rice waters.~~

[For text of subp 7, see M.R.]

7050.0220 SPECIFIC WATER QUALITY STANDARDS BY ASSOCIATED USE CLASSES.

Subpart 1. **Purpose and scope.**

A. The numeric and narrative water quality standards in this chapter prescribe the qualities or properties of the waters of the state that are necessary for the designated public uses and benefits. If the standards in this chapter are exceeded, it is considered indicative of a polluted condition that is actually or potentially deleterious, harmful, detrimental, or injurious with respect to designated uses or established classes of the waters of the state.

B. All surface waters are protected for multiple beneficial uses. Numeric water quality standards are tabulated in this part for all uses applicable to four common categories of surface waters so that applicable standards for each category are listed together in subparts 3a to 6a. The four categories are:

(1) cold water sport fish (trout waters), also protected for drinking water: classes 1B; 2A; 3A or 3B; 4A and 4B; 4D ~~when applicable to a wild rice~~ <u>for</u> water <u>bodies</u> listed in part 7050.0471; and 5 (subpart 3a);

(2) cool and warm water sport fish, also protected for drinking water: classes 1B or 1C; 2Bd; 3A or 3B; 4A and 4B; 4D ~~when applicable to a wild rice~~ <u>for</u> water <u>bodies</u> listed in part 7050.0471; and 5 (subpart 4a);

(3) cool and warm water sport fish, indigenous aquatic life, and wetlands: classes 2B, 2C, or 2D; 3A, 3B, 3C, or 3D; 4A and 4B; 4C; 4D ~~when applicable to a wild rice~~ for water bodies listed in part 7050.0471; and 5 (subpart 5a); and

(4) limited resource value waters: classes 3C; 4A and 4B; 4D ~~when applicable to a wild rice~~ for water bodies listed in part 7050.0471; 5; and 7 (subpart 6a).

[For text of subps 2 and 3, see M.R.]

Subp. 3a. **Cold water sport fish, drinking water, and associated use classes.** Water quality standards applicable to use classes 1B; 2A; 3A or 3B; 4A and 4B; 4D ~~when applicable to a wild rice~~ for water bodies listed in part 7050.0471; and 5 surface waters.

A. MISCELLANEOUS SUBSTANCE, CHARACTERISTIC, OR POLLUTANT

	2A CS	**2A MS**	**2A FAV**	**1B DC**	**3A/3B IC**	**4A IR**	**4B IR**	**4D**	**5 AN**
(1) Ammonia, un-ionized as N, µg/L	16	--	--	--	--	--	--	--	--
(2) Asbestos, >10 µm (c), fibers/L	--	--	--	7.0e+06	--	--	--	--	--
(3) Bicarbonates (HCO_3), meq/L	--	--	--	--	--	5	--	--	--
(4) Bromate, µg/L	--	--	--	10	--	--	--	--	--
(5) Chloride, mg/L	230	860	1,720	250(S)	50/100	--	--	--	--

2A CS	2A MS	2A FAV	1B DC	3A/3B IC	4A IR	4B IR	4D	5 AN
(6) Chlorine, total residual, µg/L								
11	19	38	--	--	--	--	--	--
(7) Chlorite, µg/L								
--	--	--	1,000	--	--	--	--	--
(8) Color, Pt-Co								
30	--	--	15(S)	--	--	--	--	--
(9) Cyanide, free, µg/L								
5.2	22	45	200	--	--	--	--	--
(10) *Escherichia (E.) coli* bacteria, organisms/100 mL								
See item D	--	--	--	--	--	--	--	--

2A CS	2A MS	2A FAV	1B DC	3A/3B IC	4A IR	4B IR	4D	5 AN
(11) Eutrophication standards for lakes and reservoirs (phosphorus, total, µg/L; chlorophyll-a, µg/L; Secchi disk transparency, meters)								
See part 7050.0222, subparts 2 and 2a	--	--	--	--	--	--	--	--

(12) Eutrophication standards for rivers, streams, and navigational pools (phosphorus, total µg/L; chlorophyll-a (seston), µg/L; five-day biochemical oxygen demand (BOD_5), mg/L; diel dissolved oxygen flux, mg/L; chlorophyll-a (periphyton), mg/m^2)

See part 7050.0222, subparts 2 and 2b	--	--	--	--	--	--	--	--

(13) Fluoride, mg/L

--	--	--	4	--	--	--	--	--

(14) Fluoride, mg/L

--	--	--	2(S)	--	--	--	--	--

(15) Foaming agents, µg/L

--	--	--	500(S)	--	--	--	--	--

(16) Hardness, Ca+Mg as $CaCO_3$, mg/L

--	--	--	--	50/250	--	--	--	--

2A CS	**2A MS**	**2A FAV**	**1B DC**	**3A/3B IC**	**4A IR**	**4B IR**	**4D**	**5 AN**

(17) Hydrogen sulfide, mg/L

--	--	--	--	--	--	--	--	0.02

(18) Nitrate as N, mg/L

--	--	--	10	--	--	--	--	--

(19) Nitrite as N, mg/L

	--	--	--	1	--	--	--	--	--
(20) Nitrate + Nitrite as N, mg/L									
	--	--	--	10	--	--	--	--	--
(21) Odor, TON									
	--	--	--	3(S)	--	--	--	--	--
	2A CS	**2A MS**	**2A FAV**	**1B DC**	**3A/3B IC**	**4A IR**	**4B IR**	**4D**	**5 AN**
(22) Oil, µg/L									
	500	5,000	10,000	--	--	--	--	--	--
(23) Oxygen, dissolved, mg/L									
	7, as a daily minimum	--	--	--	--	--	--	--	--
(24) pH minimum, su									
	6.5	--	--	6.5(S)	6.5/6.0	6.0	6.0	--	6.0
(25) pH maximum, su									
	8.5	--	--	8.5(S)	8.5/9.0	8.5	9.0	--	9.0
(26) Radioactive materials									
	See item E	--	--	See item E	--	See item E	See item E	--	--
	2A CS	**2A MS**	**2A FAV**	**1B DC**	**3A/3B IC**	**4A IR**	**4B IR**	**4D**	**5 AN**

(27) Salinity, total, mg/L								
--	--	--	--	--	--	1,000	--	--
(28) Sodium, meq/L								
--	--	--	--	--	60% of total cations	--	--	--
(29) Specific conductance at 25°C, µmhos/cm								
--	--	--	--	--	1,000	--	--	--
(30) Sulfate, mg/L								
--	--	--	250(S)	--	--	--	--	--
(31) Sulfate in a wild rice water								
--	--	--	--	--	--	--	--	--
See part 7050.0224, subpart 5								
2A CS	**2A MS**	**2A FAV**	**1B DC**	**3A/3B IC**	**4A IR**	**4B IR**	**4D**	**5 AN**
(32) Temperature, °F								
No material increase	--	--	--	--	--	--	--	--
(33) Total dissolved salts, mg/L								
--	--	--	--	--	700	--	--	--
(34) Total dissolved solids, mg/L								

--	--	--	500(S)	--	--	--	--	--

(35) Total suspended solids (TSS), mg/L

See part 7050.0222, subpart 2	--	--	--	--	--	--	--	--

B. METALS AND ELEMENTS

2A CS	**2A MS**	**2A FAV**	**1B DC**	**3A/3B IC**	**4A IR**	**4B LS**	**5 AN**
(1) Aluminum, total, µg/L							
87	748	1,496	50-200(S)	--	--	--	--
(2) Antimony, total, µg/L							
5.5	90	180	6	--	--	--	--
(3) Arsenic, total, µg/L							
2.0	360	720	10	--	--	--	--
(4) Barium, total, µg/L							
--	--	--	2,000	--	--	--	--
(5) Beryllium, total, µg/L							
--	--	--	4.0	--	--	--	--

2A CS	**2A MS**	**2A FAV**	**1B DC**	**3A/3B IC**	**4A IR**	**4B LS**	**5 AN**

(6) Boron, total, µg/L

--	--	--	--	--	500	--	--

(7) Cadmium, total, µg/L

1.1	3.9	7.8	5	--	--	--	--

Class 2A cadmium standards are hardness dependent. Cadmium values shown are for a total hardness of 100 mg/L only. See part 7050.0222, subpart 2, for examples at other hardness values and equations to calculate cadmium standards for any hardness value not to exceed 400 mg/L.

(8) Chromium +3, total, µg/L

207	1,737	3,469	--	--	--	--	--

Class 2A trivalent chromium standards are hardness dependent. Chromium +3 values shown are for a total hardness of 100 mg/L only. See part 7050.0222, subpart 2, for examples at other hardness values and equations to calculate trivalent chromium standards for any hardness value not to exceed 400 mg/L.

(9) Chromium +6, total, µg/L

11	16	32	--	--	--	--	--

(10) Chromium, total, µg/L

--	--	--	100	--	--	--	--

2A CS	**2A MS**	**2A FAV**	**1B DC**	**3A/3B IC**	**4A IR**	**4B LS**	**5 AN**

(11) Cobalt, total, µg/L

2.8	436	872	--	--	--	--	--

(12) Copper, total, µg/L

9.8	18	35	1,000 (S)	--	--	--	--

Class 2A copper standards are hardness dependent. Copper values shown are for a total hardness of 100 mg/L only. See part 7050.0222, subpart 2, for examples at other hardness values and equations to calculate copper standards for any hardness value not to exceed 400 mg/L.

(13) Iron, total, µg/L

--	--	--	300(S)	--	--	--	--

(14) Lead, total, µg/L

3.2	82	164	NA	--	--	--	--

Class 2A lead standards are hardness dependent. Lead values shown are for a total hardness of 100 mg/L only. See part 7050.0222, subpart 2, for examples at other hardness values and equations to calculate lead standards for any hardness value not to exceed 400 mg/L.

(15) Manganese, total, µg/L

--	--	--	50(S)	--	--	--	--

2A CS	**2A MS**	**2A FAV**	**1B DC**	**3A/3B IC**	**4A IR**	**4B LS**	**5 AN**

(16) Mercury, total, in water, ng/L

6.9	2,400*	4,900*	2,000	--	--	--	--

(17) Mercury, total in edible fish tissue, mg/kg or parts per million

0.2	--	--	--	--	--	--	--

(18) Nickel, total, µg/L

158	1,418	2,836	--	--	--	--	--

Class 2A nickel standards are hardness dependent. Nickel values shown are for a total hardness of 100 mg/L only. See part 7050.0222, subpart 2, for examples at other hardness values and equations to calculate nickel standards for any hardness value not to exceed 400 mg/L.

(19) Selenium, total, µg/L

5.0	20	40	50	--	--	--	--

(20) Silver, total, µg/L

0.12	2.0	4.1	100(S)	--	--	--	--

Class 2A silver MS and FAV are hardness dependent. Silver values shown are for a total hardness of 100 mg/L only. See part 7050.0222, subpart 2, for examples at other hardness values and equations to calculate silver standards for any hardness value not to exceed 400 mg/L.

2A CS	**2A MS**	**2A FAV**	**1B DC**	**3A/3B IC**	**4A IR**	**4B LS**	**5 AN**

(21) Thallium, total, µg/L

0.28	64	128	2	--	--	--	--

(22) Zinc, total, µg/L

106	117	234	5,000 (S)	--	--	--	--

Class 2A zinc standards are hardness dependent. Zinc values shown are for a total hardness of 100 mg/L only. See part 7050.0222, subpart 2, for examples at other hardness values and equations to calculate zinc standards for any hardness value not to exceed 400 mg/L.

C. ORGANIC POLLUTANTS OR CHARACTERISTICS

2A CS	**2A MS**	**2A FAV**	**1B DC**	**3A/3B IC**	**4A IR**	**4B LS**	**5 AN**

(1) Acenaphthene, µg/L

20	56	112	--	--	--	--	--

(2) Acetochlor, µg/L

3.6	86	173	--	--	--	--	--
(3) Acrylonitrile (c), µg/L							
0.38	1,140*	2,281*	--	--	--	--	--
(4) Alachlor (c), µg/L							
3.8	800*	1,600*	2	--	--	--	--
(5) Aldicarb, µg/L							
--	--	--	3	--	--	--	--
2A CS	**2A MS**	**2A FAV**	**1B DC**	**3A/3B IC**	**4A IR**	**4B LS**	**5 AN**
(6) Aldicarb sulfone, µg/L							
--	--	--	2	--	--	--	--
(7) Aldicarb sulfoxide, µg/L							
--	--	--	4	--	--	--	--
(8) Anthracene, µg/L							
0.035	0.32	0.63	--	--	--	--	--
(9) Atrazine (c), µg/L							
3.4	323	645	3	--	--	--	--
(10) Benzene (c), µg/L							
5.1	4,487*	8,974*	5	--	--	--	--

2A CS	2A MS	2A FAV	1B DC	3A/3B IC	4A IR	4B LS	5 AN
(11) Benzo(a)pyrene, µg/L							
--	--	--	0.2	--	--	--	--
(12) Bromoform, µg/L							
33	2,900	5,800	See sub-item (73)	--	--	--	--
(13) Carbofuran, µg/L							
--	--	--	40	--	--	--	--
(14) Carbon tetrachloride (c), µg/L							
1.9	1,750*	3,500*	5	--	--	--	--
(15) Chlordane (c), ng/L							
0.073	1,200*	2,400*	2,000	--	--	--	--

2A CS	2A MS	2A FAV	1B DC	3A/3B IC	4A IR	4B LS	5 AN
(16) Chlorobenzene, µg/L (Monochlorobenzene)							
20	423	846	100	--	--	--	--
(17) Chloroform (c), µg/L							
53	1,392	2,784	See sub-item (73)	--	--	--	--
(18) Chlorpyrifos, µg/L							

0.041	0.083	0.17	--	--	--	--	--
(19) Dalapon, µg/L							
--	--	--	200	--	--	--	--
(20) DDT (c), ng/L							
0.11	550*	1,100*	--	--	--	--	--
2A	**2A**	**2A**	**1B**	**3A/3B**	**4A**	**4B**	**5**
CS	**MS**	**FAV**	**DC**	**IC**	**IR**	**LS**	**AN**
(21) 1,2-Dibromo-3-chloropropane (c), µg/L							
--	--	--	0.2	--	--	--	--
(22) Dichlorobenzene (ortho), µg/L							
--	--	--	600	--	--	--	--
(23) 1,4-Dichlorobenzene (para) (c), µg/L							
--	--	--	75	--	--	--	--
(24) 1,2-Dichloroethane (c), µg/L							
3.5	45,050*	90,100*	5	--	--	--	--
(25) 1,1-Dichloroethylene, µg/L							
--	--	--	7	--	--	--	--
2A	**2A**	**2A**	**1B**	**3A/3B**	**4A**	**4B**	**5**
CS	**MS**	**FAV**	**DC**	**IC**	**IR**	**LS**	**AN**
(26) 1,2-Dichloroethylene (cis), µg/L							

--	--	--	70	--	--	--	--

(27) 1,2-Dichloroethylene (trans), µg/L

--	--	--	100	--	--	--	--

(28) 2,4-Dichlorophenoxyacetic acid (2,4-D), µg/L

--	--	--	70	--	--	--	--

(29) 1,2-Dichloropropane (c), µg/L

--	--	--	5	--	--	--	--

(30) Dieldrin (c), ng/L

0.0065	1,300*	2,500*	--	--	--	--	--

2A CS	**2A MS**	**2A FAV**	**1B DC**	**3A/3B IC**	**4A IR**	**4B LS**	**5 AN**

(31) Di-2-ethylhexyl adipate, µg/L

--	--	--	400	--	--	--	--

(32) Di-2-ethylhexyl phthalate (c), µg/L

1.9	--*	--*	6	--	--	--	--

(33) Di-n-Octyl phthalate, µg/L

30	825	1,650	--	--	--	--	--

(34) Dinoseb, µg/L

--	--	--	7	--	--	--	--

(35) Diquat, µg/L

--	--	--	20	--	--	--	--

2A CS	**2A MS**	**2A FAV**	**1B DC**	**3A/3B IC**	**4A IR**	**4B LS**	**5 AN**
(36) Endosulfan, µg/L							
0.0076	0.084	0.17	--	--	--	--	--
(37) Endothall, µg/L							
--	--	--	100	--	--	--	--
(38) Endrin, µg/L							
0.0039	0.090	0.18	2	--	--	--	--
(39) Ethylbenzene (c), µg/L							
68	1,859	3,717	700	--	--	--	--
(40) Ethylene dibromide, µg/L							
--	--	--	0.05	--	--	--	--

2A CS	**2A MS**	**2A FAV**	**1B DC**	**3A/3B IC**	**4A IR**	**4B LS**	**5 AN**
(41) Fluoranthene, µg/L							
1.9	3.5	6.9	--	--	--	--	--
(42) Glyphosate, µg/L							
--	--	--	700	--	--	--	--

(43) Haloacetic acids (c), µg/L (Bromoacetic acid, Dibromoacetic acid, Dichloroacetic acid, Monochloroacetic acid, and Trichloroacetic acid)

--	--	--	60	--	--	--	--

(44) Heptachlor (c), ng/L

0.10	260*	520*	400	--	--	--	--

(45) Heptachlor epoxide (c), ng/L

0.12	270*	530*	200	--	--	--	--

2A	**2A**	**2A**	**1B**	**3A/3B**	**4A**	**4B**	**5**
CS	**MS**	**FAV**	**DC**	**IC**	**IR**	**LS**	**AN**

(46) Hexachlorobenzene (c), ng/L

0.061	--*	--*	1,000	--	--	--	--

(47) Hexachlorocyclopentadiene, µg/L

--	--	--	50	--	--	--	--

(48) Lindane (c), µg/L (Hexachlorocyclohexane, gamma-)

0.0087	1.0*	2.0*	0.2	--	--	--	--

(49) Methoxychlor, µg/L

--	--	--	40	--	--	--	--

(50) Methylene chloride (c), µg/L (Dichloromethane)

45	13,875*	27,749*	5	--	--	--	--

2A	**2A**	**2A**	**1B**	**3A/3B**	**4A**	**4B**	**5**
CS	**MS**	**FAV**	**DC**	**IC**	**IR**	**LS**	**AN**

(51) Metolachlor

23	271	543	--	--	--	--	--

(52) Naphthalene, µg/L

65	409	818	--	--	--	--	--

(53) Oxamyl, µg/L (Vydate)

--	--	--	200	--	--	--	--

(54) Parathion, µg/L

0.013	0.07	0.13	--	--	--	--	--

(55) Pentachlorophenol, µg/L

0.93	15	30	1	--	--	--	--

Class 2A MS and FAV are pH dependent. Pentachlorophenol values shown are for a pH of 7.5 only. See part 7050.0222, subpart 2, for examples at other pH values and equations to calculate pentachlorophenol standards for any pH value.

2A CS	**2A MS**	**2A FAV**	**1B DC**	**3A/3B IC**	**4A IR**	**4B LS**	**5 AN**

(56) Phenanthrene, µg/L

3.6	32	64	--	--	--	--	--

(57) Phenol, µg/L

123	2,214	4,428	--	--	--	--	--

(58) Picloram, µg/L

--	--	--	500	--	--	--	--

(59) Polychlorinated biphenyls (c), ng/L (PCBs, total)

0.014	1,000*	2,000*	500	--	--	--	--

(60) Simazine, µg/L

--	--	--	4	--	--	--	--
2A	**2A**	**2A**	**1B**	**3A/3B**	**4A**	**4B**	**5**
CS	**MS**	**FAV**	**DC**	**IC**	**IR**	**LS**	**AN**

---

(61) Styrene (c), µg/L

--	--	--	100	--	--	--	--

(62) 2,3,7,8-Tetrachlorodibenzo-p-dioxin, ng/L (TCDD-dioxin)

--	--	--	0.03	--	--	--	--

(63) 1,1,2,2-Tetrachloroethane (c), µg/L

1.1	1,127*	2,253*	--	--	--	--	--

(64) Tetrachloroethylene (c), µg/L

3.8	428*	857*	5	--	--	--	--

(65) Toluene, µg/L

253	1,352	2,703	1,000	--	--	--	--
2A	**2A**	**2A**	**1B**	**3A/3B**	**4A**	**4B**	**5**
CS	**MS**	**FAV**	**DC**	**IC**	**IR**	**LS**	**AN**

---

(66) Toxaphene (c), ng/L

0.31	730*	1,500*	3,000	--	--	--	--

(67) 2,4,5-TP, µg/L (Silvex)

--	--	--	50	--	--	--	--

(68) 1,2,4-Trichlorobenzene, µg/L

--	--	--	70	--	--	--	--

(69) 1,1,1-Trichloroethane, µg/L

329	2,957	5,913	200	--	--	--	--

(70) 1,1,2-Trichloroethane, µg/L

--	--	--	5	--	--	--	--

2A	**2A**	**2A**	**1B**	**3A/3B**	**4A**	**4B**	**5**
CS	**MS**	**FAV**	**DC**	**IC**	**IR**	**LS**	**AN**

(71) 1,1,2-Trichloroethylene (c), µg/L

25	6,988	13,976*	5	--	--	--	--

(72) 2,4,6-Trichlorophenol, µg/L

2.0	102	203	--	--	--	--	--

(73) Trihalomethanes, total (c), µg/L (Bromodichloromethane, Bromoform, Chlorodibromomethane, and Chloroform)

--	--	--	80	--	--	--	--

(74) Vinyl chloride (c), µg/L

0.17	--*	--*	2	--	--	--	--

(75) Xylenes, total, µg/L

166	1,407	2,814	10,000	--	--	--	--

[For text of items D and E, see M.R.]

[For text of subp 4, see M.R.]

Subp. 4a. **Cool and warm water sport fish, drinking water, and associated use classes.** Water quality standards applicable to use classes 1B or 1C; 2Bd; 3A or 3B; 4A and 4B; 4D ~~when applicable to a wild rice~~ for water bodies listed in part 7050.0471; and 5 surface waters.

A. MISCELLANEOUS SUBSTANCE, CHARACTERISTIC, OR POLLUTANT

2Bd CS	2Bd MS	2Bd FAV	1B/1C DC	3A/3B IC	4A IR	4B LS	4D	5 AN
(1) Ammonia, un-ionized as N, µg/L								
40	--	--	--	--	--	--	--	--
(2) Asbestos, >10 µm (c), fibers/L								
--	--	--	7.0e+06	--	--	--	--	--
(3) Bicarbonates (HCO_3), meq/L								
--	--	--	--	--	5	--	--	--
(4) Bromate, µg/L								
--	--	--	10	--	--	--	--	--
(5) Chloride, mg/L								
230	860	1,720	250(S)	50/100	--	--	--	--

2Bd CS	2Bd MS	2Bd FAV	1B/1C DC	3A/3B IC	4A IR	4B LS	4D	5 AN
(6) Chlorine, total residual, µg/L								
11	19	38	--	--	--	--	--	--

(7) Chlorite, µg/L

--	--	--	1,000	--	--	--	--	--

(8) Color, Pt-Co

--	--	--	15(S)	--	--	--	--	--

(9) Cyanide, free, µg/L

5.2	22	45	200	--	--	--	--	--

(10) *Escherichia (E.) coli* bacteria, organisms/100 mL

See item D	--	--	--	--	--	--	--	--

2Bd CS	**2Bd MS**	**2Bd FAV**	**1B/1C DC**	**3A/3B IC**	**4A IR**	**4B LS**	**4D**	**5 AN**

(11) Eutrophication standards for lakes, shallow lakes, and reservoirs (phosphorus, total, µg/L; chlorophyll-a, µg/L; Secchi disk transparency, meters)

See part 7050.0222, subparts 3 and 3a	--	--	--	--	--	--	--	--

(12) Eutrophication standards for rivers, streams, and navigational pools (phosphorus, total µg/L; chlorophyll-a (seston), µg/L; five-day biochemical oxygen demand (BOD_5), mg/L; diel dissolved oxygen flux, mg/L; chlorophyll-a (periphyton), mg/m^2)

See part 7050.0222, subparts 3 and 3b	--	--	--	--	--	--	--	--

(13) Fluoride, mg/L

--	--	--	4	--	--	--	--	--

(14) Fluoride, mg/L

--	--	--	2(S)	--	--	--	--	--

(15) Foaming agents, µg/L

--	--	--	500(S)	--	--	--	--	--

(16) Hardness, Ca+Mg as $CaCO_3$, mg/L

--	--	--	--	50/250	--	--	--	--

2Bd CS	**2Bd MS**	**2Bd FAV**	**1B/1C DC**	**3A/3B IC**	**4A IR**	**4B LS**	**4D**	**5 AN**

(17) Hydrogen sulfide, mg/L

--	--	--	--	--	--	--	--	0.02

(18) Nitrate as N, mg/L

--	--	--	10	--	--	--	--	--

(19) Nitrite as N, mg/L

--	--	--	1	--	--	--	--	--

(20) Nitrate + Nitrite as N, mg/L

--	--	--	10	--	--	--	--	--

(21) Odor, TON

--	--	--	3(S)	--	--	--	--	--

2Bd CS	2Bd MS	2Bd FAV	1B/1C DC	3A/3B IC	4A IR	4B LS	4D	5 AN
(22) Oil, µg/L								
500	5,000	10,000	--	--	--	--	--	--
(23) Oxygen, dissolved, mg/L								
See part 7050.0222, subpart 3	--	--	--	--	--	--	--	--
(24) pH minimum, su								
6.5	--	--	6.5(S)	6.5/6.0	6.0	6.0	--	6.0
(25) pH maximum, su								
9.0	--	--	8.5(S)	8.5/9.0	8.5	9.0	--	9.0
(26) Radioactive materials								
See item E	--	--	See item E	--	See item E	See item E	--	--

2Bd CS	2Bd MS	2Bd FAV	1B/1C DC	3A/3B IC	4A IR	4B LS	4D	5 AN
(27) Salinity, total, mg/L								
--	--	--	--	--	--	1,000	--	--
(28) Sodium, meq/L								
--	--	--	--	--	60% of total cations	--	--	--

(29) Specific conductance at 25°C, µmhos/cm

--	--	--	--	--	1,000	--	--	--

(30) Sulfate, mg/L

--	--	--	250(S)	--	--	--	--	--

(31) Sulfate in a wild rice water

--	--	--	--	--	--	--	--	--

See part 7050.0224, subpart 5

2Bd CS	**2Bd MS**	**2Bd FAV**	**1B/1C DC**	**3A/3B IC**	**4A IR**	**4B LS**	**4D**	**5 AN**

(32) Temperature, °F

See item F	--	--	--	--	--	--	--	--

(33) Total dissolved salts, mg/L

--	--	--	--	--	700	--	--	--

(34) Total dissolved solids, mg/L

--	--	--	500(S)	--	--	--	--	--

(35) Total suspended solids (TSS), mg/L

See part 7050.0222, subpart 3	--	--	--	--	--	--	--	--

B. METALS AND ELEMENTS

2Bd CS	2Bd MS	2Bd FAV	1B/1C DC	3A/3B IC	4A IR	4B LS	5 AN
(1) Aluminum, total, µg/L							
125	1,072	2,145	50-200(S)	--	--	--	--
(2) Antimony, total, µg/L							
5.5	90	180	6	--	--	--	--
(3) Arsenic, total, µg/L							
2.0	360	720	10	--	--	--	--
(4) Barium, total, µg/L							
--	--	--	2,000	--	--	--	--
(5) Beryllium, total, µg/L							
--	--	--	4.0	--	--	--	--

2Bd CS	2Bd MS	2Bd FAV	1B/1C DC	3A/3B IC	4A IR	4B LS	5 AN
(6) Boron, total, µg/L							
--	--	--	--	--	500	--	--
(7) Cadmium, total, µg/L							
1.1	33	67	5	--	--	--	--

Class 2Bd cadmium standards are hardness dependent. Cadmium values shown are for a total hardness of 100 mg/L only. See part 7050.0222, subpart 3, for examples at other hardness values and equations to calculate cadmium standards for any hardness value not to exceed 400 mg/L.

(8) Chromium +3, total, µg/L

207	1,737	3,469	--	--	--	--	--

Class 2Bd trivalent chromium standards are hardness dependent. Chromium +3 values shown are for a total hardness of 100 mg/L only. See part 7050.0222, subpart 3, for examples at other hardness values and equations to calculate trivalent chromium standards for any hardness value not to exceed 400 mg/L.

(9) Chromium +6, total, µg/L

11	16	32	--	--	--	--	--

(10) Chromium, total, µg/L

--	--	--	100	--	--	--	--

2Bd CS	**2Bd MS**	**2Bd FAV**	**1B/1C DC**	**3A/3B IC**	**4A IR**	**4B LS**	**5 AN**

(11) Cobalt, total, µg/L

2.8	436	872	--	--	--	--	--

(12) Copper, total, µg/L

9.8	18	35	1,000 (S)	--	--	--	--

Class 2Bd copper standards are hardness dependent. Copper values shown are for a total hardness of 100 mg/L only. See part 7050.0222, subpart 3, for examples at other hardness values and equations to calculate copper standards for any hardness value not to exceed 400 mg/L.

(13) Iron, total, µg/L

--	--	--	300(S)	--	--	--	--

(14) Lead, total, µg/L

3.2	82	164	NA	--	--	--	--

Class 2Bd lead standards are hardness dependent. Lead values shown are for a total hardness of 100 mg/L only. See part 7050.0222, subpart 3, for examples at other hardness values and equations to calculate lead standards for any hardness value not to exceed 400 mg/L.

(15) Manganese, total, µg/L

--	--	--	50(S)	--	--	--	--

2Bd CS	**2Bd MS**	**2Bd FAV**	**1B/1C DC**	**3A/3B IC**	**4A IR**	**4B LS**	**5 AN**

(16) Mercury, total in water, ng/L

6.9	2,400*	4,900*	2,000	--	--	--	--

(17) Mercury, total in edible fish tissue, mg/kg or parts per million

0.2	--	--	--	--	--	--	--

(18) Nickel, total, µg/L

158	1,418	2,836	--	--	--	--	--

Class 2Bd nickel standards are hardness dependent. Nickel values shown are for a total hardness of 100 mg/L only. See part 7050.0222, subpart 3, for examples at other hardness values and equations to calculate nickel standards for any hardness value not to exceed 400 mg/L.

(19) Selenium, total, µg/L

5.0	20	40	50	--	--	--	--

(20) Silver, total, µg/L

1.0	2.0	4.1	100(S)	--	--	--	--

Class 2Bd silver MS and FAV are hardness dependent. Silver values shown are for a total hardness of 100 mg/L only. See part 7050.0222, subpart 3, for examples at other hardness values and equations to calculate silver standards for any hardness value not to exceed 400 mg/L.

2Bd CS	2Bd MS	2Bd FAV	1B/1C DC	3A/3B IC	4A IR	4B LS	5 AN
(21) Thallium, total, µg/L							
0.28	64	128	2	--	--	--	--
(22) Zinc, total, µg/L							
106	117	234	5,000 (S)	--	--	--	--

Class 2Bd zinc standards are hardness dependent. Zinc values shown are for a total hardness of 100 mg/L only. See part 7050.0222, subpart 3, for examples at other hardness values and equations to calculate zinc standards for any hardness value not to exceed 400 mg/L.

C. ORGANIC POLLUTANTS OR CHARACTERISTICS

2Bd CS	2Bd MS	2Bd FAV	1B/1C DC	3A/3B ICIC	4A IR	4B LS	5 AN
(1) Acenaphthene, µg/L							
20	56	112	--	--	--	--	--
(2) Acetochlor, µg/L							
3.6	86	173	--	--	--	--	--
(3) Acrylonitrile (c), µg/L							
0.38	1,140*	2,281*	--	--	--	--	--
(4) Alachlor (c), µg/L							

4.2	800*	1,600*	2	--	--	--	--

(5) Aldicarb, µg/L

--	--	--	3	--	--	--	--

2Bd	**2Bd**	**2Bd**	**1B/1C**	**3A/3B**	**4A**	**4B**	**5**
CS	**MS**	**FAV**	**DC**	**ICIC**	**IR**	**LS**	**AN**

(6) Aldicarb sulfone, µg/L

--	--	--	2	--	--	--	--

(7) Aldicarb sulfoxide, µg/L

--	--	--	4	--	--	--	--

(8) Anthracene, µg/L

0.035	0.32	0.63	--	--	--	--	--

(9) Atrazine (c), µg/L

3.4	323	645	3	--	--	--	--

(10) Benzene (c), µg/L

6.0	4,487*	8,974*	5	--	--	--	--

2Bd	**2Bd**	**2Bd**	**1B/1C**	**3A/3B**	**4A**	**4B**	**5**
CS	**MS**	**FAV**	**DC**	**ICIC**	**IR**	**LS**	**AN**

(11) Benzo(a)pyrene, µg/L

--	--	--	0.2	--	--	--	--

(12) Bromoform, µg/L

41	2,900	5,800	See subitem (73)	--	--	--	--

(13) Carbofuran, µg/L

--	--	--	40	--	--	--	--

(14) Carbon tetrachloride (c), µg/L

1.9	1,750*	3,500*	5	--	--	--	--

(15) Chlordane (c), ng/L

0.29	1,200*	2,400*	2,000	--	--	--	--

2Bd CS	**2Bd MS**	**2Bd FAV**	**1B/1C DC**	**3A/3B ICIC**	**4A IR**	**4B LS**	**5 AN**

(16) Chlorobenzene, µg/L (Monochlorobenzene)

20	423	846	100	--	--	--	--

(17) Chloroform (c), µg/L

53	1,392	2,784	See subitem (73)	--	--	--	--

(18) Chlorpyrifos, µg/L

0.041	0.083	0.17	--	--	--	--	--

(19) Dalapon, µg/L

--	--	--	200	--	--	--	--

(20) DDT (c), ng/L

1.7	550*	1,100*	--	--	--	--	--

2Bd CS	**2Bd MS**	**2Bd FAV**	**1B/1C DC**	**3A/3B ICIC**	**4A IR**	**4B LS**	**5 AN**

(21) 1,2-Dibromo-3-chloropropane (c), µg/L

--	--	--	0.2	--	--	--	--

(22) Dichlorobenzene (ortho), µg/L

--	--	--	600	--	--	--	--

(23) 1,4-Dichlorobenzene (para) (c), µg/L

--	--	--	75	--	--	--	--

(24) 1,2-Dichloroethane (c), µg/L

3.8	45,050*	90,100*	5	--	--	--	--

(25) 1,1-Dichloroethylene, µg/L

--	--	--	7	--	--	--	--

2Bd CS	**2Bd MS**	**2Bd FAV**	**1B/1C DC**	**3A/3B ICIC**	**4A IR**	**4B LS**	**5 AN**

(26) 1,2-Dichloroethylene (cis), µg/L

--	--	--	70	--	--	--	--

(27) 1,2-Dichloroethylene (trans), µg/L

--	--	--	100	--	--	--	--

(28) 2,4-Dichlorophenoxyacetic acid (2,4-D), µg/L

--	--	--	70	--	--	--	--

(29) 1,2-Dichloropropane (c), µg/L

--	--	--	5	--	--	--	--

(30) Dieldrin (c), ng/L

0.026	1,300*	2,500*	--	--	--	--	--

2Bd	2Bd	2Bd	1B/1C	3A/3B	4A	4B	5
CS	**MS**	**FAV**	**DC**	**ICIC**	**IR**	**LS**	**AN**

(31) Di-2-ethylhexyl adipate, µg/L

--	--	--	400	--	--	--	--

(32) Di-2-ethylhexyl phthalate (c), µg/L

1.9	--*	--*	6	--	--	--	--

(33) Di-n-Octyl phthalate, µg/L

30	825	1,650	--	--	--	--	--

(34) Dinoseb, µg/L

--	--	--	7	--	--	--	--

(35) Diquat, µg/L

--	--	--	20	--	--	--	--

2Bd	2Bd	2Bd	1B/1C	3A/3B	4A	4B	5
CS	**MS**	**FAV**	**DC**	**ICIC**	**IR**	**LS**	**AN**

(36) Endosulfan, µg/L

0.029	0.28	0.56	--	--	--	--	--

(37) Endothall, µg/L

--	--	--	100	--	--	--	--

(38) Endrin, µg/L

0.016	0.090	0.18	2	--	--	--	--

(39) Ethylbenzene (c), µg/L

68	1,859	3,717	700	--	--	--	--

(40) Ethylene dibromide, µg/L

--	--	--	0.05	--	--	--	--

2Bd CS	**2Bd MS**	**2Bd FAV**	**1B/1C DC**	**3A/3B ICIC**	**4A IR**	**4B LS**	**5 AN**

(41) Fluoranthene, µg/L

1.9	3.5	6.9	--	--	--	--	--

(42) Glyphosate, µg/L

--	--	--	700	--	--	--	--

(43) Haloacetic acids (c), µg/L (Bromoacetic acid, Dibromoacetic acid, Dichloroacetic acid, Monochloroacetic acid, and Trichloroacetic acid)

--	--	--	60	--	--	--	--

(44) Heptachlor (c), ng/L

0.39	260*	520*	400	--	--	--	--

(45) Heptachlor epoxide (c), ng/L

0.48	270*	530*	200	--	--	--	--

2Bd CS	**2Bd MS**	**2Bd FAV**	**1B/1C DC**	**3A/3B ICIC**	**4A IR**	**4B LS**	**5 AN**
(46) Hexachlorobenzene (c), ng/L							
0.24	--*	--*	1,000	--	--	--	--
(47) Hexachlorocyclopentadiene, µg/L							
--	--	--	50	--	--	--	--
(48) Lindane (c), µg/L (Hexachlorocyclohexane, gamma-)							
0.032	4.4*	8.8*	0.2	--	--	--	--
(49) Methoxychlor, µg/L							
--	--	--	40	--	--	--	--
(50) Methylene chloride (c), µg/L (Dichloromethane)							
46	13,875*	27,749*	5	--	--	--	--

2Bd CS	**2Bd MS**	**2Bd FAV**	**1B/1C DC**	**3A/3B ICIC**	**4A IR**	**4B LS**	**5 AN**
(51) Metolachlor							
23	271	543	--	--	--	--	--
(52) Naphthalene, µg/L							
81	409	818	--	--	--	--	--
(53) Oxamyl, µg/L (Vydate)							

--	--	--	200	--	--	--	--

(54) Parathion, µg/L

0.013	0.07	0.13	--	--	--	--	--

(55) Pentachlorophenol, µg/L

1.9	15	30	1	--	--	--	--

Class 2Bd MS and FAV are pH dependent. Pentachlorophenol values shown are for a pH of 7.5 only. See part 7050.0222, subpart 3, for examples at other pH values and equations to calculate pentachlorophenol standards for any pH value.

2Bd CS	**2Bd MS**	**2Bd FAV**	**1B/1C DC**	**3A/3B ICIC**	**4A IR**	**4B LS**	**5 AN**
(56) Phenanthrene, µg/L							
3.6	32	64	--	--	--	--	--
(57) Phenol, µg/L							
123	2,214	4,428	--	--	--	--	--
(58) Picloram, µg/L							
--	--	--	500	--	--	--	--
(59) Polychlorinated biphenyls (c), ng/L (PCBs, total)							
0.029	1,000*	2,000*	500	--	--	--	--
(60) Simazine, µg/L							
--	--	--	4	--	--	--	--

2Bd CS	2Bd MS	2Bd FAV	1B/1C DC	3A/3B ICIC	4A IR	4B LS	5 AN
(61) Styrene (c), µg/L							
--	--	--	100	--	--	--	--
(62) 2,3,7,8-Tetrachlorodibenzo-p-dioxin, ng/L (TCDD-dioxin)							
--	--	--	0.03	--	--	--	--
(63) 1,1,2,2-Tetrachloroethane (c), µg/L							
1.5	1,127*	2,253*	--	--	--	--	--
(64) Tetrachloroethylene (c), µg/L							
3.8	428*	857*	5	--	--	--	--
(65) Toluene, µg/L							
253	1,352	2,703	1,000	--	--	--	--

2Bd CS	2Bd MS	2Bd FAV	1B/1C DC	3A/3B ICIC	4A IR	4B LS	5 AN
(66) Toxaphene (c), ng/L							
1.3	730*	1,500*	3,000	--	--	--	--
(67) 2,4,5-TP, µg/L (Silvex)							
--	--	--	50	--	--	--	--
(68) 1,2,4-Trichlorobenzene, µg/L							
--	--	--	70	--	--	--	--

(69) 1,1,1-Trichloroethane, µg/L

329	2,957	5,913	200	--	--	--	--

(70) 1,1,2-Trichloroethane, µg/L

--	--	--	5	--	--	--	--

2Bd CS	**2Bd MS**	**2Bd FAV**	**1B/1C DC**	**3A/3B ICIC**	**4A IR**	**4B LS**	**5 AN**

(71) 1,1,2-Trichloroethylene (c), µg/L

25	6,988*	13,976*	5	--	--	--	--

(72) 2,4,6-Trichlorophenol, µg/L

2.0	102	203	--	--	--	--	--

(73) Trihalomethanes, total (c), µg/L (Bromodichloromethane, Bromoform, Chlorodibromomethane, and Chloroform)

--	--	--	80	--	--	--	--

(74) Vinyl chloride (c), µg/L

0.18	--*	--*	2	--	--	--	--

(75) Xylenes, total, µg/L

166	1,407	2,814	10,000	--	--	--	--

[For text of items D to F, see M.R.]

[For text of subp 5, see M.R.]

Subp. 5a. **Cool and warm water sport fish and associated use classes.** Water quality standards applicable to use classes 2B, 2C, or 2D; 3A, 3B, or 3C; 4A and 4B; 4D ~~when applicable to a wild rice~~ for water bodies listed in part 7050.0471; and 5 surface waters.

See parts 7050.0223, subpart 5; 7050.0224, subparts 4 and 5; and 7050.0225, subpart 2, for class 3D, 4C, and 5 standards applicable to wetlands, respectively. See part 7050.0224, subpart 5, for standards applicable to wetlands that are also class 4D wild rice waters.

A. MISCELLANEOUS SUBSTANCE, CHARACTERISTIC, OR POLLUTANT

2B,C&D CS	**2B,C&D MS**	**2B,C&D FAV**	**3A/3B/3C IC**	**4A IR**	**4B LS**	**4D**	**5 AN**
(1) Ammonia, un-ionized as N, µg/L							
40	--	--	--	--	--	--	--
(2) Bicarbonates (HCO_3), meq/L							
--	--	--	--	5	--	--	--
(3) Chloride, mg/L							
230	860	1,720	50/100/250	--	--	--	--
(4) Chlorine, total residual, µg/L							
11	19	38	--	--	--	--	--
(5) Cyanide, free, µg/L							
5.2	22	45	--	--	--	--	--

2B,C&D CS	**2B,C&D MS**	**2B,C&D FAV**	**3A/3B/3C IC**	**4A IR**	**4B LS**	**4D**	**5 AN**
(6) *Escherichia (E.) coli* bacteria, organisms/100 mL							
See item D	--	--	--	--	--	--	--

(7) Eutrophication standards for lakes, shallow lakes, and reservoirs (phosphorus, total, µg/L; chlorophyll-a, µg/L; Secchi disk transparency, meters)

See part 7050.0222, subparts 4, 4a, and 5	--	--	--	--	--	--	--

(8) Eutrophication standards for rivers, streams, and navigational pools (phosphorus, total µg/L; chlorophyll-a (seston), µg/L; five-day biochemical oxygen demand (BOD_5), mg/L; diel dissolved oxygen flux, mg/L; chlorophyll-a (periphyton), mg/m^2)

See part 7050.0222, subparts 4 and 4b	--	--	--	--	--	--	--	--

(9) Hardness, Ca+Mg as $CaCO_3$, mg/L

--	--	--	50/250/500	--	--	--	--

(10) Hydrogen sulfide, mg/L

--	--	--	--	--	--	--	0.02

(11) Oil, µg/L

500	5,000	10,000	--	--	--	--	--

2B,C&D CS	**2B,C&D MS**	**2B,C&D FAV**	**3A/3B/3C IC**	**4A IR**	**4B LS**	**4D**	**5 AN**

(12) Oxygen, dissolved, mg/L

See part 7050.0222,	--	--	--	--	--	--	--

subparts
4 to 6

(13) pH minimum, su

6.5 See item E	--	--	6.5/6.0/6.0	6.0	6.0	--	6.0

(14) pH maximum, su

9.0 See item E	--	--	8.5/9.0/9.0	8.5	9.0	--	9.0

(15) Radioactive materials

See item F	--	--	--	See item F	See item F	--	--

(16) Salinity, total, mg/L

--	--	--	--	--	1,000	--	--

2B,C&D CS	**2B,C&D MS**	**2B,C&D FAV**	**3A/3B/3C IC**	**4A IR**	**4B LS**	**4D**	**5 AN**

(17) Sodium, meq/L

--	--	--	--	60% of total cations	--	--	--

(18) Specific conductance at 25°C, μ mhos/cm

--	--	--	--	1,000	--	--	--

(19) Sulfate in a wild rice water

--	--	--	--	--	--	--	--

See part 7050.0224, subpart 5

(20) Temperature, °F

See item G	--	--	--	--	--	--	--

(21) Total dissolved salts, mg/L

--	--	--	--	700	--	--	--

(22) Total suspended solids (TSS), mg/L

See part 7050.0222, subpart 4	--	--	--	--	--	--	--

B. METALS AND ELEMENTS

2B,C&D CS	2B,C&D MS	2B,C&D FAV	3A/3B/3C IC	4A IR	4B LS	5 AN
(1) Aluminum, total, µg/L						
125	1,072	2,145	--	--	--	--
(2) Antimony, total, µg/L						
31	90	180	--	--	--	--
(3) Arsenic, total, µg/L						
53	360	720	--	--	--	--
(4) Boron, total, µg/L						
--	--	--	--	500	--	--

(5) Cadmium, total, µg/L

1.1	33	67	--	--	--	--

Class 2B, 2C, and 2D cadmium standards are hardness dependent. Cadmium values shown are for a total hardness of 100 mg/L only. See part 7050.0222, subpart 4, for examples at other hardness values and equations to calculate cadmium standards for any hardness value not to exceed 400 mg/L.

2B,C&D	**2B,C&D**	**2B,C&D**	**3A/3B/3C**	**4A**	**4B**	**5**
CS	**MS**	**FAV**	**IC**	**IR**	**LS**	**AN**

(6) Chromium +3, total, µg/L

207	1,737	3,469	--	--	--	--

Class 2B, 2C, and 2D trivalent chromium standards are hardness dependent. Chromium +3 values shown are for a total hardness of 100 mg/L only. See part 7050.0222, subpart 4, for examples at other hardness values and equations to calculate trivalent chromium standards for any hardness value not to exceed 400 mg/L.

(7) Chromium +6, total, µg/L

11	16	32	--	--	--	--

(8) Cobalt, total, µg/L

5.0	436	872	--	--	--	--

(9) Copper, total, µg/L

9.8	18	35	--	--	--	--

Class 2B, 2C, and 2D copper standards are hardness dependent. Copper values shown are for a total hardness of 100 mg/L only. See part 7050.0222, subpart 4, for examples at other hardness values and equations to calculate copper standards for any hardness value not to exceed 400 mg/L.

(10) Lead, total, µg/L

3.2	82	164	--	--	--	--

Class 2B, 2C, and 2D lead standards are hardness dependent. Lead values shown are for a total hardness of 100 mg/L only. See part 7050.0222, subpart 4, for examples at other hardness values and equations to calculate lead standards for any hardness value not to exceed 400 mg/L.

2B,C&D CS	**2B,C&D MS**	**2B,C&D FAV**	**3A/3B/3C IC**	**4A IR**	**4B LS**	**5 AN**
(11) Mercury, total in water, ng/L						
6.9	2,400*	4,900*	--	--	--	--
(12) Mercury, total in edible fish tissue, mg/kg or parts per million						
0.2	--	--	--	--	--	--
(13) Nickel, total, µg/L						
158	1,418	2,836	--	--	--	--

Class 2B, 2C, and 2D nickel standards are hardness dependent. Nickel values shown are for a total hardness of 100 mg/L only. See part 7050.0222, subpart 4, for examples at other hardness values and equations to calculate nickel standards for any hardness value not to exceed 400 mg/L.

2B,C&D CS	**2B,C&D MS**	**2B,C&D FAV**	**3A/3B/3C IC**	**4A IR**	**4B LS**	**5 AN**
(14) Selenium, total, µg/L						
5.0	20	40	--	--	--	--
(15) Silver, total, µg/L						
1.0	2.0	4.1	--	--	--	--

Class 2B, 2C, and 2D silver MS and FAV are hardness dependent. Silver values shown are for a total hardness of 100 mg/L only. See part 7050.0222, subpart 4, for examples at other hardness values and equations to calculate silver standards for any hardness value not to exceed 400 mg/L.

2B,C&D CS	2B,C&D MS	2B,C&D FAV	3A/3B/3C IC	4A IR	4B LS	5 AN
(16) Thallium, total, µg/L						
0.56	64	128	--	--	--	--
(17) Zinc, total, µg/L						
106	117	234	--	--	--	--

Class 2B, 2C, and 2D zinc standards are hardness dependent. Zinc values shown are for a total hardness of 100 mg/L only. See part 7050.0222, subpart 4, for examples at other hardness values and equations to calculate zinc standards for any hardness value not to exceed 400 mg/L.

C. ORGANIC POLLUTANTS OR CHARACTERISTICS

2B,C&D CS	2B,C&D MS	2B,C&D FAV	3A/3B/3C IC	4A IR	4B LS	5 AN
(1) Acenaphthene, µg/L						
20	56	112	--	--	--	--
(2) Acetochlor, µg/L						
3.6	86	173	--	--	--	--
(3) Acrylonitrile (c), µg/L						
0.89	1,140*	2,281*	--	--	--	--
(4) Alachlor (c), µg/L						
59	800	1,600	--	--	--	--
(5) Anthracene, µg/L						

0.035	0.32	0.63	--	--	--	--

2B,C&D CS	**2B,C&D MS**	**2B,C&D FAV**	**3A/3B/3C IC**	**4A IR**	**4B LS**	**5 AN**
(6) Atrazine (c), µg/L						
10	323	645	--	--	--	--
(7) Benzene (c), µg/L						
98	4,487	8,974	--	--	--	--
(8) Bromoform, µg/L						
466	2,900	5,800	--	--	--	--
(9) Carbon tetrachloride (c), µg/L						
5.9	1,750*	3,500*	--	--	--	--
(10) Chlordane (c), ng/L						
0.29	1,200*	2,400*	--	--	--	--

2B,C&D CS	**2B,C&D MS**	**2B,C&D FAV**	**3A/3B/3C IC**	**4A IR**	**4B LS**	**5 AN**
(11) Chlorobenzene, µg/L (Monochlorobenzene)						
20	423	846	--	--	--	--
(12) Chloroform (c), µg/L						
155	1,392	2,78	--	--	--	--
(13) Chlorpyrifos, µg/L						

0.041	0.083	0.17	--	--	--	--
(14) DDT (c), ng/L						
1.7	550*	1,100*	--	--	--	--
(15) 1,2-Dichloroethane (c), µg/L						
190	45,050*	90,100*	--	--	--	--
2B,C&D CS	**2B,C&D MS**	**2B,C&D FAV**	**3A/3B/3C IC**	**4A IR**	**4B LS**	**5 AN**
(16) Dieldrin (c), ng/L						
0.026	1,300*	2,500*	--	--	--	--
(17) Di-2-ethylhexyl phthalate (c), µg/L						
2.1	--*	--*	--	--	--	--
(18) Di-n-Octyl phthalate, µg/L						
30	825	1,650	--	--	--	--
(19) Endosulfan, µg/L						
0.031	0.28	0.56	--	--	--	--
(20) Endrin, µg/L						
0.016	0.090	0.18	--	--	--	--
2B,C&D CS	**2B,C&D MS**	**2B,C&D FAV**	**3A/3B/3C IC**	**4A IR**	**4B LS**	**5 AN**
(21) Ethylbenzene (c), µg/L						

68	1,859	3,717	--	--	--	--

(22) Fluoranthene, µg/L

1.9	3.5	6.9	--	--	--	--

(23) Heptachlor (c), ng/L

0.39	260*	520*	--	--	--	--

(24) Heptachlor epoxide (c), ng/L

0.48	270*	530*	--	--	--	--

(25) Hexachlorobenzene (c), ng/L

0.24	--*	--*	--	--	--	--

2B,C&D CS	**2B,C&D MS**	**2B,C&D FAV**	**3A/3B/3C IC**	**4A IR**	**4B LS**	**5 AN**

(26) Lindane (c), µg/L (Hexachlorocyclohexane, gamma-)

0.036	4.4*	8.8*	--	--	--	--

(27) Methylene chloride (c), µg/L (Dichloromethane)

1,940	13,875	27,749	--	--	--	--

(28) Metolachlor

23	271	543	--	--	--	--

(29) Naphthalene, µg/L

81	409	818	--	--	--	--

(30) Parathion, µg/L

0.013	0.07	0.13	--	--	--	--

2B,C&D CS	**2B,C&D MS**	**2B,C&D FAV**	**3A/3B/3C IC**	**4A IR**	**4B LS**	**5 AN**

(31) Pentachlorophenol, µg/L

5.5	15	30	--	--	--	--

Class 2B, 2C, and 2D standards are pH dependent, except that the CS will not exceed 5.5 µg/L. Pentachlorophenol values shown are for a pH of 7.5 only. See part 7050.0222, subpart 4, for examples at other pH values and equations to calculate pentachlorophenol standards for any pH value.

(32) Phenanthrene, µg/L

3.6	32	64	--	--	--	--

(33) Phenol, µg/L

123	2,214	4,428	--	--	--	--

(34) Polychlorinated biphenyls (c), ng/L (PCBs, total)

0.029	1,000*	2,000*	--	--	--	--

(35) 1,1,2,2-Tetrachloroethane (c), µg/L

13	1,127	2,253	--	--	--	--

2B,C&D CS	**2B,C&D MS**	**2B,C&D FAV**	**3A/3B/3C IC**	**4A IR**	**4B LS**	**5 AN**

(36) Tetrachloroethylene (c), µg/L

8.9	428	857	--	--	--	--

(37) Toluene, µg/L

	253	1,352	2,703	--	--	--	--
(38) Toxaphene (c), ng/L							
	1.3	730*	1,500*	--	--	--	--
(39) 1,1,1-Trichloroethane, µg/L							
	329	2,957	5,913	--	--	--	--
(40) 1,1,2-Trichloroethylene (c), µg/L							
	120	6,988	13,976	--	--	--	--
	2B,C&D CS	**2B,C&D MS**	**2B,C&D FAV**	**3A/3B/3C IC**	**4A IR**	**4B LS**	**5 AN**
(41) 2,4,6-Trichlorophenol, µg/L							
	2.0	102	203	--	--	--	--
(42) Vinyl chloride (c), µg/L							
	9.2	--*	--*	--	--	--	--
(43) Xylenes, total, µg/L							
	166	1,407	2,814	--	--	--	--

[For text of items D to G, see M.R.]

[For text of subp 6, see M.R.]

Subp. 6a. **Limited resource value waters and associated use classes.**

A. WATER QUALITY STANDARDS APPLICABLE TO USE CLASSES 3C, 4A, 4B, 4D ~~WHEN APPLICABLE TO WILD RICE~~ FOR WATER BODIES LISTED IN PART 7050.0471, 5, AND 7 SURFACE WATERS

7 LIMITED RESOURCE VALUE	3C 1C	4A 1R	4B LS	4D	5 AN
(1) Bicarbonates (HCO_3), meq/L					
--	--	5	--	--	--
(2) Boron, µg/L					
--	--	500	--	--	--
(3) Chloride, mg/L					
--	250	--	--	--	--
(4) *Escherichia (E.) coli* bacteria, organisms/100 mL					
See item B	--	--	--	--	--
(5) Hardness, Ca+Mg as $CaCO_3$, mg/L					
--	500	--	--	--	--

7 LIMITED RESOURCE VALUE	3C 1C	4A 1R	4B LS	4D	5 AN
(6) Hydrogen sulfide, mg/L					
--	--	--	--	--	0.02
(7) Oxygen, dissolved, mg/L					
See item C	--	--	--	--	--

(8) pH minimum, su

6.0	6.0	6.0	6.0	--	6.0

(9) pH maximum, su

9.0	9.0	8.5	9.0	--	9.0

(10) Radioactive materials

--	--	See item D	See item D	--	--

7 LIMITED RESOURCE VALUE	**3C 1C**	**4A 1R**	**4B LS**	**4D**	**5 AN**

(11) Salinity, total, mg/L

--	--	--	1,000	--	--

(12) Sodium, meq/L

--	--	60% of total cations	--	--	--

(13) Specific conductance at 25°C, µmhos/cm

--	--	1,000	--	--	--

(14) Sulfate in a wild rice water

--	--	--	--	--	--

See part 7050.0224, subpart 5

(15) Total dissolved salts, mg/L

--	--	700	--	--	--

(16) Toxic pollutants

See item E	--	--	--	--	--

[For text of items B to E, see M.R.]

[For text of subp 7, see M.R.]

7050.0224 SPECIFIC WATER QUALITY STANDARDS FOR CLASS 4 WATERS OF THE STATE; AGRICULTURE AND WILDLIFE.

Subpart 1. **General.** The numeric and narrative water quality standards in this part prescribe the qualities or properties of the waters of the state that are necessary for the agriculture and wildlife designated public uses and benefits. If the standards in this part are exceeded in waters of the state that have the class 4 designation, it is considered indicative of a polluted condition that is actually or potentially deleterious, harmful, detrimental, or injurious with respect to the designated uses.

Subp. 2. **Class 4A waters.** The quality of class 4A waters of the state shall be such as to permit their use for irrigation without significant damage or adverse effects upon any crops or vegetation usually grown in the waters or area, including truck garden crops. The following standards shall be used as a guide in determining the suitability of the waters for such uses, together with the recommendations contained in Handbook 60 published by the Salinity Laboratory of the United States Department of Agriculture, and any revisions, amendments, or supplements to it:

Substance, Characteristic, or Pollutant	Class 4A Standard
Bicarbonates (HCO_3)	5 milliequivalents per liter
Boron (B)	0.5 mg/L
pH, minimum value	6.0

pH, maximum value	8.5
Specific conductance	1,000 micromhos per centimeter at 25°C
Total dissolved salts	700 mg/L
Sodium (Na)	60% of total cations as milliequivalents per liter
Radioactive materials	Not to exceed the lowest concentrations permitted to be discharged to an uncontrolled environment as prescribed by the appropriate authority having control over their use.

[For text of subps 3 and 4, see M.R.]

Subp. 5. **Class 4D waters; wild rice waters.**

A. The ~~standards~~ standard in ~~items~~ item B ~~and C apply~~ applies to wild rice waters identified in part 7050.0471 to protect the use of the grain of wild rice as a food source for wildlife and humans. The ~~numeric~~ sulfate standard for wild rice is designed to maintain sulfide concentrations in pore water at 120 micrograms per liter or less. The commissioner must maintain all numeric expressions of the sulfate ~~standards~~ standard for wild rice waters on a public Web site.

B. The annual average concentration of sulfate in the surface water of a wild rice water must not exceed the concentration established as the ~~calculated~~ numeric expression of the sulfate standard ~~under subitem (1) or alternate sulfate standard under subitem (2)~~ more than one year out of every ten years.

~~(1)~~ The ~~calculated~~ numeric expression of the sulfate standard, expressed as milligrams of sulfate ion per liter (mg SO_4^{2-}/L), is determined by the following equation:

~~Calculated~~ Numeric expression of the sulfate standard = ~~0.0000121~~ 0.0000854 x

$$\frac{\text{iron}^{\cancel{1.923}\ 1.637}}{\text{organic carbon}^{\cancel{1.197}\ 1.041}}$$

~~Where:~~ The numeric expression of the sulfate standard is the sulfate value resulting from applying the equation to the sampling data, as described in Sampling and Analytical Methods for Wild Rice Waters, except that:

(1) if the sulfate value resulting from applying the equation to the sampling data is less than 0.5 mg/L, then the numeric expression of the sulfate standard is 0.5 mg/L; and

(2) if the sulfate value resulting from applying the equation to the sampling data is greater than 335 mg/L, then the numeric expression of the sulfate standard is 335 mg/L.

~~(a) organic carbon is the amount of organic matter in dry sediment. The concentration is expressed as percentage of carbon, as determined using the method for organic carbon analysis in Sampling and Analytical Methods for Wild Rice Waters, which is incorporated by reference in item E;~~

~~(b) iron is the amount of extractable iron in dry sediment. The concentration is expressed as micrograms of iron per gram of dry sediment, as determined using the method for extractable iron in Sampling and Analytical Methods for Wild Rice Waters;~~

~~(c) sediment samples are collected using the procedures established in Sampling and Analytical Methods for Wild Rice Waters; and~~

~~(d) the calculated sulfate standard is the lowest sulfate value resulting from the application of the equation to each pair of organic carbon and iron values collected and analyzed in accordance with units (a) to (c).~~

~~(2) The commissioner may establish an alternate sulfate standard for a wild rice water when the ambient sulfate concentration is above the calculated sulfate standard and data demonstrates that sulfide concentrations in pore water are 120 micrograms per~~

~~liter or less. Data must be gathered using the procedures specified in Sampling and Analytical Methods for Wild Rice Waters, which is incorporated by reference in item E. The alternate sulfate standard established must be either the annual average sulfate concentration in the ambient water or a level of sulfate the commissioner has determined will maintain the sulfide concentrations in pore water at or below 120 micrograms per liter.~~

~~C. The commissioner may establish a site-specific sulfate standard using the process in part 7050.0220, subpart 7, or 7052.0270 when the commissioner determines that the beneficial use is not harmed. This decision must be based on reliable and representative data characterizing the health and viability of the wild rice in the wild rice water.~~

~~D~~ <u>C</u>. Discharges of sulfate in sewage, industrial waste, or other wastes affecting class 4D waters must be controlled so that the numeric <u>expression of the</u> sulfate standard for wild rice is maintained at stream flows that are equal to or greater than $365Q_{10}$.

~~E~~ <u>D</u>. Sampling and Analytical Methods for Wild Rice Waters, Minnesota Pollution Control Agency ~~(2017)~~ <u>(2018)</u>, is incorporated by reference. The document is not subject to frequent change and is available on the agency's Web site at www.pca.state.mn.us/regulations/minnesota-rulemaking and through the Minitex interlibrary loan system.

Subp. 6. **Class 4D [WR]; selected wild rice waters.** In recognition of the ecological importance of the wild rice resource and in conjunction with Minnesota Indian tribes, selected class 4D wild rice waters have been specifically identified [WR] and listed in part 7050.0470, subpart 1. The quality of these waters and the aquatic habitat necessary to support propagation and maintenance of wild rice plant species must not be materially impaired or degraded.

7050.0470 CLASSIFICATIONS FOR SURFACE WATERS IN MAJOR DRAINAGE BASINS.

Subpart 1. **Lake Superior basin.** The water use classifications for the listed waters in the Lake Superior basin are as identified in items A to D. See parts 7050.0425, 7050.0430, and 7050.0471 for the classifications of waters not listed.

[For text of items A to D, see M.R.]

Subp. 2. **Rainy River-Lake of the Woods basin.** The water use classifications for the listed waters in Rainy River-Lake of the Woods basin are as identified in items A to D. See parts 7050.0425, 7050.0430, and 7050.0471 for the classifications of waters not listed.

[For text of items A to D, see M.R.]

Subp. 3. **Red River of the North basin.** The water use classifications for the listed waters in the Red River of the North basin are as identified in items A to D. See parts 7050.0425, 7050.0430, and 7050.0471 for the classifications of waters not listed.

[For text of items A to D, see M.R.]

Subp. 4. **Upper Mississippi River basin (headwaters to the confluence with the St. Croix River).** The water use classifications for the listed waters in the upper Mississippi River basin from the headwaters to the confluence with the St. Croix River are as identified in items A to D. See parts 7050.0425, 7050.0430, and 7050.0471 for the classifications of waters not listed.

[For text of items A to D, see M.R.]

Subp. 5. **Minnesota River basin.** The water use classifications for the listed waters in the Minnesota River basin are as identified in items A to D. See parts 7050.0425, 7050.0430, and 7050.0471 for the classifications of waters not listed.

[For text of items A to D, see M.R.]

Subp. 6. **Saint Croix River basin.** The water use for the listed waters in the Saint Croix River basin are as identified in items A to D. See parts 7050.0425, 7050.0430, and 7050.0471 for the classifications of waters not listed.

[For text of items A to D, see M.R.]

Subp. 7. **Lower Mississippi River basin (from the confluence with the St. Croix River to the Iowa border).** The water use classifications for the listed waters in the lower Mississippi River basin from the confluence with the St. Croix River to the Iowa border are as identified in items A to D. See parts 7050.0425, 7050.0430, and 7050.0471 for the classifications of waters not listed.

[For text of items A to D, see M.R.]

Subp. 8. **Cedar-Des Moines Rivers basin.** The water use classifications for the listed waters in the Cedar-Des Moines Rivers basin are as identified in items A to D. See parts 7050.0425, 7050.0430, and 7050.0471 for the classifications of waters not listed.

[For text of items A to D, see M.R.]

Subp. 9. **Missouri River basin.** The water use classifications for the listed waters in the Missouri River basin are as identified in items A to D. See parts 7050.0425, 7050.0430, and 7050.0471 for the classifications of waters not listed.

[For text of items A to D, see M.R.]

7050.0471 CLASS 4D SURFACE WATERS IN MAJOR DRAINAGE BASINS.

Subpart 1. **Scope.** Class 4D waters are identified in subparts 3 to 9. Identified waters are described by a water identification number.

Subp. 2. **Triennial review and future listing of wild rice waters.** As part of each triennial review of water-quality standards conducted under Code of Federal Regulations, title 40, section 131.20, the commissioner must solicit evidence that supports identifying additional wild rice waters in rule. ~~The~~ Identifying additional wild rice waters in rule must be based on evidence ~~must demonstrate~~ that supports a demonstration that the wild rice beneficial use exists or has existed on or after November 28, 1975, in the water body, such as by showing a history of human harvest or use of the grain as food for wildlife or by showing that a cumulative total of at least two acres of wild rice are present. Acceptable types of evidence include:

A. written or oral histories that meet the criteria of validity, reliability, and consistency;

B. written records, such as harvest records;

C. photographs, aerial surveys, or field surveys; or

D. other quantitative or qualitative information that provides a reasonable basis to conclude that the wild rice beneficial use exists.

Subp. 3. **Lake Superior basin.** The Lake Superior basin includes all or portions of Aitkin, Carlton, Cook, Itasca, Lake, Pine, and St. Louis Counties. The waters in each of the major watersheds in the Lake Superior basin that are identified as class 4D are listed in items A to E. Waters designated with [WR] were identified as wild rice waters in 1998 under part 7050.0470, subpart 1.

A. 04010101 Lake Superior - North:

	Name	**County**	**WID**	**Water Type**
(1)	Baker Lake	Cook	16-0486-00	Lake
(2)	Bigsby Lake	Cook	16-0344-00	Lake
(3)	Bluebill Lake [WR]	Lake	38-0261-00	Lake
(4)	Bower Trout Lake	Cook	16-0175-00	Lake
(5)	Brule River	Cook	04010101-502	Stream
(6)	Cabin Lake [WR]	Lake	38-0260-00	Lake

(7)	Caribou Lake [WR]	Cook	16-0360-00	Lake
(8)	Christine Lake [WR]	Cook	16-0373-00	Lake
(9)	Cramer Homestead Lake	Lake	38-0246-00	Lake
(10)	Cramer Lake	Lake	38-0014-00	Lake
(11)	Crooked Lake	Lake	38-0024-00	Lake
(12)	Cross River Lake	Lake	38-0002-00	Lake
(13)	Crown Lake	Lake	38-0419-00	Lake
~~(14)~~	~~Cuffs Lake~~	~~Cook~~	~~16-0006-00~~	~~Lake~~
~~(15)~~				
(14)	Dick Lake	Cook	16-0157-00	Lake
~~(16)~~				
(15)	East Pipe Lake	Cook	16-0386-00	Lake
~~(17)~~				
(16)	Elbow Lake	Cook	16-0096-00	Lake
~~(18)~~				
(17)	Four Mile Lake [WR]	Cook	16-0639-00	Lake
~~(19)~~				
(18)	Grassy Lake	Cook	16-0390-00	Lake
~~(20)~~				
(19)	Gust Lake	Cook	16-0380-00	Lake
~~(21)~~				
(20)	Hoist Creek	Lake	04010101-D81	Stream
~~(22)~~				
(21)	Hoist Lake	Lake	38-0251-00	Lake
~~(23)~~				
(22)	Jack Lake	Cook	16-0521-00	Lake
~~(24)~~				
(23)	John Lake	Cook	16-0035-00	Lake
~~(25)~~				
(24)	Kelly Lake	Cook	16-0476-00	Lake

~~(26)~~ (25)	Kelso Lake	Cook	16-0706-00	Lake
~~(27)~~ (26)	Kowalski Lake	Lake	38-0016-00	Lake
~~(28)~~ (27)	Little John Lake	Cook	16-0026-00	Lake
~~(29)~~ (28)	Mark Lake	Cook	16-0250-00	Lake
~~(30)~~ (29)	Marsh Lake	Cook	16-0048-00	Lake
~~(31)~~ (30)	Marsh Lake [WR]	Cook	16-0488-00	Lake
~~(32)~~ (31)	Merganser Lake	Cook	16-0107-00	Lake
~~(33)~~ (32)	Moore Lake [WR]	Cook	16-0489-00	Lake
~~(34)~~ (33)	Moose Lake	Lake	38-0036-00	Lake
~~(35)~~	~~Mt. Maud Wetland~~	~~Cook~~	~~16-0914-00~~	~~Wetland~~
~~(36)~~ (34)	North Fowl Lake	Cook	16-0036-00	Lake
~~(37)~~ (35)	North Wigwam Lake	Cook	16-0804-00	Lake
~~(38)~~ (36)	Northern Light Lake [WR]	Cook	16-0089-00	Lake
~~(39)~~ (37)	Otter Lake	Cook	16-0032-00	Lake
~~(40)~~ (38)	Peterson Lake	Cook	16-0478-00	Lake
~~(41)~~ (39)	Pigeon River	Cook	04010101-501	Stream

~~(42)~~ (40)	Prout Lake	Cook	16-0013-00	Lake
~~(43)~~ (41)	Rice Lake [WR]	Cook	16-0453-00	Lake
~~(44)~~ (42)	Richey Lake	Cook	16-0643-00	Lake
~~(45)~~ (43)	Round Island Lake [WR]	Lake	38-0417-00	Lake
~~(46)~~ (44)	Royal Lake	Cook	16-0025-00	Lake
~~(47)~~ (45)	Royal River	Cook	04010101-D75	Stream
~~(48)~~ (46)	Sonju Lake	Lake	38-0248-00	Lake
~~(49)~~ (47)	South Fowl Lake	Cook	16-0034-00	Lake
~~(50)~~ (48)	South Wigwam Lake	Lake	38-0001-00	Lake
~~(51)~~ (49)	Swamp Lake	Cook	16-0009-00	Lake
~~(52)~~ (50)	Swamp Lake	Cook	16-0256-00	Lake
~~(53)~~ (51)	Swamp River Reservoir [WR]	Cook	16-0901-00	Lake
~~(54)~~	~~Teal Lake~~	~~Cook~~	~~16-0003-00~~	~~Lake~~
~~(55)~~ (52)	Temperance River	Cook	04010101-610	Stream
~~(56)~~ (53)	Toohey Lake	Cook	16-0645-00	Lake
~~(57)~~ (54)	Turtle Lake	Cook	16-0251-00	Lake

~~(58)~~ (55)	Twentythree Lake	Lake	38-0247-00	Lake
~~(59)~~ (56)	Two Island Lake	Cook	16-0156-00	Lake
~~(60)~~	~~Unnamed stream (Grand Portage)~~	~~Cook~~	~~04010101-757~~	~~Stream~~
~~(61)~~ (57)	Vern River	Cook	04010101-899	Stream
~~(62)~~ (58)	White Pine Lake [WR]	Cook	16-0369-00	Lake
~~(63)~~ (59)	Wonder Lake	Cook	16-0664-00	Lake

B. 04010102 Lake Superior - South:

	Name	**County**	**WID**	**Water Type**
(1)	Christianson Lake	Lake	38-0750-00	Lake
(2)	Eagle Lake	St. Louis	69-0238-00	Lake

C. 04010201 St. Louis River:

	Name	**County**	**WID**	**Water Type**
(1)	Anchor Lake	St. Louis	69-0641-00	Lake
(2)	Andy Lake	St. Louis	69-0618-00	Lake
(3)	Artichoke Lake [WR]	St. Louis	69-0623-00	Lake
~~(4)~~	~~Bang Lake~~	~~Carlton~~	~~09-0046-00~~	~~Lake~~
~~(5)~~ (4)	Bug Creek	St. Louis	04010201-545	Stream
~~(6)~~ (5)	Bug (Whitchel) Lake	St. Louis	69-0531-00	Lake
~~(7)~~ (6)	Butterball (Long) Lake [WR]	St. Louis	69-0044-00	Lake
~~(8)~~ (7)	Cedar Island Lake	St. Louis	69-0568-00	Lake
~~(9)~~	~~Cedar Lake~~	~~Carlton~~	~~09-0031-00~~	~~Lake~~
~~(10)~~ (8)	Comet Lake	St. Louis	69-0267-00	Lake

~~(11)~~ (9)	Cranberry Lake	St. Louis	69-0147-00	Lake
~~(12)~~	~~Dead Fish Lake~~	~~Carlton~~	~~09-0051-00~~	~~Lake~~
~~(13)~~ (10)	Dollar Lake	St. Louis	69-0534-00	Lake
~~(14)~~ (11)	East Stone Lake	St. Louis	69-0638-00	Lake
~~(15)~~ (12)	Elliott Lake	St. Louis	69-0642-00	Lake
~~(16)~~ (13)	Embarrass Lake	St. Louis	69-0496-00	Lake
~~(17)~~ (14)	Embarrass River	St. Louis	~~04010201-577~~ 04010201-A99	Stream
~~(18)~~ (15)	Embarrass River	St. Louis	04010201-579	Stream
~~(19)~~ (16)	Esquagama Lake	St. Louis	69-0565-00	Lake
~~(20)~~ (17)	Fourth Lake	St. Louis	69-0573-00	Lake
~~(21)~~ (18)	Gill Lake	St. Louis	69-0667-00	Lake
~~(22)~~ (19)	Grass Lake	St. Louis	69-0776-00	Lake
~~(23)~~	~~Hardwood Lake~~	~~Carlton~~	~~09-0030-00~~	~~Lake~~
~~(24)~~ (20)	Hay Lake	St. Louis	69-0150-00	Lake
~~(25)~~ (21)	Hay Lake	St. Louis	69-0417-00	Lake
~~(26)~~ (22)	Hay Lake	St. Louis	69-0439-00	Lake
~~(27)~~ (23)	Hay Lake	St. Louis	69-0441-00	Lake

~~(28)~~ (24)	Hay Lake [WR]	St. Louis	69-0435-00	Lake
~~(29)~~ (25)	Hush Lake	St. Louis	69-0988-00	Lake
~~(30)~~	~~Jaskari Lake~~	~~Carlton~~	~~09-0050-00~~	~~Lake~~
~~(31)~~ (26)	Kingburg Lake	St. Louis	69-0771-00	Lake
~~(32)~~ (27)	Leeman Lake	St. Louis	69-0875-00	Lake
~~(33)~~ (28)	Little Birch Lake	St. Louis	69-0271-00	Lake
~~(34)~~ (29)	Lobo Lake	Lake	38-0766-00	Lake
~~(35)~~	~~Martin Lake~~	~~St. Louis~~	~~69-0768-00~~	~~Lake~~
~~(36)~~	~~Miller Lake~~	~~Carlton~~	~~09-0053-00~~	~~Lake~~
~~(37)~~ (30)	Mogie Lake	St. Louis	69-0391-00	Lake
~~(38)~~ (31)	Moose Lake	St. Louis	69-0442-00	Lake
~~(39)~~ (32)	Mud (Black Mallard) Lake	St. Louis	69-0047-00	Lake
~~(40)~~ (33)	Mud Hen Lake	St. Louis	69-0494-00	Lake
~~(41)~~ (34)	Mud Lake	St. Louis	69-0151-00	Lake
~~(42)~~	~~Mud Lake~~	~~St. Louis~~	~~69-0652-00~~	~~Lake~~
~~(43)~~ (35)	Nichols Lake	St. Louis	69-0627-00	Lake
~~(44)~~ (36)	Partridge River	St. Louis	04010201-552	Stream
~~(45)~~ (37)	Perch Lake	St. Louis	69-0688-00	Lake

~~(46)~~	~~Perch Lake~~	~~Carlton~~	~~09-0036-00~~	~~Lake~~
~~(47)~~ (38)	Pine Lake	St. Louis	69-0001-00	Lake
~~(48)~~	~~Rice Portage Lake~~	~~Carlton~~	~~09-0037-00~~	~~Lake~~
~~(49)~~	~~Round Lake~~	~~St. Louis~~	~~69-0649-00~~	~~Lake~~
~~(50)~~ (39)	Round Lake [WR]	St. Louis	69-0048-00	Lake
~~(51)~~ (40)	Second Creek	St. Louis	04010201-952	Stream
~~(52)~~ (41)	Seven Beaver Lake [WR]	St. Louis	69-0002-00	Lake
~~(53)~~ (42)	Shiver Creek impoundment	St. Louis	04010201-A37	Stream
~~(54)~~	~~Side Lake~~	~~St. Louis~~	~~69-0699-00~~	~~Lake~~
~~(55)~~	~~Simian Lake~~	~~St. Louis~~	~~69-0619-00~~	~~Lake~~
~~(56)~~ (43)	St. Louis River/Estuary	St. Louis	04010201-532	Stream
~~(57)~~ (44)	St. Louis Estuary (2)	St. Louis	04010201-533	Stream
~~(58)~~ (45)	St. Louis River	St. Louis	04010201-644	Stream
~~(59)~~ (46)	St. Louis River [WR]	St. Louis	04010201-631	Stream
~~(60)~~ (47)	Stone Lake [WR]	St. Louis	69-0686-00	Lake
~~(61)~~ (48)	Stone Lake [WR]	St. Louis	69-0046-00	Lake
~~(62)~~ (49)	Sullivan Lake	St. Louis	69-0246-00	Lake
~~(63)~~ (50)	Turpela Lake	St. Louis	69-0427-00	Lake

~~(64)~~ (51)	Twin Lake	St. Louis	69-0504-00	Lake
~~(65)~~	~~Twin Lake~~	~~St. Louis~~	~~69-0695-00~~	~~Lake~~
~~(66)~~	~~Unnamed lake (FDL1)~~	~~Carlton~~	~~09-0178-00~~	~~Lake~~
~~(67)~~	~~Unnamed lake (FDL2)~~	~~St. Louis~~	~~69-1454-00~~	~~Lake~~
~~(68)~~ (52)	Unnamed lake	St. Louis	69-0634-00	Lake
~~(69)~~ (53)	Upper Bug Lake	St. Louis	69-0406-00	Lake
~~(70)~~ (54)	Vang Lake	St. Louis	69-0876-00	Lake
~~(71)~~ (55)	Wabuse Lake	St. Louis	69-0408-00	Lake
~~(72)~~ (56)	Washusk #1 Lake	St. Louis	69-0409-00	Lake
~~(73)~~ (57)	Washusk #2 Lake	St. Louis	69-0410-00	Lake
~~(74)~~ (58)	White Lake	St. Louis	69-0571-00	Lake
~~(75)~~ (59)	Wynne Lake	St. Louis	69-0434-02	Lake

D. 04010202 Cloquet River:

	Name	**County**	**WID**	**Water Type**
(1)	Alden Lake	St. Louis	69-0131-00	Lake
(2)	Angell Pool	St. Louis	69-1466-00	Lake
(3)	Bassett Lake	St. Louis	69-0041-00	Lake
(4)	Bear (Mudd) Lake	St. Louis	69-0112-00	Lake
(5)	Beaver (Joker) Lake	St. Louis	69-0015-00	Lake
(6)	Breda Lake [WR]	St. Louis	69-0037-00	Lake

(7)	Caribou Lake	St. Louis	69-0489-00	Lake
(8)	Clark Lake	Lake	38-0647-00	Lake
(9)	Cloquet Lake	Lake	38-0539-00	Lake
(10)	Cloquet River	Lake	04010202-507	Stream
(11)	Driller Lake	Lake	38-0652-00	Lake
(12)	Fish Lake (East)	St. Louis	69-0491-00	Lake
(13)	Grand Lake	St. Louis	69-0511-00	Lake
(14)	Hjalmer Lake	Lake	38-0758-00	Lake
(15)	Indian Lake	St. Louis	69-0023-00	Lake
(16)	Island Lake Reservoir	St. Louis	69-0372-00	Lake
(17)	King Lake	St. Louis	69-0008-00	Lake
(18)	Kookoosh Lake	St. Louis	69-0009-00	Lake
(19)	Kylen Lake	St. Louis	69-0034-00	Lake
(20)	Lake George	St. Louis	69-0040-00	Lake
(21)	Langley Lake	Lake	38-0648-00	Lake
(22)	Legler Lake	Lake	38-0649-00	Lake
(23)	Lieuna (Lieung) Lake [WR]	St. Louis	69-0123-00	Lake
(24)	Little Cloquet River	St. Louis	04010202-590	Stream
(25)	Little Stone Lake	St. Louis	69-0028-00	Lake
(26)	Papoose Lake [WR]	St. Louis	69-0024-00	Lake
(27)	Petrel Creek	St. Louis	04010202-664	Stream
(28)	Ruth Lake	St. Louis	69-0014-00	Lake
(29)	Sink Lake	Lake	38-0540-00	Lake
(30)	Smith (Little Pequaywan) Lake	St. Louis	69-0111-00	Lake
(31)	Stone (Tommila) Lake [WR]	St. Louis	69-0035-00	Lake
(32)	Trettel Pool	St. Louis	69-1482-00	Lake
(33)	Upland Lake	Lake	38-0756-00	Lake

(34)	Warren Lake	St. Louis	69-0017-00	Lake
(35)	Wild Rice Reservoir	St. Louis	69-0371-00	Lake
(36)	Wolf Lake	St. Louis	69-0143-00	Lake

E. 04010301 Nemadji River:

	Name	**County**	**WID**	**Water Type**
(1)	Hay Lake	Carlton	09-0010-00	Lake
(2)	Net Lake	Pine	58-0038-00	Lake

Subp. 4. **Rainy River-Lake of the Woods basin.** The Rainy River-Lake of the Woods basin includes all or portions of Beltrami, Cook, Itasca, Koochiching, Lake of the Woods, St. Louis, and Roseau Counties. The waters in each of the major watersheds in the Rainy River-Lake of the Woods basin that are identified as class 4D are listed in items A to G.

A. 09030001 Rainy River - Headwaters:

	Name	**County**	**WID**	**Water Type**
(1)	August Lake	Lake	38-0691-00	Lake
(2)	Bald Eagle Lake	Lake	38-0637-00	Lake
(3)	Basswood Lake	Lake	38-0645-00	Lake
(4)	Bear Island River	St. Louis	09030001-608	Stream
(5)	Beartrap Lake	St. Louis	69-0089-00	Lake
(6)	Big Lake	St. Louis	69-0190-00	Lake
(7)	Big Rice Lake	St. Louis	69-0178-00	Lake
(8)	Birch Lake	St. Louis	69-0003-00	Lake
(9)	Blueberry Lake	St. Louis	69-0054-00	Lake
(10)	Bonga Lake	Lake	38-0762-00	Lake
(11)	Bootleg Lake	St. Louis	69-0452-00	Lake
(12)	Burntside Lake	St. Louis	69-0118-00	Lake
(13)	Burntside River	St. Louis	09030001-808	Stream

(14)	Camp East Creek	Lake	09030001-623	Stream
(15)	Campers Lake	Lake	38-0679-00	Lake
(16)	Canary Lake	St. Louis	69-0055-00	Lake
(17)	Charity Lake	Lake	38-0055-00	Lake
(18)	Comfort Lake	Lake	38-0290-00	Lake
(19)	Cougar Lake	Lake	38-0767-00	Lake
(20)	Crooked Lake	Lake	38-0817-00	Lake
(21)	Deadman's Lake	St. Louis	69IMP001	Lake
(22)	Dragon Lake	Lake	38-0552-00	Lake
(23)	Duck Lake	St. Louis	69-0191-00	Lake
(24)	Dumbbell Lake	Lake	38-0393-00	Lake
(25)	Dumbbell River	Lake	09030001-632	Stream
(26)	Dumbbell River Pool	Lake	38-0270-00	Lake
(27)	Dunnigan Lake	Lake	38-0664-00	Lake
(28)	Ed Shave Lake	St. Louis	69-0199-00	Lake
(29)	Eighteen Lake	Lake	38-0432-00	Lake
(30)	Ella Hall Lake	Lake	38-0727-00	Lake
(31)	Fall Lake	Lake	38-0811-00	Lake
(32)	Farm Lake	Lake	38-0779-00	Lake
(33)	Fente Lake	Cook	16-0741-00	Lake
(34)	Flat Horn Lake	Lake	38-0568-00	Lake
(35)	Fools Lake	Lake	38-0761-00	Lake
(36)	Gabbro Lake	Lake	38-0701-00	Lake
(37)	Garden Lake	Lake	38-0782-00	Lake
(38)	Gegoka Lake	Lake	38-0573-00	Lake
(39)	Grass Lake	Lake	38-0635-00	Lake
(40)	Grassy Lake	St. Louis	69-0082-00	Lake

(41)	Grassy Lake	St. Louis	69-0216-00	Lake
(42)	Green Wing Lake	Lake	38-0264-00	Lake
(43)	Greenwood Lake	Lake	38-0656-00	Lake
(44)	Grouse Lake	Lake	38-0557-00	Lake
(45)	Gull Lake	St. Louis	69-0092-00	Lake
(46)	Harriet Lake	Lake	38-0048-00	Lake
(47)	Harris Lake	Lake	38-0736-00	Lake
(48)	Horse River	Lake	09030001-719	Stream
(49)	Horseshoe Lake	St. Louis	69-0255-00	Lake
(50)	Hula Lake	Lake	38-0728-00	Lake
(51)	Iron Lake	Cook	16-0328-00	Lake
(52)	Isabella Lake	Lake	38-0396-00	Lake
(53)	Isabella River	Lake	09030001-527	Stream
(54)	Island River	Lake	09030001-563	Stream
(55)	Island River Lake	Lake	38-0289-00	Lake
(56)	Island River Lake	Lake	38-0842-00	Lake
(57)	Jeanette Lake	St. Louis	69-0456-00	Lake
(58)	Johnson Lake	St. Louis	69-0117-00	Lake
(59)	Kawishiwi Lake	Lake	38-0080-00	Lake
(60)	Kawishiwi River	Lake	09030001-512	Stream
(61)	Kitigan Lake	Lake	38-0559-00	Lake
(62)	Lapond Lake	St. Louis	69-0177-00	Lake
(63)	Little Gabbro Lake	Lake	38-0703-00	Lake
(64)	Little Indian Sioux River	St. Louis	09030001-636	Stream
(65)	Little Indian Sioux River	St. Louis	09030001-637	Stream
(66)	Little Indian Sioux River	St. Louis	09030001-641	Stream
(67)	Little Indian Sioux River	St. Louis	09030001-642	Stream

(68)	Little Indian Sioux River	St. Louis	09030001-643	Stream
(69)	Little Indian Sioux River	St. Louis	09030001-557	Stream
(70)	Little Rice Lake	St. Louis	69-0180-00	Lake
(71)	Little Vermilion Lake	St. Louis	69-0608-00	Lake
(72)	Little Wampus Lake	Lake	38-0684-00	Lake
(73)	Low Lake	St. Louis	69-0070-00	Lake
(74)	Lower Pauness Lake	St. Louis	69-0464-00	Lake
(75)	Manomin Lake	Lake	38-0616-00	Lake
(76)	Middle McDougal Lake	Lake	38-0658-00	Lake
(77)	Moose Lake	Lake	38-0644-00	Lake
(78)	Moose River	St. Louis	09030001-540	Stream
(79)	Mud Lake	Lake	38-0742-00	Lake
(80)	Muskeg Lake	Lake	38-0788-00	Lake
(81)	Nels Lake	St. Louis	69-0080-00	Lake
(82)	Newton Lake	Lake	38-0784-00	Lake
(83)	Nina Moose River	St. Louis	09030001-650	Stream
(84)	Nine A.M. Lake	Lake	38-0445-00	Lake
(85)	North McDougal Lake	Lake	38-0686-00	Lake
(86)	One Pine Lake	St. Louis	69-0061-00	Lake
(87)	Osier Lake	Lake	38-0420-00	Lake
(88)	Papoose Lake	Lake	38-0818-00	Lake
(89)	Pea Soup Lake	Lake	38-0739-00	Lake
(90)	Perent Lake	Lake	38-0220-00	Lake
(91)	Phantom Lake	Lake	38-0653-00	Lake
(92)	Phoebe Lake	Cook	16-0808-00	Lake
(93)	Picket Lake	St. Louis	69-0079-00	Lake
(94)	Polly Lake	Lake	38-0104-00	Lake

(95)	Railroad Lake	Lake	38-0655-00	Lake
(96)	Rat Lake	Lake	38-0567-00	Lake
(97)	Rib Lake	Cook	16-0544-00	Lake
(98)	Rice Lake	St. Louis	69-0180-00	Lake
(99)	Rice Lake	Lake	38-0465-00	Lake
(100)	Riparian, stream wetland	Lake	09030001-985	Wetland
(101)	Roe Lake	Lake	38-0139-00	Lake
(102)	Sand Lake	Lake	38-0735-00	Lake
(103)	Scarp (Cliff) Lake	Lake	38-0058-00	Lake
(104)	Scott Lake	Lake	38-0271-00	Lake
(105)	Silver Island Lake	Lake	38-0219-00	Lake
(106)	Slate (Spider) Lake	Lake	38-0666-00	Lake
(107)	Snowbank Lake	Lake	38-0529-00	Lake
(108)	Source Lake	Lake	38-0654-00	Lake
(109)	Sourdough Lake	Lake	38-0708-00	Lake
(110)	South Farm Lake	Lake	38-0778-00	Lake
(111)	South Kawishiwi River	Lake	09030001-536	Stream
(112)	South McDougal Lake	Lake	38-0659-00	Lake
(113)	Stony Lake	Lake	38-0660-00	Lake
(114)	Stony (Sand) River	Lake	09030001-985	Stream
(115)	Surprise Lake	Lake	38-0550-00	Lake
(116)	Swallow (Shallow, Deep) Lake	Lake	38-0668-00	Lake
(117)	Sylvania Lake	Lake	38-0395-00	Lake
(118)	Twin (East Twin) Lake	St. Louis	69-0163-00	Lake
(119)	Twin (East Twin) Lake	St. Louis	69-0174-00	Lake
(120)	Unnamed (Scott Creek tributary) creek	Lake	09030001-598	Stream

(121)	Unnamed lake	Cook	16-0416-00	Lake
(122)	Upper Pauness Lake	St. Louis	69-0465-00	Lake
(123)	Vera Lake	Lake	38-0491-00	Lake
(124)	Wampus Lake	Lake	38-0685-00	Lake
(125)	White Iron Lake	St. Louis	69-0004-00	Lake
(126)	Wind Lake	Lake	38-0642-00	Lake
(127)	Wood Lake	Lake	38-0729-00	Lake
(128)	Wye Lake	Lake	38-0042-00	Lake

B. 09030002 Vermilion River:

	Name	**County**	**WID**	**Water Type**
(1)	Black Lake	St. Louis	69-0740-00	Lake
(2)	Camp 97 impoundment	St. Louis	69-0594-00	Lake
(3)	Camp Forty Creek	St. Louis	09030002-586	Stream
(4)	Crane Lake	St. Louis	69-0616-00	Lake
(5)	Eagles Nest 3 Lake	St. Louis	69-0285-03	Lake
(6)	Echo Lake	St. Louis	69-0615-00	Lake
(7)	Echo River	St. Louis	09030002-532	Stream
(8)	Elbow River	St. Louis	09030002-602	Stream
(9)	Five Mile Lake	St. Louis	69-0288-00	Lake
(10)	Four Mile Lake	St. Louis	69-0281-00	Lake
(11)	Gafvert Lake	St. Louis	69-0280-00	Lake
(12)	Hay Lake	St. Louis	69-0579-00	Lake
(13)	Hoodoo Lake	St. Louis	69-0802-00	Lake
(14)	Kabustasa (Rice) Lake	St. Louis	69-0679-00	Lake
(15)	Little Sandy Lake	St. Louis	69-0729-00	Lake
(16)	Myrtle Lake	St. Louis	69-0749-00	Lake

(17)	Oriniack Lake	St. Louis	69-0587-00	Lake
(18)	Pelican Lake	St. Louis	69-0841-00	Lake
(19)	Pelican River	St. Louis	09030002-530	Stream
(20)	Pike River	St. Louis	09030002-503	Stream
(21)	Rice Lake	St. Louis	69-0803-00	Lake
(22)	Rice Lake	St. Louis	69-0578-00	Lake
(23)	Sand River	St. Louis	09030002-501	Stream
(24)	Sandy Lake	St. Louis	69-0730-00	Lake
(25)	Six Mile Lake	St. Louis	69-0283-00	Lake
(26)	Sunset Lake	St. Louis	69-0764-00	Lake
(27)	Susan Lake	St. Louis	69-0741-00	Lake
(28)	Vermilion River	St. Louis	09030002-531	Stream
(29)	Vermilion River Lake	St. Louis	69-0613-00	Lake
(30)	Vermilion (Rice Bay) Lake	St. Louis	69-0378-00	Lake

C. 09030003 Rainy River - Rainy Lake:

	Name	**County**	**WID**	**Water Type**
(1)	Rainy Lake	Koochiching	69-0694-00	Lake
(2)	Rat Root Lake	Koochiching	36-0006-00	Lake
(3)	Tilson Creek	Koochiching	09030003-629	Stream

D. 09030005 Little Fork River:

	Name	**County**	**WID**	**Water Type**
(1)	Auto Lake	St. Louis	69-0731-00	Lake
(2)	Balkan Lake	St. Louis	69-0860-00	Lake
(3)	Big Rice Lake	St. Louis	69-0669-00	Lake
(4)	Herrigan Lake	Itasca	31-0174-00	Lake
(5)	Kelly Lake	Itasca	31-0291-00	Lake

(6)	Knuckey (Mud) Lake	St. Louis	69-0800-00	Lake
(7)	Little Rice Lake	St. Louis	69-0612-00	Lake
(8)	Moose Lake	St. Louis	69-0798-00	Lake
(9)	Mud (Watercress) Lake	St. Louis	69-0797-00	Lake
(10)	Nett Lake	Koochiching	36-0001-00	Lake
(11)	Otter Lake	Itasca	31-0301-00	Lake
(12)	Rat (Jamer) Lake	St. Louis	69-0737-00	Lake
(13)	Sand Lake	St. Louis	69-0736-00	Lake
(14)	Shannon Lake	St. Louis	69-0925-00	Lake
(15)	Shannon River	St. Louis	09030005-605	Stream
(16)	Sturgeon Lake	St. Louis	69-0939-01	Lake
(17)	Sturgeon Lake, Middle	St. Louis	69-0939-02	Lake
(18)	Sturgeon River	St. Louis	09030005-527	Stream
(19)	Unnamed lake	Itasca	31-0066-00	Lake
(20)	Unnamed lake	Itasca	31-0322-00	Lake
(21)	Unnamed lake	Itasca	31-0288-00	Lake
(22)	Unnamed lake	Itasca	31-0961-00	Lake
(23)	Wagon Wheel Lake	St. Louis	69-0735-00	Lake
(24)	Walters Lake	Itasca	31-0298-00	Lake

E. 09030006 Big Fork River:

	Name	**County**	**WID**	**Water Type**
(1)	Aspen Lake	Itasca	31-0690-00	Lake
(2)	Big Fork River	Itasca	09030006-505	Stream
(3)	Blue Rock Lake	Itasca	31-0919-00	Lake
(4)	Bowstring River	Itasca	09030006-555	Stream
(5)	Cameron Lake	Itasca	31-0544-00	Lake

(6)	Canoe Lake (unnamed)	Itasca	31-0519-00	Lake
(7)	Coddington Lake	Itasca	31-0883-00	Lake
(8)	Deer Lake	Itasca	31-0334-00	Lake
(9)	Dishpan Lake	Itasca	31-0992-00	Lake
(10)	Dora Lake	Itasca	31-0882-00	Lake
(11)	Fiske Lake	Itasca	31-0918-00	Lake
(12)	Grass Lake	Itasca	31-0727-00	Lake
(13)	Hamrey Lake	Itasca	31-0911-00	Lake
(14)	Helen Lake	Itasca	31-0840-00	Lake
(15)	Hinken Creek	Itasca	09030006-538	Stream
(16)	Little Island Lake	Itasca	31-0179-00	Lake
(17)	Little Spring Lake	Itasca	31-0797-00	Lake
(18)	Marie Lake	Itasca	31-0507-00	Lake
(19)	Natures Lake	Itasca	31-0877-00	Lake
(20)	Popple River	Itasca	09030006-512	Stream
(21)	Rice Lake	Itasca	31-0876-00	Lake
(22)	Rice Lake	Itasca	31-0315-00	Lake
(23)	Rice Lake	Itasca	31-0707-00	Lake
(24)	Rice River	Itasca	09030006-539	Stream
(25)	Ruby Lake	Itasca	31-0422-00	Lake
(26)	Shallow Pond	Itasca	31-0910-00	Lake
(27)	Teufer (Labrie) Lake	Koochiching	36-0019-00	Lake
(28)	Whitefish Lake	Itasca	31-0843-00	Lake

F. 09030008 Rainy River - Lower:

	Name	**County**	**WID**	**Water Type**
(1)	Baudette River	Lake of the Woods	09030008-535	Stream

(2)	Rainy River	Lake of the Woods	09030008-505	Stream
(3)	Silver Creek	Lake of the Woods	09030008-513	Stream
(4)	Winter Road River	Lake of the Woods	09030008-502	Stream

G. 09030009 Lake of the Woods:

	Name	County	WID	Water Type
(1)	Bednar impoundment	Roseau	68-0150-00	Lake
(2)	Lake of the Woods	Lake of the Woods	39-0002-00	Lake

Subp. 5. **Red River of the North basin.** The Red River of the North basin includes all or portions of Becker, Beltrami, Big Stone, Clay, Clearwater, Grant, Itasca, Kittson, Koochiching, Lake of the Woods, Mahnomen, Marshall, Norman, Otter Tail, Pennington, Polk, Red Lake, Roseau, Stevens, Traverse, and Wilkin Counties. The waters in each of the major watersheds in the Red River of the North basin identified as class 4D are listed in items A to F.

A. 09020103 Otter Tail River:

	Name	County	WID	Water Type
(1)	Acorn Lake	Becker	03-0258-00	Lake
(2)	Albertson Lake	Becker	03-0266-00	Lake
(3)	Berger Lake	Otter Tail	56-1149-00	Lake
(4)	Big Elbow Lake	Becker	03-0159-00	Lake
(5)	Big Floyd Lake	Becker	03-0387-00	Lake
(6)	Big Pine Lake	Otter Tail	56-0130-00	Lake
(7)	Blackbird Lake	Becker	03-0197-00	Lake
(8)	Boedigheimer Lake	Otter Tail	56-0212-00	Lake

(9)	Bolton Lake	Otter Tail	56-0318-00	Lake
(10)	Booth Lake	Becker	03-0198-00	Lake
(11)	Bray Lake	Otter Tail	56-0472-00	Lake
(12)	Bush Lake	Becker	03-0212-00	Lake
(13)	Camp Seven Lake	Becker	03-0151-00	Lake
(14)	Carman Lake	Becker	03-0209-00	Lake
(15)	Chippewa Lake	Becker	03-0196-00	Lake
(16)	Crane Lake	Otter Tail	56-0293-00	Lake
(17)	Crystal Lake	Otter Tail	56-0749-00	Lake
(18)	Dead Lake	Becker	03-0160-00	Lake
(19)	Dead Lake	Otter Tail	56-0383-00	Lake
(20)	Deer Lake	Otter Tail	56-0298-00	Lake
(21)	Depressional wetland	Otter Tail	56-1554-00	Wetland
(22)	Duck Lake	Otter Tail	56-0925-00	Lake
(23)	East Battle Lake	Otter Tail	56-0138-00	Lake
(24)	East Loon Lake	Otter Tail	56-0523-00	Lake
(25)	East Lost Lake	Otter Tail	56-0378-00	Lake
(26)	East Red River Lake	Otter Tail	56-0573-00	Lake
(27)	East Wing Pond	Otter Tail	56-1787-00	Wetland
(28)	Emma Lake	Otter Tail	56-0194-00	Lake
(29)	Equay Lake	Becker	03-0219-00	Lake
(30)	Fish Lake	Otter Tail	56-0768-00	Lake
(31)	Flat Lake	Becker	03-0242-00	Lake
(32)	Fogard Lake	Otter Tail	56-0571-00	Lake
(33)	Hanson Lake	Becker	03-0177-00	Lake
(34)	Head Lake	Otter Tail	56-0213-00	Lake
(35)	Height of Land Lake	Becker	03-0195-00	Lake

(36)	Heilberger Lake	Otter Tail	56-0695-00	Lake
(37)	Hoffman Lake	Otter Tail	56-1627-00	Lake
(38)	Hoot Lake	Otter Tail	56-0782-00	Lake
(39)	Hubbel Pond Lake	Becker	03-0240-00	Lake
(40)	Ida Lake	Becker	03-0582-00	Lake
(41)	Jim Lake	Otter Tail	56-0364-00	Lake
(42)	Johnson Lake	Becker	03-0199-00	Lake
(43)	Johnson Lake	Becker	03-0374-01	Lake
(44)	Lake Sixteen	Otter Tail	56-0100-00	Lake
(45)	Lida North Lake	Otter Tail	56-0747-01	Lake
(46)	Little Flat Lake	Becker	03-0217-00	Lake
(47)	Little Floyd Lake	Becker	03-0386-00	Lake
(48)	Little Rice Lake	Becker	03-0239-00	Lake
(49)	Little Toad Lake	Becker	03-0189-00	Lake
(50)	Lizzie Lake	Otter Tail	56-0760-01	Lake
(51)	Long Lake	Otter Tail	56-0210-00	Lake
(52)	Long Lake	Otter Tail	56-0784-00	Lake
(53)	Long Lake	Becker	03-0383-00	Lake
(54)	Long Lake	Otter Tail	56-0388-00	Lake
(55)	Lower Egg Lake	Becker	03-0210-00	Lake
(56)	Many Point Lake	Becker	03-0158-00	Lake
(57)	Maria Lake	Otter Tail	56-0498-00	Lake
(58)	Marion Lake	Otter Tail	56-0243-00	Lake
(59)	Mud Lake	Otter Tail	56-0222-00	Lake
(60)	Otter Tail Lake	Otter Tail	56-0242-00	Lake
(61)	Otter Tail River	Otter Tail	09020103-541	Stream
(62)	Otter Tail River	Otter Tail	09020103-570	Stream

(63)	Pelican Lake	Otter Tail	56-0786-00	Lake
(64)	Red River Lake	Otter Tail	56-0711-00	Lake
(65)	Reeves Lake	Becker	03-0374-02	Lake
(66)	Rice Lake	Becker	03-0201-00	Lake
(67)	Rice Lake	Otter Tail	56-0211-00	Lake
(68)	Rice Lake	Otter Tail	56-0363-00	Lake
(69)	Rose Lake	Otter Tail	56-0360-00	Lake
(70)	Round Lake	Becker	03-0155-00	Lake
(71)	Rush Lake	Otter Tail	56-0141-00	Lake
(72)	Saint Patrick Lake	Becker	03-0277-00	Lake
(73)	Scalp Lake	Otter Tail	56-0358-00	Lake
(74)	Schultz Lake	Becker	03-0278-00	Lake
(75)	Sieverson (Sivertson) Lake	Becker	03-0108-00	Lake
(76)	Spindler Lake	Becker	03-0214-00	Lake
(77)	Star Lake	Otter Tail	56-0385-00	Lake
(78)	Stuart Lake	Otter Tail	56-0191-00	Lake
(79)	Tamarac NWR - Egg River (Ogemash Pool)	Becker	09020103-748	Stream
(80)	Tamarack Lake	Becker	03-0388-00	Lake
(81)	Tea Cracker Lake	Becker	03-0157-00	Lake
(82)	Toad Lake	Becker	03-0107-00	Lake
(83)	Town Lake	Becker	03-0264-00	Lake
(84)	Trieglaff Lake	Becker	03-0263-00	Lake
(85)	Unnamed lake	Otter Tail	56-0927-00	Lake
(86)	Unnamed lake (Big Slough Lake)	Becker	03-0185-00	Lake
(87)	Unnamed lake (Davis Lake)	Becker	03-0268-00	Lake
(88)	Unnamed lake	Becker	03-1093-00	Lake

(89)	Unnamed lake	Becker	03-0776-00	Lake
(90)	Unnamed lake	Becker	03-0716-00	Lake
(91)	Unnamed wetland (Myrel's Pond)	Becker	03-1285-00	Wetland
(92)	Unnamed wetland (Osprey Pond)	Becker	03-1284-00	Wetland
(93)	Unnamed wetland (Trout Pond)	Becker	03-1286-00	Wetland
(94)	Upper Egg Lake	Becker	03-0206-00	Lake
(95)	Walker Lake	Otter Tail	56-0310-00	Lake
(96)	West Battle Lake	Otter Tail	56-0239-00	Lake
(97)	West Lost Lake	Otter Tail	56-0481-00	Lake
(98)	West Silent	Otter Tail	56-0519-00	Lake
(99)	Winter Lake	Becker	03-0216-00	Lake
(100)	Wright Lake	Otter Tail	56-0783-00	Lake

B. 09020106 Buffalo River:

	Name	**County**	**WID**	**Water Type**
(1)	Balsam Lake	Becker	03-0292-00	Lake
(2)	Big Sugarbush Lake	Becker	03-0304-00	Lake
(3)	Buffalo Lake	Becker	03-0350-00	Lake
(4)	Bullhead Lake	Becker	03-0312-00	Lake
(5)	Eagen Lake	Becker	03-0318-00	Lake
(6)	Little Round Lake	Becker	03-0302-00	Lake
(7)	Mary Yellowhead Lake	Becker	03-0243-00	Lake
(8)	Rice Lake	Becker	03-0291-00	Lake
(9)	Rock Lake	Becker	03-0293-00	Lake
(10)	St. Clair Lake	Becker	03-0430-00	Lake
(11)	Tamarack North Lake	Becker	03-0241-02	Lake

(12)	Tamarack South Lake	Becker	03-0241-01	Lake
(13)	Unnamed lake	Becker	03-0434-00	Lake

C. 09020108 Wild Rice River:

	Name	**County**	**WID**	**Water Type**
(1)	Anderson Lake	Clearwater	15-0074-00	Lake
(2)	Big Rat Lake	Becker	03-0246-00	Lake
(3)	Cabin Lake	Becker	03-0346-00	Lake
(4)	Depressional wetland	Mahnomen	44-0054-00	Wetland
(5)	Gull Creek	Becker	09020108-569	Stream
(6)	Lone Long Lake	Mahnomen	44-0002-00	Lake
(7)	Lower Rice Lake	Clearwater	15-0130-00	Lake
(8)	Mahn Lake	Mahnomen	44-0572-00	Wetland
(9)	McCraney Lake	Mahnomen	44-0080-00	Lake
(10)	Minerva Lake	Clearwater	15-0079-00	Lake
(11)	Mud Lake	Clearwater	15-0061-00	Lake
(12)	Roy Lake	Mahnomen	44-0001-00	Lake
(13)	Unnamed lake (Rice Bed)	Clearwater	15-0021-00	Lake
(14)	Upper Rice Lake	Clearwater	15-0059-00	Lake
(15)	White Earth Lake	Becker	03-0328-00	Lake
(16)	Wild Rice River	Clearwater	09020108-512	Stream
(17)	Wild Rice River	Mahnomen	09020108-510	Stream

D. 09020302 Upper/Lower Red Lake:

	Name	**County**	**WID**	**Water Type**
(1)	Blackduck Lake	Beltrami	04-0069-00	Lake
(2)	Blackduck River	Beltrami	09020302-513	Stream
(3)	Cranberry Lake	Beltrami	04-0123-00	Lake

(4)	George Lake	Beltrami	04-0175-00	Lake
(5)	Gourd Lake	Beltrami	04-0253-00	Lake
(6)	Heart Lake	Beltrami	04-0271-00	Lake
(7)	Little Puposky Lake	Beltrami	04-0197-00	Lake
(8)	Medicine Lake	Beltrami	04-0122-00	Lake
(9)	Norman Lake	Beltrami	04-0029-00	Lake
(10)	Puposky Lake	Beltrami	04-0198-00	Lake
(11)	Whitefish Lake	Beltrami	04-0309-00	Lake

E. 09020305 Clearwater River:

	Name	County	WID	Water Type
(1)	Bagley Lake	Clearwater	15-0040-00	Lake
(2)	Bee Lake	Polk	60-0192-00	Lake
(3)	Clearwater Lake	Beltrami	04-0343-00	Lake
(4)	Clearwater River	Clearwater	09020305-517	Stream
(5)	Clearwater River	Clearwater, Pennington	09020305-647	Stream
(6)	Eighteen Lake	Polk	60-0199-00	Lake
(7)	First Lake	Clearwater	15-0139-00	Lake
(8)	Lomond Lake	Clearwater	15-0081-00	Lake
(9)	Minnow Lake	Clearwater	15-0137-00	Lake
(10)	Pine Lake	Clearwater	15-0149-00	Lake
(11)	Second Lake	Clearwater	15-0140-00	Lake
(12)	Second Lake	Clearwater	15-0091-00	Lake
(13)	Spike Lake	Clearwater	15-0035-00	Lake
(14)	Third Lake	Clearwater	15-0141-00	Lake
(15)	Unnamed lake (Round)	Polk	60-0721-00	Lake
(16)	Walker Brook Lake	Clearwater	15-0060-00	Lake

F. 09020314 Roseau River:

	Name	County	WID	Water Type
(1)	Roseau Flowage	Lake of the Woods	39-0009-00	Lake
(2)	Roseau River WMA - Pool 2	Roseau	68-0006-00	Lake
(3)	Roseau River WMA - Pool 3	Roseau	68-0007-00	Lake

Subp. 6. **Upper Mississippi River basin.** The upper Mississippi River basin includes the headwaters to the confluence with the St. Croix River and all or portions of Aitkin, Anoka, Becker, Beltrami, Benton, Carlton, Carver, Cass, Chisago, Clearwater, Crow Wing, Dakota, Douglas, Hennepin, Hubbard, Isanti, Itasca, Kanabec, Kandiyohi, McLeod, Meeker, Mille Lacs, Morrison, Otter Tail, Pope, Ramsey, Renville, St. Louis, Sherburne, Sibley, Stearns, Todd, Wadena, Washington, and Wright Counties. The waters in each of the major watersheds in the upper Mississippi River basin that are identified as class 4D are listed in items A to O.

A. 07010101 Mississippi River - Headwaters:

	Name	County	WID	Water Type
(1)	Bass Lake	Itasca	31-0576-00	Lake
(2)	Big Vermillion Lake	Cass	11-0029-00	Lake
(3)	Blackwater Lake	Itasca	31-0561-00	Lake
(4)	Bootleg Lake	Beltrami	04-0211-00	Lake
(5)	Campbell Lake	Beltrami	04-0196-00	Lake
(6)	Carr Lake	Beltrami	04-0141-00	Lake
(7)	Damon Lake	Itasca	31-0944-00	Lake
(8)	Decker Lake	Itasca	31-0934-00	Lake
(9)	Depressional wetland	Beltrami	04-0460-00	Wetland
(10)	Dixon Lake	Itasca	31-0921-00	Lake

(11)	Dutchman Lake	Beltrami	04-0921-00	Lake
(12)	Elk Lake	Clearwater	15-0010-00	Lake
(13)	Erickson Lake (northwest portion)	Beltrami	04-0068-01	Lake
(14)	Erickson Lake (southeast portion)	Beltrami	04-0068-02	Lake
(15)	Gill Lake	Clearwater	15-0019-00	Lake
(16)	Grant Creek	Beltrami	07010101-546	Stream
(17)	Gull Lake	Beltrami	04-0064-00	Lake
(18)	Gull Lake	Beltrami	04-0120-00	Lake
(19)	Hattie Lake	Hubbard	29-0300-00	Lake
(20)	Irving Lake	Beltrami	04-0140-00	Lake
(21)	Island Lake	Itasca	31-0754-00	Lake
(22)	Itasca Lake	Clearwater	15-0016-00	Lake
(23)	Lake Alice	Hubbard	29-0286-00	Lake
(24)	Lake George	Hubbard	29-0216-00	Lake
(25)	Lillian Lake	Itasca	31-0750-00	Lake
(26)	Little Drum Lake	Itasca	31-0741-00	Lake
(27)	Little Moose Lake	Itasca	31-0610-00	Lake
(28)	Little Rice Lake	Itasca	31-0716-00	Lake
(29)	Little Turtle Lake	Beltrami	04-0155-00	Lake
(30)	Little Vermillion Lake	Cass	11-0030-00	Lake
(31)	Long Lake	Beltrami	04-0227-00	Lake
(32)	Mallard Lake	Clearwater	15-0018-00	Lake
(33)	Manomin Lake	Beltrami	04-0286-00	Lake
(34)	Marie Lake	Itasca	31-0937-00	Lake
(35)	Marquette Lake	Beltrami	04-0142-00	Lake
(36)	Mary Lake	Hubbard	29-0289-00	Lake
(37)	Mississippi River	Itasca	07010101-756	Stream

(38)	Mississippi River	Clearwater, Hubbard	07010101-753	Stream
(39)	Moose Lake	Beltrami	04-0342-00	Lake
(40)	Moose Lake	Beltrami	04-0011-00	Lake
(41)	Morph Lake	Itasca	31-0929-00	Lake
(42)	Movil Lake	Beltrami	04-0152-00	Lake
(43)	Mud Lake	Hubbard	29-0065-00	Lake
(44)	Munzer Lake	Itasca	31-0360-00	Lake
(45)	North Turtle River	Beltrami	07010101-570	Stream
(46)	Pimushe Lake	Beltrami	04-0032-00	Lake
(47)	Plantagenet Lake	Hubbard	29-0156-00	Lake
(48)	Pokegama Lake	Itasca	31-0532-00	Lake
(49)	Rabideau Lake	Beltrami	04-0034-00	Lake
(50)	Rice Lake	Itasca	31-0717-00	Lake
(51)	Rice Pond	Beltrami	04-0059-00	Lake
(52)	Schoolcraft Lake	Hubbard	29-0215-00	Lake
(53)	Skimmerhorn Lake	Itasca	31-0939-00	Lake
(54)	Skunk Lake	Cass	11-0027-00	Lake
(55)	Spring Lake	Cass	11-0022-00	Lake
(56)	Stevens Lake	Itasca	31-0718-00	Lake
(57)	Sucker Lake	Clearwater	15-0020-00	Lake
(58)	Third River	Itasca	07010101-526	Stream
(59)	Three Island Lake	Beltrami	04-0134-00	Lake
(60)	Turtle Lake	Beltrami	04-0159-00	Lake
(61)	Turtle River	Beltrami	07010101-510	Stream
(62)	Turtle River Lake	Beltrami	04-0111-00	Lake

(63)	White Oak Lake	Itasca	31-0776-00	Lake
(64)	Winnibigoshish Lake	Cass	11-0147-00	Lake

B. 07010102 Leech Lake River:

	Name	County	WID	Water Type
(1)	Baby Lake	Cass	11-0283-00	Lake
(2)	Bass Lake 2	Hubbard	29-0132-00	Lake
(3)	Big Sand Lake	Cass	11-0077-00	Lake
(4)	Birch Lake	Cass	11-0412-00	Lake
(5)	Boy Lake	Cass	11-0143-00	Lake
(6)	Boy River	Cass	07010102-520	Stream
(7)	Boy River	Cass	07010102-518	Stream
(8)	Cedar Lake	Cass	11-0082-00	Lake
(9)	Cedar Lake	Cass	11-0481-00	Lake
(10)	Child Lake	Cass	11-0263-00	Lake
(11)	Garfield Lake	Hubbard	29-0061-00	Lake
(12)	Girl Lake	Cass	11-0174-00	Lake
(13)	Goose Lake	Cass	11-0096-00	Lake
(14)	Hart Lake	Hubbard	29-0063-00	Lake
(15)	Horseshoe Lake	Hubbard	29-0059-00	Lake
(16)	Hunter Lake	Cass	11-0170-00	Lake
(17)	Inguadona Lake	Cass	11-0120-00	Lake
(18)	Kabekona Lake	Hubbard	29-0075-00	Lake
(19)	Kabekona River	Hubbard	07010102-511	Stream
(20)	Kerr Lake	Cass	11-0268-00	Lake
(21)	Kid Lake	Cass	11-0262-00	Lake
(22)	Laura Lake	Cass	11-0104-00	Lake

(23)	Leech Lake	Cass	11-0203-00	Lake
(24)	Little Boy Lake	Cass	11-0167-00	Lake
(25)	Little Gulch Lake	Hubbard	29-0123-00	Lake
(26)	Little Swift Lake	Cass	11-0131-00	Lake
(27)	Little Woman Lake	Cass	11-0265-00	Lake
(28)	Lower Milton Lake	Cass	11-0080-00	Lake
(29)	Lower Trelipe Lake	Cass	11-0129-00	Lake
(30)	McCarthey Lake	Cass	11-0168-00	Lake
(31)	McKeown Lake	Cass	11-0261-00	Lake
(32)	Moon Lake	Cass	11-0078-00	Lake
(33)	Mud Lake	Cass	11-0100-00	Lake
(34)	Necktie River	Hubbard	07010102-502	Stream
(35)	Oak Lake	Hubbard	29-0060-00	Lake
(36)	Ododikossi Lake	Cass	11-0074-00	Lake
(37)	Oxbow Lake	Cass	11-0075-00	Lake
(38)	Pick Lake	Cass	11-0267-00	Lake
(39)	Pleasant Lake	Cass	11-0383-00	Lake
(40)	Portage Lake	Cass	11-0476-00	Lake
(41)	Rice Lake	Cass	11-0162-00	Lake
(42)	Shingobee Lake	Hubbard	29-0043-00	Lake
(43)	Swift Lake	Cass	11-0133-00	Lake
(44)	Tamarack Lake	Cass	11-0189-00	Lake
(45)	Twin (East Twin) Lake	Cass	11-0123-00	Lake
(46)	Upper Trelipe Lake	Cass	11-0105-00	Lake
(47)	Wabedo Lake	Cass	11-0171-00	Lake
(48)	Wax Lake	Cass	11-0124-00	Lake

(49)	West Twin Lake	Cass	11-0125-00	Lake
(50)	Woman Lake	Cass	11-0201-00	Lake

C. 07010103 Mississippi River - Grand Rapids:

	Name	**County**	**WID**	**Water Type**
(1)	Aitkin Lake	Aitkin	01-0040-00	Lake
(2)	Anderson Lake	Aitkin	01-0031-00	Lake
(3)	Ann Lake	Itasca	31-0305-00	Lake
(4)	Big Birch Lake	Cass	11-0017-00	Lake
(5)	Big Rice Lake	Cass	11-0073-00	Lake
(6)	Big Sandy Lake	Aitkin	01-0062-00	Lake
(7)	Blackberry Lake	Itasca	31-0210-00	Lake
(8)	Bluebill Lake	Itasca	31-0265-00	Lake
(9)	Bosley Lake	Itasca	31-0403-00	Lake
(10)	Brown Lake	Aitkin	01-0078-00	Lake
(11)	Buckman Lake	Itasca	31-0272-00	Lake
(12)	Clear Lake	Aitkin	01-0106-00	Lake
(13)	Clearwater Lake	Itasca	31-0402-00	Lake
(14)	Cornish Lake	Aitkin	01-0427-00	Lake
(15)	Crescent Lake	Itasca	31-0294-00	Lake
(16)	Crooked Lake	Itasca	31-0193-00	Lake
(17)	Crooked Lake	Itasca	31-0203-00	Lake
(18)	Cross Lake	Carlton	09-0062-00	Lake
(19)	Davis Lake	Aitkin	01-0071-01	Lake
(20)	Day Brook	Itasca, St. Louis	07010103-542	Stream
(21)	Flowage Lake	Aitkin	01-0061-00	Lake
(22)	Flower Lake	Carlton	09-0064-00	Lake

(23)	Gunny Sack Lake	Itasca	31-0267-00	Lake
(24)	Hay Lake	Itasca	31-0037-00	Lake
(25)	Hockey Lake	St. Louis	69-0849-00	Lake
(26)	Horseshoe Lake	Aitkin	01-0034-00	Lake
(27)	Hunters Lake	Itasca	31-0450-00	Lake
(28)	Island Lower Lake	Carlton	09-0060-02	Lake
(29)	Island Upper Lake	Carlton	09-0060-01	Lake
(30)	Lawrence Lake	Itasca	31-0231-00	Lake
(31)	Little Birch Lake	Cass	11-0018-00	Lake
(32)	Little Hill River WMA - impoundment	Aitkin	01-0433-00	Lake
(33)	Little McKinney Lake	Aitkin	01-0197-00	Lake
(34)	Little Red Horse Lake	Aitkin	01-0052-00	Lake
(35)	Long Lake	Carlton	09-0066-00	Lake
(36)	Marble Lake	Itasca	31-0271-00	Lake
(37)	Minnewawa Lake	Aitkin	01-0033-00	Lake
(38)	Moose Lake	Aitkin	01-0140-00	Lake
(39)	Moose Lake	Itasca	31-0242-00	Lake
(40)	Moose River	Aitkin	~~07010103-524~~ 07010103-749	Stream
(41)	Moose River pool	Aitkin	01-0358-00	Lake
(42)	Moose Willow WMA - Willow Pool	Aitkin	01-0431-00	Lake
(43)	Mud Lake	Itasca	31-0206-00	Lake
(44)	Mud Lake	Aitkin	01-0194-00	Lake
(45)	Nagel Lake	Itasca	31-0377-00	Lake
(46)	Nelson Lake	Aitkin	01-0010-00	Lake
(47)	O'Brien (Leighton) Lake	Itasca	31-0032-00	Lake
(48)	O'Donnell Lake	Itasca	31-0303-00	Lake

(49)	Ox Hide Lake	Itasca	31-0106-00	Lake
(50)	Prairie Lake	Itasca	31-0384-00	Lake
(51)	Prairie Lake	Itasca	31-0053-00	Lake
(52)	Prairie Lake	St. Louis	69-0848-00	Lake
(53)	Prairie River	Itasca	07010103-508	Stream
(54)	Prairie River	Aitkin	07010103-515	Stream
(55)	Prairie River	St. Louis	07010103-516	Stream
(56)	Rat House Lake	Aitkin	01-0053-00	Lake
(57)	Rat Lake	Aitkin	01-0077-00	Lake
(58)	Red Lake	Aitkin	01-0107-00	Lake
(59)	Rice Lake	Aitkin	01-0005-00	Lake
(60)	Rice Lake	Itasca	31-0201-00	Lake
(61)	Rice Pad Lake	Cass	11-0720-00	Lake
(62)	Rock Lake	Aitkin	01-0072-00	Lake
(63)	Sailor Lake	Cass	11-0019-00	Lake
(64)	Salo Marsh WMA - impoundment	Aitkin	01-0415-00	Lake
(65)	Sanders Lake	Aitkin	01-0076-00	Lake
(66)	Sandy River	Aitkin	07010103-512	Stream
(67)	Sandy River Lake	Aitkin	01-0060-00	Lake
(68)	Savanna Lake	Aitkin	01-0014-00	Lake
(69)	Savanna River	Aitkin	07010103-514	Stream
(70)	Shovel Lake	Aitkin	01-0200-00	Lake
(71)	Soneman Lake	Itasca	31-0276-00	Lake
(72)	Spruce Lake	Itasca	31-0347-00	Lake
(73)	Steamboat Lake	Aitkin	01-0071-02	Lake
(74)	Stony Lake	Aitkin	01-0017-00	Lake
(75)	Swan Lake (Southwest Bay)	Itasca	31-0067-03	Lake

(76)	Swan River	Itasca	~~07010103-506~~ 07010103-753	Stream
(77)	Tamarack Lake	Carlton	09-0067-00	Lake
(78)	Tamarack River	Aitkin	07010103-758	Stream
~~(78)~~ (79)	Tamarack River	Aitkin, Carlton	~~07010103-521~~ 07010103-757	Stream
~~(79)~~ (80)	Thiebault Lake	Cass	11-0020-00	Lake
~~(80)~~ (81)	Third Guide Lake	Cass	11-0001-00	Lake
~~(81)~~ (82)	Thunder Lake	Cass	11-0062-00	Lake
~~(82)~~ (83)	Unnamed lake	Itasca	31-0204-00	Lake
~~(83)~~ (84)	Washburn Lake	Aitkin	01-0111-00	Lake
~~(84)~~ (85)	White Elk Lake	Aitkin	01-0148-00	Lake
~~(85)~~ (86)	White Fish Lake	Itasca	31-0142-00	Lake
~~(86)~~ (87)	Wolf Lake	Itasca	31-0152-00	Lake
~~(87)~~ (88)	Woodbury Lake	Carlton	09-0063-00	Lake

D. 07010104 Mississippi River - Brainerd:

	Name	**County**	**WID**	**Water Type**
(1)	Bay Lake	Crow Wing	18-0034-00	Lake
(2)	Beauty Lake	Todd	77-0035-00	Lake
(3)	Big Swan Lake	Todd	77-0023-00	Lake
(4)	Birch Lake	Aitkin	01-0206-00	Lake

(5)	Blind Lake	Aitkin	01-0188-00	Lake
(6)	Buffalo Lake	Crow Wing	18-0152-00	Lake
(7)	Camp Lake	Aitkin	01-0098-00	Lake
(8)	Cedar Lake	Aitkin	01-0209-00	Lake
(9)	Crow Wing Lake	Crow Wing	18-0155-00	Lake
(10)	Deadman's Lake	Crow Wing	18-0188-00	Lake
(11)	Deer Lake	Crow Wing	18-0182-00	Lake
(12)	Dog Lake	Crow Wing	18-0107-00	Lake
(13)	Elm Island Lake	Aitkin	01-0123-00	Lake
(14)	Farm Island Lake	Aitkin	01-0159-00	Lake
(15)	Faupel Lake	Crow Wing	18-0237-00	Lake
(16)	Flanders Lake	Crow Wing	18-0247-00	Lake
(17)	Fleming Lake	Aitkin	01-0105-00	Lake
(18)	Gilbert Lake	Crow Wing	18-0320-00	Lake
(19)	Gun Lake	Aitkin	01-0099-00	Lake
(20)	Half Moon Lake	Crow Wing	18-0238-00	Lake
(21)	Hanging Kettle Lake	Aitkin	01-0170-00	Lake
(22)	Happy Lake	Crow Wing	18-0101-00	Lake
(23)	Hay Lake	Crow Wing	18-0444-00	Lake
(24)	Hay Lake	Crow Wing	18-0120-00	Lake
(25)	Hickory Lake	Aitkin	01-0179-00	Lake
(26)	Horseshoe Lake	Crow Wing	18-0317-00	Lake
(27)	Island Lake	Crow Wing	18-0052-00	Lake
(28)	Island Lake	Crow Wing	18-0383-00	Lake
(29)	Jewett WMA - impoundment	Aitkin	01-0383-00	Lake
(30)	Johnson Lake	Aitkin	01-0131-00	Lake
(31)	Killroy Lake	Aitkin	01-0238-00	Lake

(32)	Kimberly WMA - lower pool	Aitkin	01-0411-00	Lake
(33)	Kimberly WMA - upper pool	Aitkin	01-0410-00	Lake
(34)	Krilwitz Lake	Aitkin	01-0283-00	Lake
(35)	Lily Lake	Aitkin	01-0088-00	Lake
(36)	Little Pine Lake	Aitkin	01-0176-00	Lake
(37)	Little Willow River WMA - upper pool	Aitkin	01-0420-00	Lake
(38)	Little Willow River WMA - Pool 2	Aitkin	01-0332-00	Lake
(39)	Long Lake	Todd	77-0027-00	Lake
(40)	Lower Dean Lake	Crow Wing	18-0181-00	Lake
(41)	Lower Mission Lake	Crow Wing	18-0243-00	Lake
(42)	Mallard Lake	Aitkin	01-0149-00	Lake
(43)	Mandy Lake	Aitkin	01-0068-00	Lake
(44)	Maple Lake	Crow Wing	18-0045-00	Lake
(45)	Miller Lake	Morrison	49-0051-00	Lake
(46)	Mississippi River	Crow Wing	07010104-656	Stream
(47)	Monson Lake	Aitkin	01-0126-00	Lake
(48)	Mud Lake	Crow Wing	18-0094-00	Lake
(49)	Mud Lake	Crow Wing	18-0137-00	Lake
(50)	Nelson Lake	Crow Wing	18-0164-00	Lake
(51)	Newstrom Lake	Aitkin	01-0097-00	Lake
(52)	Olson Lake	Crow Wing	18-0171-00	Lake
(53)	Pointon Lake	Crow Wing	18-0105-00	Lake
(54)	Portage Lake	Aitkin	01-0069-00	Lake
(55)	Rice (Blomberg's) Lake	Crow Wing	18-0121-00	Lake
(56)	Rice (Deerwood) Lake	Crow Wing	18-0068-00	Lake
(57)	Rice Lake (Hesitation WMA)	Crow Wing	18-0053-00	Lake

(58)	Rice (Pratt's) Lake	Crow Wing	18-0316-00	Lake
(59)	Rice Lake	Aitkin	01-0067-00	Lake
(60)	Rice River	Aitkin	07010104-508	Stream
(61)	Ripple Lake	Aitkin	01-0146-00	Lake
(62)	Ripple River	Aitkin	07010104-661	Stream
(63)	Robbinson Pond	Todd	77-0378-00	Lake
(64)	Rogers Lake	Crow Wing	18-0184-00	Lake
(65)	Round Lake	Crow Wing	18-0147-00	Lake
(66)	Sebie Lake	Crow Wing	18-0161-00	Lake
(67)	Section Ten Lake	Aitkin	01-0115-00	Lake
(68)	Section Twelve Lake	Aitkin	01-0120-00	Lake
(69)	Sewells Pond	Crow Wing	18-0446-00	Lake
(70)	Sisabagamah Lake	Aitkin	01-0129-00	Lake
(71)	Sitas Lake	Aitkin	01-0134-00	Lake
(72)	Sjodin Lake	Aitkin	01-0316-00	Lake
(73)	South Long Lake	Crow Wing	18-0136-00	Lake
(74)	Spirit Lake	Aitkin	01-0178-00	Lake
(75)	Spruce Lake	Aitkin	01-0151-00	Lake
(76)	Swamp Lake	Aitkin	01-0092-00	Lake
(77)	Tamarack Lake	Crow Wing	18-0318-00	Lake
(78)	Terry Lake	Crow Wing	18-0162-00	Lake
(79)	Twin Island Lake	Crow Wing	18-0106-00	Lake
(80)	Twin Lake	Todd	77-0021-00	Lake
(81)	Unnamed lake (Little Willow River WMA)	Aitkin	01-0332-00	Lake
(82)	Unnamed lake (Nokasippi River rice bed)	Crow Wing	18-0485-00	Lake

(83)	Unnamed lake (Round Lake pothole)	Aitkin	01-0285-00	Lake
(84)	Unnamed lake	Crow Wing	18-0550-00	Lake
(85)	Upper Blind Lake	Aitkin	01-0331-00	Lake
(86)	Upper Dean Lake	Crow Wing	18-0170-00	Lake
(87)	Upper Mission Lake	Crow Wing	18-0242-00	Lake
(88)	Waukenabo Lake	Aitkin	01-0136-00	Lake
(89)	West Lake	Aitkin	01-0287-00	Lake
(90)	Wilson Lake	Crow Wing	18-0049-00	Lake
(91)	Wolf Lake	Crow Wing	18-0112-00	Lake

E. 07010105 Pine River:

	Name	**County**	**WID**	**Water Type**
(1)	Arrowhead Lake	Crow Wing	18-0366-00	Lake
(2)	Beuber Lake	Cass	11-0353-00	Lake
(3)	Big Bird Lake	Crow Wing	18-0285-00	Lake
(4)	Big Portage Lake	Cass	11-0308-00	Lake
(5)	Birchdale Lake	Crow Wing	18-0175-00	Lake
(6)	Bowen Lake	Cass	11-0350-00	Lake
(7)	Brockway Lake	Cass	11-0366-00	Lake
(8)	Caraway Lake	Crow Wing	18-0179-00	Lake
(9)	Cedar Lake	Cass	11-0444-00	Lake
(10)	Clough Creek Lake	Crow Wing	18-0414-00	Lake
(11)	Dahler Lake	Crow Wing	18-0204-00	Lake
(12)	Ding Pot Lake	Cass	11-0565-00	Lake
(13)	Duck Lake	Crow Wing	18-0178-00	Lake
(14)	Duck Lake	Crow Wing	18-0314-00	Lake
(15)	Eagle Lake	Crow Wing	18-0296-00	Lake

(16)	Emily Lake	Crow Wing	18-0203-00	Lake
(17)	Five Point Lake	Cass	11-0351-00	Lake
(18)	George Lake	Cass	11-0101-00	Lake
(19)	Goodrich Lake	Crow Wing	18-0226-00	Lake
(20)	Google Lake	Crow Wing	18-0223-00	Lake
(21)	Grass Lake	Crow Wing	18-0230-00	Lake
(22)	Greer Lake	Crow Wing	18-0287-00	Lake
(23)	Hattie Lake	Cass	11-0232-00	Lake
(24)	Hay Lake	Cass	11-0199-00	Lake
(25)	Island Lake	Cass	11-0360-00	Lake
(26)	Island Lake	Cass	11-0102-00	Lake
(27)	Jail Lake	Crow Wing	18-0415-00	Lake
(28)	Lily Pad Lake	Crow Wing	18-0275-00	Lake
(29)	Lind (Lindsey) Lake	Cass	11-0367-00	Lake
(30)	Little Hattie Lake	Cass	11-0232-01	Lake
(31)	Little Pine Lake	Crow Wing	18-0266-00	Lake
(32)	Little Pine Lake	Crow Wing	18-0176-00	Lake
(33)	Lizotte Lake	Cass	11-0231-00	Lake
(34)	Lizzie Lake	Crow Wing	18-0416-00	Lake
(35)	Lower Hand Lake	Cass	11-0251-00	Lake
(36)	Lows Lake	Crow Wing	18-0180-00	Lake
(37)	Mitchell Lake	Crow Wing	18-0294-00	Lake
(38)	Mud Lake	Crow Wing	18-0198-00	Lake
(39)	Mud Lake	Cass	11-0309-00	Lake
(40)	Norway Lake	Cass	11-0307-00	Lake
(41)	Ossawinnamakee Lake	Crow Wing	18-0352-00	Lake
(42)	Pelican Lake	Crow Wing	18-0308-00	Lake

(43)	Peterson Lake	Cass	11-0154-00	Lake
(44)	Pine Lake	Crow Wing	18-0261-00	Lake
(45)	Pine Mountain Lake	Cass	11-0411-00	Lake
(46)	Pine River (Norway Brook)	Cass	07010105-671	Stream
(47)	Potshot Lake	Cass	11-0149-00	Lake
(48)	Rainy Lake	Cass	11-0356-00	Lake
(49)	Rat Lake	Crow Wing	18-0410-00	Lake
(50)	Rice (Carrol's) Lake	Cass	11-0227-00	Lake
(51)	Rice Bed Lake	Crow Wing	18-0187-00	Lake
(52)	Schafer Lake	Cass	11-0004-00	Lake
(53)	Scribner Lake	Cass	11-0441-00	Lake
(54)	South Fork Pine River	Cass	07010105-534	Stream
(55)	Stewart Lake	Crow Wing	18-0367-00	Lake
(56)	Tamarack Lake	Cass	11-0347-00	Lake
(57)	Unnamed lake (Lost Rice)	Crow Wing	18-0228-00	Lake
(58)	Unnamed lake (Pistol Lake rice bed)	Cass	11-0738-00	Lake
(59)	Unnamed lake	Crow Wing	18-0413-00	Lake
(60)	Upper Hand Lake	Cass	11-0242-00	Lake
(61)	Upper Hay Lake	Crow Wing	18-0412-00	Lake
(62)	Upper Whitefish Lake	Crow Wing	18-0310-00	Lake
(63)	Velvet Lake	Crow Wing	18-0284-00	Lake
(64)	Washburn Lake	Cass	11-0059-00	Lake

F. 07010106 Crow Wing River:

	Name	**County**	**WID**	**Water Type**
(1)	Abners Lake	Becker	03-0039-00	Lake
(2)	Aspinwall Lake	Becker	03-0104-00	Lake

(3)	Bass Lake	Becker	03-0088-00	Lake
(4)	Beden Lake	Hubbard	29-0265-00	Lake
(5)	Belle Taine Lake	Hubbard	29-0146-00	Lake
(6)	Bergkeller Lake	Cass	11-0447-00	Lake
(7)	Big Basswood Lake	Becker	03-0096-00	Lake
(8)	Big Rush Lake	Becker	03-0103-00	Lake
(9)	Blueberry Lake	Becker	03-0007-00	Lake
(10)	Blueberry Lake	Wadena	80-0034-00	Lake
(11)	Burgen Lake	Wadena	80-0018-00	Lake
(12)	Cat Lake	Cass	11-0509-00	Lake
(13)	Clark Lake	Crow Wing	18-0374-00	Lake
(14)	Clausens Lake	Hubbard	29-0097-00	Lake
(15)	Crow Wing Lake	Hubbard	29-0116-00	Lake
(16)	Crow Wing River	Hubbard	07010106-516	Stream
(17)	Deer Lake	Hubbard	29-0090-00	Lake
(18)	Dinner Lake	Becker	03-0044-00	Lake
(19)	Duck Lake	Hubbard	29-0142-00	Lake
(20)	Eagle Lake	Hubbard	29-0256-00	Lake
(21)	Edward Lake	Crow Wing	18-0556-00	Lake
(22)	Eighth Crow Wing Lake	Hubbard	29-0072-00	Lake
(23)	Esterday Lake	Cass	11-0511-00	Lake
(24)	Farnham Lake	Cass	11-0513-00	Lake
(25)	Fifth Crow Wing Lake	Hubbard	29-0092-00	Lake
(26)	Finn Lake	Wadena	80-0028-00	Lake
(27)	First Crow Wing Lake	Hubbard	29-0086-00	Lake
(28)	First Crow Wing River	Hubbard	07010106-523	Stream
(29)	Fishhook River	Hubbard	07010106-627	Stream

(30)	Fish Hook Lake	Hubbard	29-0242-00	Lake
(31)	Fourth Crow Wing Lake	Hubbard	29-0078-00	Lake
(32)	Garden Lake	Crow Wing	18-0329-00	Lake
(33)	Granning Lake	Wadena	80-0012-00	Lake
(34)	Gull Lake	Cass	11-0305-00	Lake
(35)	Gull River	Cass	07010106-502	Stream
(36)	Gyles Lake	Becker	03-0066-00	Lake
(37)	Hardy Lake	Cass	11-0332-00	Lake
(38)	Hay Creek	Hubbard	07010106-617	Stream
(39)	Hole-in-the-Day Lake	Crow Wing	18-0401-00	Lake
(40)	Indian Creek	Becker	07010106-569	Stream
(41)	Island Lake	Hubbard	29-0254-00	Lake
(42)	Johnson Lake	Crow Wing	18-0328-00	Lake
(43)	Kane Lake	Becker	03-0042-00	Lake
(44)	Kelly Lake	Cass	11-0428-00	Lake
(45)	Kneebone Lake	Becker	03-0090-00	Lake
(46)	Knutson Lake	Becker	03-0004-00	Lake
(47)	Little Basswood Lake	Becker	03-0092-00	Lake
(48)	Little Dinner Lake	Becker	03-0045-00	Lake
(49)	Little Mud Lake	Becker	03-0022-00	Lake
(50)	Little Sand Lake	Hubbard	29-0150-00	Lake
(51)	Love Lake	Crow Wing	18-0388-00	Lake
(52)	Lower Bottle Lake	Hubbard	29-0180-00	Lake
(53)	Lower Mud Lake	Hubbard	29-0267-00	Lake
(54)	Lower Twin Lake	Wadena	80-0030-00	Lake
(55)	Mallard Lake	Crow Wing	18-0334-00	Lake
(56)	Mantrap Lake	Hubbard	29-0151-00	Lake

(57)	Margaret Lake	Cass	11-0222-00	Lake
(58)	Mayo Lake	Crow Wing	18-0408-00	Lake
(59)	Middle Cullen Lake	Crow Wing	18-0377-00	Lake
(60)	Mollie Lake	Crow Wing	18-0335-00	Lake
(61)	Moose Lake	Cass	11-0424-00	Lake
(62)	Mud Lake	Becker	03-0120-00	Lake
(63)	Mud Lake	Hubbard	29-0119-00	Lake
(64)	Mud Lake	Becker	03-0067-00	Lake
(65)	Mud Lake	Becker	03-0023-00	Lake
(66)	Mud Lake	Crow Wing	18-0326-00	Lake
(67)	Ninth Crow Wing Lake	Hubbard	29-0025-00	Lake
(68)	Nisswa Lake	Crow Wing	18-0399-00	Lake
(69)	North Long Lake	Crow Wing	18-0372-00	Lake
(70)	Perch Lake	Crow Wing	18-0304-00	Lake
(71)	Pillager Lake	Cass	11-0320-00	Lake
(72)	Placid Lake	Morrison	49-0080-00	Lake
(73)	Portage Lake	Hubbard	29-0250-00	Lake
(74)	Potato Lake	Hubbard	29-0243-00	Lake
(75)	Ray Lake	Cass	11-0220-00	Lake
(76)	Red Sand Lake	Crow Wing	18-0386-00	Lake
(77)	Rice (Clark) Lake	Crow Wing	18-0327-00	Lake
(78)	Rice Lake (Lowell WMA)	Crow Wing	18-0405-00	Lake
(79)	Rice (Pillager) Lake	Cass	11-0321-00	Lake
(80)	Rice Lake	Hubbard	29-0177-00	Lake
(81)	Rock Lake	Cass	11-0324-00	Lake
(82)	Round Lake	Crow Wing	18-0373-00	Lake
(83)	Round Lake	Wadena	80-0019-00	Lake

(84)	Roy Lake	Crow Wing	18-0398-00	Lake
(85)	Second Crow Wing Lake	Hubbard	29-0085-00	Lake
(86)	Seventh Crow Wing Lake	Hubbard	29-0091-00	Lake
(87)	Shallow Lake	Hubbard	29-0089-00	Lake
(88)	Shell Lake	Becker	03-0102-00	Lake
(89)	Shell River	Hubbard	07010106-681	Stream
(90)	Shipman Lake	Becker	03-0005-00	Lake
(91)	Sibley Lake	Crow Wing	18-0404-00	Lake
(92)	Sixth Crow Wing Lake	Hubbard	29-0093-00	Lake
(93)	Stocking Lake	Wadena	80-0037-00	Lake
(94)	Strike Lake	Wadena	80-0013-00	Lake
(95)	Sylvan Lake	Cass	11-0304-00	Lake
(96)	Tamarack Lake	Hubbard	29-0094-00	Lake
(97)	Tenth Crow Wing Lake	Hubbard	29-0045-00	Lake
(98)	Third Crow Wing Lake	Hubbard	29-0077-00	Lake
(99)	Twin Island Lake	Becker	03-0033-00	Lake
(100)	Two Inlets Lake	Becker	03-0017-00	Lake
(101)	Unnamed lake (Blackie's Slough)	Crow Wing	18-0544-00	Lake
(102)	Unnamed lake (Hay Creek)	Hubbard	29-0554-00	Lake
(103)	Unnamed lake (Indian Creek Pool)	Becker	03-0786-00	Lake
(104)	Unnamed lake (Total's Pothole)	Crow Wing	18-0543-00	Lake
(105)	Unnamed creek (Mud Creek)	Hubbard	07010106-722	Stream
(106)	Unnamed lake	Cass	11-0777-00	Lake
(107)	Unnamed lake	Wadena	80-0007-00	Lake
(108)	Unnamed lake	Cass	11-0780-00	Lake
(109)	Upper Bottle Lake	Hubbard	29-0148-00	Lake
(110)	Upper Cullen Lake	Crow Wing	18-0376-00	Lake

(111)	Upper Gull Lake	Cass	11-0218-00	Lake
(112)	Upper Mud Lake	Hubbard	29-0284-00	Lake
(113)	Upper Twin Lake	Hubbard	29-0157-00	Lake
(114)	Whipple Lake	Crow Wing	18-0387-00	Lake
(115)	Yaeger Lake	Wadena	80-0022-00	Lake

G. 07010107 Redeye River:

	Name	County	WID	Water Type
(1)	East Leaf Lake	Otter Tail	56-0116-02	Lake
(2)	Gourd Lake	Otter Tail	56-0139-00	Lake
(3)	Grass Lake	Otter Tail	56-0115-00	Lake
(4)	Middle Leaf Lake	Otter Tail	56-0116-01	Lake
(5)	North Maple Lake	Otter Tail	56-0013-00	Lake
(6)	South Maple Lake	Otter Tail	56-0004-00	Lake
(7)	Tamarack Lake	Otter Tail	56-0192-00	Lake
(8)	Unnamed lake (Cemetery)	Otter Tail	56-0024-00	Lake
(9)	West Leaf Lake	Otter Tail	56-0114-00	Lake
(10)	Wing River	Otter Tail	56-0043-00	Lake
(11)	Wolf Lake	Becker	03-0101-00	Lake

H. 07010108 Long Prairie River:

	Name	County	WID	Water Type
(1)	Alexander Lake	Morrison	49-0079-00	Lake
(2)	Beck Lake	Todd	77-0056-00	Lake
(3)	Cass County Lake	Todd	77-0004-00	Lake
(4)	Charlotte Lake	Todd	77-0120-00	Lake
(5)	Fish Trap Lake	Morrison	49-0137-00	Lake
(6)	Ham Lake	Morrison	49-0136-00	Lake

(7)	Ida Lake	Douglas	21-0123-00	Lake
(8)	Irene Lake	Douglas	21-0076-00	Lake
(9)	Jaeger Lake	Todd	77-0075-00	Lake
(10)	Jessie Lake	Douglas	21-0055-00	Lake
(11)	Latoka Lake	Douglas	21-0106-00	Lake
(12)	Long Lake	Todd	77-0069-00	Lake
(13)	Long Prairie River	Morrison	07010108-501	Stream
(14)	Long Prairie River	Douglas	07010108-505	Stream
(15)	Long Prairie River	Douglas	07010108-535	Stream
(16)	Louise Lake	Douglas	21-0094-00	Lake
(17)	Mill Pond Lake	Douglas	21-0034-00	Lake
(18)	Miltona Lake	Douglas	21-0083-00	Lake
(19)	Mud Lake	Morrison	49-0072-00	Lake
(20)	Mud Lake	Todd	77-0087-00	Lake
(21)	Rice Lake	Todd	77-0061-00	Lake
(22)	Rogers Lake	Todd	77-0073-00	Lake
(23)	Shamineau Lake	Morrison	49-0127-00	Lake
(24)	Stoney (Stone) Lake	Douglas	21-0101-00	Lake
(25)	Taylor Lake	Douglas	21-0105-00	Lake
(26)	Turtle Creek	Todd	07010108-513	Stream
(27)	Turtle Lake	Todd	77-0088-00	Lake
(28)	Union (North Union) Lake	Douglas	21-0095-00	Lake
(29)	Union Lake	Douglas	21-0041-00	Lake
(30)	Unnamed lake	Douglas	21-0416-00	Lake
(31)	Unnamed lake	Todd	77-0178-00	Lake
(32)	Unnamed lake	Todd	77-0176-00	Lake
(33)	West Nelson Lake	Todd	77-0005-00	Lake

I. 07010201 Mississippi River - Sartell:

	Name	County	WID	Water Type
(1)	Anna Lake	Stearns	73-0126-00	Lake
(2)	Bass Lake	Crow Wing	18-0011-00	Lake
(3)	Big Spunk	Stearns	73-0117-00	Lake
(4)	Bulldog Lake	Crow Wing	18-0014-00	Lake
(5)	Coon Lake	Morrison	49-0020-00	Lake
(6)	Erskine Lake	Crow Wing	18-0009-00	Lake
(7)	Hannah Lake	Morrison	49-0014-00	Lake
(8)	Linneman Lake	Stearns	73-0127-00	Lake
(9)	Little Rice Lake	Stearns	73-0167-00	Lake
(10)	Long Lake	Morrison	49-0015-00	Lake
(11)	Lower Spunk Lake	Stearns	73-0123-00	Lake
(12)	Mud Lake	Morrison	49-0027-00	Lake
(13)	Ochotto Lake	Stearns	73-0122-00	Lake
(14)	Peavy Lake	Morrison	49-0005-00	Lake
(15)	Pelkey Lake	Morrison	49-0030-00	Lake
(16)	Platte Lake	Crow Wing	18-0088-00	Lake
(17)	Platte River	Morrison	07010201-507	Stream
(18)	Rice Creek	Morrison	07010201-618	Stream
(19)	Rice Lake	Morrison	49-0025-00	Lake
(20)	Rock Lake	Crow Wing	18-0016-00	Lake
(21)	Round Lake	Morrison	49-0019-00	Lake
(22)	Skunk Lake	Morrison	49-0026-00	Lake
(23)	Sullivan Lake	Morrison	49-0016-00	Lake
(24)	Twenty Two Lake	Crow Wing	18-0008-00	Lake

J. 07010202 Sauk River:

	Name	County	WID	Water Type
(1)	Cedar Lake	Stearns	73-0226-00	Lake
(2)	Goodners Lake	Stearns	73-0076-00	Lake
(3)	Grand Lake	Stearns	73-0055-00	Lake
(4)	Little Birch Lake	Todd	77-0089-00	Lake
(5)	Little Osakis Lake	Todd	77-0201-00	Lake
(6)	McCormic Lake	Stearns	73-0273-00	Lake
(7)	South Twin Lake	Stearns	73-0276-00	Lake
(8)	Unnamed lake (Tower WMA)	Stearns	73-0343-00	Lake
(9)	Unnamed lake	Stearns	73-0274-00	Lake
(10)	Westport Lake	Pope	61-0029-00	Lake

K. 07010203 Mississippi River - St. Cloud:

	Name	County	WID	Water Type
(1)	Beaver Lake	Stearns	73-0023-00	Lake
(2)	Big Mud Lake	Sherburne	71-0085-00	Lake
(3)	Boyd Lake	Sherburne	71-0118-00	Lake
(4)	Buck Lake	Sherburne	71-0187-00	Lake
(5)	Clearwater Lake	Wright	86-0252-00	Lake
(6)	Jim Lake	Sherburne	71-0111-00	Lake
(7)	Johnson Slough	Sherburne	71-0084-00	Lake
(8)	Josephine Pool	Sherburne	71-0068-00	Lake
(9)	Little Mary (Maria) Lake	Wright	86-0139-02	Lake
(10)	Lower Roadside Lake	Sherburne	71-0376-00	Lake
(11)	Lundberg Slough	Sherburne	71-0109-00	Lake
(12)	Muskrat Pool	Sherburne	71-0297-00	Lake

(13)	Nixon Lake	Wright	86-0238-00	Lake
(14)	Orrock Lake	Sherburne	71-0085-00	Lake
(15)	Pool 2	Sherburne	71-0084-00	Lake
(16)	Rice Lake	Sherburne	71-0078-00	Lake
(17)	Rice Lake	Sherburne	71-0142-00	Lake
(18)	Sand Prairie WMA - Vision Pool	Sherburne	DNR	Lake
(19)	Sandy Lake	Wright	86-0224-00	Lake
(20)	Schoolhouse Pool	Sherburne	71-0296-00	Lake
(21)	Sugar Lake	Wright	86-0233-00	Lake
(22)	Unnamed lake	Wright	86-0231-00	Lake

L. 07010204 North Fork Crow River:

	Name	County	WID	Water Type
(1)	Crow Lake	Stearns	73-0279-00	Lake
(2)	Depressional wetland	Kandiyohi	34-0143-00	Wetland
(3)	Fish Lake	Stearns	73-0281-00	Lake
(4)	Grove Lake	Pope	61-0023-00	Lake
(5)	Middle Fork Crow River	Kandiyohi	07010204-537	Stream
(6)	Monongalia Lake	Kandiyohi	34-0158-00	Lake
(7)	North Fork Crow River (North Fork WMA)	Stearns	07010204-685	Stream
(8)	Padua Lake	Stearns	73-0277-00	Lake
(9)	Raymond Lake	Stearns	73-0285-00	Lake
(10)	Smith Lake	Wright	86-0250-00	Lake
(11)	Stella Lake	Meeker	47-0068-00	Lake
(12)	Tamarack Lake	Stearns	73-0278-00	Lake
(13)	Unnamed lake	Kandiyohi	34-0611-00	Lake
(14)	West Lake Sylvia	Wright	86-0279-00	Lake

M. 07010205 South Fork Crow River:

	Name	County	WID	Water Type
(1)	Cedar Lake	Wright	86-0034-00	Lake
(2)	Dagger Slough	McLeod	43-0168-00	Wetland

N. 07010206 Mississippi River - Twin Cities:

	Name	County	WID	Water Type
(1)	Amelia Lake	Anoka	02-0014-00	Lake
(2)	Carlos Avery WMA - Pool 13	Anoka	02-0520-00	Lake
(3)	Carlos Avery WMA - Pool 14	Anoka	02-0520-00	Lake
(4)	Rice Lake	Washington	82-0146-00	Lake

O. 07010207 Rum River:

	Name	County	WID	Water Type
(1)	Borden Lake	Crow Wing	18-0020-00	Lake
(2)	Camp Lake	Crow Wing	18-0018-00	Lake
(3)	Deer Lake	Aitkin	01-0086-00	Lake
(4)	German Lake	Isanti	30-0100-00	Lake
(5)	Hickey Lake	Anoka	02-0096-00	Lake
(6)	Holt Lake	Crow Wing	18-0029-00	Lake
(7)	Long Lake	Crow Wing	18-0031-00	Lake
(8)	Long Lake	Isanti	30-0056-00	Lake
(9)	Long Pond	Sherburne	71-0036-00	Lake
(10)	Mille Lacs	Mille Lacs	48-0002-00	Lake
(11)	Mille Lacs WMA - Korsness Pool 1	Mille Lacs	48-0035-00	Lake
(12)	Ogechie Lake	Mille Lacs	48-0014-00	Lake
(13)	Onamia Lake	Mille Lacs	48-0009-00	Lake

(14)	Pickerel Lake	Anoka	02-0130-00	Lake
(15)	Round Lake (Round-Rice Bed WMA)	Crow Wing	18-0032-00	Lake
(16)	Scott Lake	Crow Wing	18-0033-00	Lake
(17)	Shakopee Lake	Mille Lacs	48-0012-00	Lake
(18)	Smith Lake	Crow Wing	18-0028-00	Lake
(19)	Stanchfield Creek	Isanti	07010207-518	Stream
(20)	Swan Lake	Anoka	02-0098-00	Lake
(21)	Trott Brook	Anoka	07010207-680	Stream
(22)	Twelve Lake	Morrison	49-0006-00	Lake
(23)	Twenty Lake	Aitkin	01-0085-00	Lake
(24)	Unnamed lake	Anoka	02-0101-00	Lake
(25)	Whitefish Lake	Crow Wing	18-0001-00	Lake
(26)	Williams Lake	Crow Wing	18-0024-00	Lake

Subp. 7. **Minnesota River basin.** The Minnesota River basin includes all or portions of Big Stone, Blue Earth, Brown, Carver, Chippewa, Cottonwood, Dakota, Douglas, Hennepin, Faribault, Freeborn, Grant, Jackson, Kandiyohi, Lac qui Parle, Le Sueur, Lincoln, Lyon, Martin, McLeod, Murray, Nicollet, Otter Tail, Pipestone, Pope, Ramsey, Redwood, Renville, Rice, Scott, Sibley, Stearns, Steele, Stevens, Swift, Traverse, Waseca, Watonwan, and Yellow Medicine Counties. The waters in each of the major watersheds in the Minnesota River basin that are identified as class 4D are listed in items A to D.

A. 07020002 Pomme de Terre River:

	Name	**County**	**WID**	**Water Type**
(1)	Ina Lake	Douglas	21-0355-00	Lake
(2)	North Turtle Lake	Otter Tail	56-0379-00	Lake
(3)	South Turtle Lake	Otter Tail	56-0377-00	Lake
(4)	Spitzer Lake	Otter Tail	56-0160-00	Lake

(5)	Stalker Lake	Otter Tail	56-0437-00	Lake
(6)	Tamarack Lake	Otter Tail	56-0433-00	Lake

B. 07020005 Chippewa River:

	Name	**County**	**WID**	**Wetland**
(1)	Andrea Wetland	Kandiyohi	34-0652-00	Wetland
(2)	Blaamyhre Lake	Kandiyohi	34-0345-00	Lake
(3)	Glesne Slough Lake (unnamed)	Kandiyohi	34-0353-00	Lake
(4)	Ole Lake	Kandiyohi	34-0342-00	Lake
(5)	Signalness (Mountain) Lake	Pope	61-0149-00	Lake

C. 07020011 Le Sueur River:

	Name	**County**	**WID**	**Water Type**
(1)	Lily Lake	Waseca	81-0067-00	Lake
(2)	Spicer Lake	Freeborn	24-0045-00	Lake
(3)	Trenton Lake	Freeborn	24-0049-00	Lake

D. 07020012 Lower Minnesota River:

	Name	**County**	**WID**	**Water Type**
(1)	Blue Lake	Scott	70-0088-00	Lake
(2)	Fisher Lake	Scott	70-0087-00	Lake
(3)	Hatch Lake	Rice	66-0063-00	Lake
(4)	Rice Lake	Scott	70-0025-00	Lake

Subp. 8. **St. Croix River basin.** The St. Croix River basin includes all or portions of Aitkin, Anoka, Carlton, Chisago, Isanti, Kanabec, Mille Lacs, Pine, Ramsey, and Washington Counties. The waters in each of the major watersheds in the St. Croix River basin that are identified as class 4D are listed in items A to D.

A. 07030001 Upper St. Croix River:

	Name	County	WID	Water Type
(1)	Crooked Lake	Pine	58-0026-00	Lake
(2)	Hay Creek	Pine	07030001-511	Stream
(3)	Hay Creek flowage	Pine	58-0005-00	Lake
(4)	Riparian, stream wetland	Pine	07030001-549	Wetland

B. 07030003 Kettle River:

	Name	County	WID	Water Type
(1)	Bob Lake	Carlton	09-0026-00	Lake
(2)	Cedar Lake	Pine	58-0089-00	Lake
(3)	Fox Lake	Pine	58-0102-00	Lake
(4)	Grindstone River (south fork)	Pine	07030003-516	Stream
(5)	Kettle Lake	Carlton	09-0074-00	Lake
(6)	Kettle Lake	Carlton	09-0049-00	Lake
(7)	Kettle River	Pine	07030003-502	Stream
(8)	Kettle River	Carlton	07030003-511	Stream
(9)	Little Island Lake	Pine	58-0061-00	Lake
(10)	Little Kettle Lake	Carlton	09-0077-00	Lake
(11)	Little North Sturgeon Lake	Pine	58-0066-00	Lake
(12)	McCormick Lake	Pine	58-0058-00	Lake
(13)	Moose (Little) Lake	Carlton	09-0043-00	Lake
(14)	Moose Horn River	Carlton	07030003-531	Stream
(15)	Moosehead Lake	Carlton	09-0041-00	Lake
(16)	Pine Lake	Aitkin	01-0001-00	Lake
(17)	Sawyer WMA - unnamed pool	Carlton	09-0145-00	Lake
(18)	Sawyer WMA - Sterly Pool	Carlton	09-0187-00	Lake
(19)	Split Rock Lake	Aitkin	01-0002-00	Lake

(20)	Stanton Lake	Pine	58-0111-00	Lake
(21)	Unnamed lake (Southwest Torchlight)	Carlton	09-0027-00	Lake
(22)	Walli Lake	Carlton	09-0071-00	Lake
~~(23)~~	~~Wild Rice Lake~~	~~Carlton~~	~~09-0023-00~~	~~Lake~~
~~(24)~~ (23)	Willow River	Pine	07030003-504	Stream

C. 07030004 Snake River:

	Name	**County**	**WID**	**Water Type**
(1)	Ann Lake	Kanabec	33-0040-00	Lake
(2)	Ann riparian wetland	Kanabec	07030004-511	Riparian wetland
(3)	Dewitt Marsh Lake	Mille Lacs	48-0020-00	Lake
(4)	Ernst Pool Lake	Mille Lacs	48-0036-00	Lake
(5)	Mille Lacs WMA - Headquarters 2P	Mille Lacs	48-0044-03	Wetland
(6)	Mille Lacs WMA - Jones 1 Pool	Mille Lacs	48-0044-02	Wetland
(7)	Mille Lacs WMA - Olson Pool	Mille Lacs	48-0074-00	Wetland
(8)	Mille Lacs WMA - Townhall Pool	Mille Lacs	48-0078-00	Wetland
(9)	Mission Creek	Pine	07030004-547	Stream
(10)	Mud (Quamba) Lake	Kanabec	33-0015-00	Lake
(11)	Pokegama Creek	Pine	07030004-533	Stream
(12)	Pokegama Creek (Pokegama River)	Pine	07030004-533	Riparian, stream wetland
(13)	Pokegama Lake	Pine	58-0142-00	Lake
(14)	Snake River Bay	Pine	07030004-503	Stream
(15)	Unnamed lake (Pool 3)	Mille Lacs	48-0054-00	Lake
(16)	Unnamed lake	Mille Lacs	48-0043-00	Lake

(17)	Unnamed lake	Kanabec	33-0111-00	Lake
(18)	Upper Rice Lake	Isanti	30-0057-00	Lake

D. 07030005 Lower St. Croix River:

	Name	**County**	**WID**	**Water Type**
(1)	Carlos Avery WMA - Pool 1	Anoka	02-0505-00	Lake
(2)	Carlos Avery WMA - Pool 2	Anoka	02-0505-00	Lake
(3)	Carlos Avery WMA - Pool 3	Anoka	02-0505-00	Lake
(4)	Carlos Avery WMA - Pool 5	Anoka	02-0504-00	Lake
(5)	Carlos Avery WMA - Pool 7	Anoka	02-0497-00	Lake
(6)	Carlos Avery WMA - Pool 9	Anoka	02-0504-00	Lake
(7)	Carlos Avery - Pool 9 (2)	Anoka	02-0508-00	Lake
(8)	Carlos Avery WMA - Pool 22	Anoka	02-0029-00	Lake
(9)	Carlos Avery WMA - Pool 24	Anoka	02-0496-00	Lake
(10)	Carlos Avery WMA - Pool 26	Anoka	02-0029-00	Lake
(11)	Carlos Avery WMA - Mud Lake	Chisago	13-0059-02	Lake
(12)	Carlos Avery WMA - North Sunrise Pool	Chisago	13-0059-03	Lake
(13)	Carlos Avery WMA - Peterson Slough	Chisago	13-0060-00	Lake
(14)	Carlos Avery WMA - South Sunrise Pool	Chisago	13-0059-01	Lake
(15)	Little Coon Lake	Anoka	02-0032-00	Lake

Subp. 9. **Lower Mississippi River basin.** The lower Mississippi River basin includes all or portions of Blue Earth, Dakota, Dodge, Faribault, Fillmore, Freeborn, Goodhue, Houston, Le Sueur, Mower, Olmsted, Rice, Scott, Steele, Wabasha, Waseca, Washington, and Winona Counties. The waters in each of the major watersheds in the lower Mississippi River basin that are identified as class 4D are listed in items A to F.

A. 07040001 Mississippi River - Lake Pepin:

Name	County	WID	Water Type
Sturgeon Lake	Goodhue	25-0017-01	Lake

B. 07040002 Cannon River:

	Name	County	WID	Water Type
(1)	Cedar Lake	Rice	66-0052-00	Lake
(2)	Everson Lake	Waseca	81-0027-00	Lake
(3)	Hunt Lake	Rice	66-0047-00	Lake
(4)	Mud Lake	Rice	66-0054-00	Lake
(5)	Oak Glen Lake	Steele	74-0004-00	Lake
(6)	Weinberger Lake	Rice	66-0041-00	Lake
(7)	Willing Lake	Rice	66-0051-00	Lake

C. 07040003 Mississippi River - Winona:

	Name	County	WID	Water Type
(1)	Maloney Lake	Wabasha	79-0001-03	Lake
(2)	Mississippi River Pool 4 (Robinson Lake)	Wabasha	79-0005-02	Lake
(3)	Mississippi River Pool 5 (Spring Lake)	Wabasha	07040003-627	Stream
(4)	Unnamed lake (McCarthy Lake WMA)	Wabasha	79-0052-00	Lake

D. 07040004 Zumbro River:

Name	County	WID	Water Type
Rice Lake	Steele	74-0001-00	Lake

E. 07040006 Mississippi River - La Crescent:

	Name	County	WID	Water Type
(1)	Blue Lake	Houston	28-0005-03	Lake
(2)	Target Lake	Houston	28-0005-02	Lake

F. 07060001 Mississippi River - Reno:

	Name	County	WID	Water Type
(1)	Lawrence Lake	Houston	28-0005-01	Lake
(2)	Mississippi River backwater	Houston	28-0005-00	Wetland
(3)	Mississippi River Pool 8	Houston	28-0005-99	Stream

7053.0135 GENERAL DEFINITIONS.

[For text of subps 1 and 2, see M.R.]

Subp. 2a. **Annual average ten-year low flow or $365Q_{10}$.** "Annual average ten-year low flow" or "$365Q_{10}$" has the meaning given in part 7050.0130, subpart 2a.

[For text of subps 3 to 10, see M.R.]

7053.0205 GENERAL REQUIREMENTS FOR DISCHARGES TO WATERS OF THE STATE.

[For text of subps 1 to 6, see M.R.]

Subp. 7. **Minimum stream flow.**

A. Except as provided in items B, C, and E, discharges of sewage, industrial waste, or other wastes must be controlled so that the water quality standards are maintained at all stream flows that are equal to or greater than the $7Q_{10}$ for the critical month or months.

[For text of items B to D, see M.R.]

E. Discharges of sulfate in sewage, industrial waste, or other wastes must be controlled so that the sulfate water-quality standard for wild rice is maintained as specified in part 7050.0224, subpart 5. When determining reasonable potential and calculating effluent limits, the flow rate for receiving water is the $365Q_{10}$ flow.

[For text of subps 8 to 13, see M.R.]

7053.0406 REQUIREMENTS FOR FACILITIES DISCHARGING TO WILD RICE WATERS.

~~Subpart 1.~~ ~~**No effluent limit required based on site-specific conditions.**~~ ~~If the commissioner determines that, based on the location of the discharge in the wild rice water or site-specific hydraulic or substrate conditions, the effluent will not affect the class 4D wild rice beneficial use in the wild rice water, the commissioner must not establish a water-quality-based effluent limitation for the class 4D sulfate in that discharge.~~

~~Subp. 2.~~ ~~**Variances.**~~

A. A permit applicant may apply for a variance from the sulfate standard for wild rice ~~and associated water-quality-based effluent limit (WQBEL),~~ as specified in parts 7000.7000, 7050.0190, 7052.0280, and 7053.0195, as applicable.

~~B.~~ ~~The commissioner must base the determination of widespread economic and social effect on the procedures established in Interim Economic Guidance for Water Quality Standards, EPA-823-B-95-002 (March 1995 and as subsequently amended), which is incorporated by reference, is not subject to frequent change, and is available at https://www.epa.gov/wqs-tech/economic-guidance-water-quality-standards.~~

~~C~~ B. Publicly owned wastewater treatment plants are exempt from the variance fee requirement under part 7002.0253.

REFERENCE CHANGE. The range reference "7050.0400 to 7050.0470 " is changed to "7050.0400 to 7050.0471 " in Minnesota Rules, parts 7050.0110, 7050.0440, and 7053.0225.

ATTACHMENT 9

SF-00006-05(4/86)

DEPARTMENT: POLLUTION CONTROL AGENCY

STATE OF MINNESOTA

Office Memorandum

DATE: January 19, 1999

TO: Minnesota Pollution Control Agency Board Water Quality Committee

FROM: Marvin E. Hora, Manager
Environmental Research and Reporting
Environmental Outcomes Division

PHONE: 296-7201

SUBJECT: Proposed Revisions of Minn. Rules ch. 7050

The scope of proposed amendments to Minn. R. ch. 7050 has been narrowed following recent decisions by the Environmental Research and Reporting Section to postpone revising the state-wide ammonia and silver standards. The purpose of this memorandum is to outline the full scope of the proposed revisions, and to present a revised schedule for the completion of rulemaking. The proposed changes include those based on recommendations from the Water Quality Standards Advisory Committee (WQSAC) and several items not dealt with by the WQSAC (see Table 1). The proposed limited resource value water reaches (Class 7) are listed in Attachment 1, and all the proposed housekeeping changes are listed in Attachment 2.

It is proposed to adopt these amendments through the non-controversial rulemaking process; that is, promulgation of the changes without a public hearing. If successful, the non-controversial approach should shorten the rulemaking process by two, possibly three, months.

We feel the non-controversial approach is feasible in this instance because none of the items being proposed is innately controversial on a state-wide basis. Most of the items with the potential to become controversial were discussed by the WQSAC and reflect a consensus recommendation from that committee. Thus, there has been considerable public input into these items already. Consensus in this context means no one on the committee was opposed to the recommendation (no one or two finger votes in the five-finger voting protocol). Also, none of the proposed changes will result in increased treatment or operational and maintenance costs to dischargers. In fact, the proposal to shorten the fecal coliform standard season by one month will result in immediate savings for all dischargers that disinfect their wastewater on a seasonal basis. Other proposed changes, such as the switch to dissolved metal standards and the site-specific language for the dissolved oxygen standard, could mean savings for some dischargers in the future.

In the case of the Class 2B/C (warm water fish) dissolved oxygen (DO) standard, no proposal before the WQSAC received consensus support from the committee. However, based on the extensive discussions, including information provided by Dr. Gary Chapman, national DO expert and author of the EPA national DO criterion, the MPCA is proposing to add site-specific language to the existing standard. This will reinforce but limit in the case of the DO standard what the rule already allows, which is the modification of any standard on a site-specific basis. The site-specific DO standard would be a 5 mg/L daily average and 4 mg/L daily minimum DO standard during those times of the year when sensitive early life stages are not present in the receiving stream. The current year-round DO standard of 5 mg/L as a daily minimum is not proposed to be changed; and, it will be in effect at all locations regardless of whether or not there is a site-specific standard, during the times of the year when early life stages are present. The site-specific DO standard as described above is consistent with the EPA national DO criterion.

Of the proposed non-WQSAC changes shown in Table 1, two items stand out as having a higher priority. The first of these is the adoption of new limited resource value (Class 7) waters (see Attachment 1). The second is the proposal to change the averaging period for the total phosphorus effluent limit (Minn. R. pt. 7050.0211, subp. 1) from a monthly mean to an averaging period of up to one year.

The list of trout (Class 2A) waters was not updated during the last rulemaking and updating the list now should not be controversial. The change to the industrial design flow will not impact permit limits and also should not be controversial.

Table 1. Proposed Changes to Minn. R. ch. 7050.

ITEMS	PROPOSED CHANGE
Recommendations from WQSAC	
Trace metal standards	Change from total to dissolved standards
Mercury standard	Label mercury and all Class 2 standards as to basis (aquatic life toxicity or human health-based)
Chlorine standard	Update to agree with EPA criterion
Fecal coliform standard	Change season the standard is in effect from March-October to April-October
Tier II standards	Update eight standards using new GLI* method
Tier II method in pt. 7050.0218, subp. 5	Update state-wide Tier II method to agree with new GLI* method in Minn. R. ch. 7052
Stream design flow in pt. 7050.0210, subp. 7	Use 30Q10 rather than 7Q10 for ammonia
Proposal on which WQSAC was Divided	
Dissolved oxygen standard	Allow seasonal site-specific modifications from 5 mg/L min. standard to 5 mg/L avg./4 mg/L min.
Non-WQSAC	
Class 7, limited resource value waters	Ten proposed reclassifications (Attachment 1)
Class 2A, trout waters	Update list of trout streams and lakes to agree with latest list from MDNR
Design flow for industries in pt. 7050.0185, subp. 5	Clarify design flow for industrial discharges used to establish trigger for nondegradation for all waters
Phosphorus effluent limit in pt. 7050.0211, subp. 1	Provide flexibility in setting averaging period for limit
Housekeeping changes	Non-substantive corrections and clarifications (Attachment 2)

*GLI = Great Lakes Initiative (Minn. R. ch. 7052)

Adoption of the proposed amendments should be attainable in the time frame shown in Table 2. This is about four months behind the rulemaking schedule originally given to the WQSAC last spring and to the Board Water Quality Committee in July, 1998.

Table 2. Proposed Schedule for Rulemaking

Date, 1997	Activity
December	Last regular WQSAC meeting
Date, 1998	**Activity**
April	Final report from WQSAC to MPCA
October	Second WQSAC meeting on ammonia criteria and standards; last WQSAC meeting for foreseeable future
November	Revision of state-wide ammonia and silver standards postponed; proposed scope of amendments finalized
Date, 1999	**Activity**
January	Solicit outside public comments on proposed amendments in *State Register* (second notice)
January	Draft rule language
April	Complete SONAR and other supportive materials, including potential economic impacts
May	Publish proposed rule and hearing notice in *State Register*, 30-day
July	[Public hearings if necessary - receive Administrative Law Judge's report in September 1999]
August	Request MPCA Board approval of amendments - non-controversial [November 1999 if hearing is necessary]
October	Final rule - non-controversial [December 1999 if hearing is necessary]

MEH:jmg

Attachments

Attachment 1.

List of Waters Proposed for Class 7 Reclassification

1. Branch No. 3, Lateral No. 2 of County Ditch 67 and 13 at East Bethel, Anoka Co. (Note: the alternate name for Co. Ditch 67 and 13 is Crooked Brook. No portion of this watercourse is being proposed by MPCA staff for Class 7 reclassification.)

2. Trout Brook, at St. Paul, Ramsey Co.

3. Unnamed Ditch, near Owatonna, Steele Co.

4. Unnamed Ditch and County Ditch No. 37 near Renville, Renville Co.

5. Unnamed Ditch and High Island Ditch, near Arlington, Sibley Co.

6. County Ditch No. 17, near St. Cloud, Stearns Co.

7. Unnamed Creek, Laketown Township, Carver Co.

8. Lateral 5 of Judicial Ditch No. 3, at Green Isle, Sibley Co.

9. County Ditch No. 28, near Ham Lake, Anoka Co.

10. Unnamed Ditch and Unnamed Creek near Blooming Prairie, Steele Co. (Note: The unnamed ditch drains to the unnamed creek. Only a short segment of the unnamed creek is being proposed for Class 7 reclassification. The total length of what would be classified as a Class 7 water from the point of discharge would be just under 0.5 river miles.)

Attachment 2.

List of all the Proposed Housekeeping Changes in Order of Their Appearance in the Rule

1. Minn. R. pt. 7050.0185, subp. 4. Revise.
   Current wording: "...the costs of additional treatment beyond what is required of non-significant dischargers..."
   Proposed new wording: "...the costs of additional treatment beyond what is required in subp. 3..."

2. Minn. R. pt. 7050.0185, subp. 5. Revise
   Current wording: If the discharge is sewage or industrial waste, the flow rate used to determine significance under this part is the design average wet weather flow for the wettest 30-day period.
   Proposed new wording: no specific wording available but intent is to clarify design flows used to establish significance for industrial and other discharges that trigger a nondegradation review for all waters.

3. Minn. R. pt. 7050.0210, subp. 12. Revise
   Current wording: Liquid substances "... shall be stored in accordance with parts 7100.0010 to 7100.0090, and any revisions or amendments thereto."
   Proposed new wording: Liquid substances "... shall be stored in accordance with ch. 7151."

4. Minn. R. pt. 7050.0213. Insert after the five-day CBOD limit of 5 mg/L, a new paragraph as follows: "This limit shall not apply to discharges to surface waters classified as limited resource value waters pursuant to parts 7050.0200, subpart 8, and 7050.0400 to 7050.0470." Delete the last sentence in this part: "This section shall not apply to discharges to surface waters classified as limited resource value waters pursuant to parts 7050.0200, subpart 8, and 7050.0400 to 7050.0470."

5. Minn. R. pt. 7050.0214, subp. 1. Add to the beginning of the footnote: "This limit shall not apply to Class 7 waters if the principal method of wastewater treatment is through stabilization ponds or aerated ponds, in which case the limitations in parts 7050.0211, subp. 3 and 7050.0212, subp. 5 shall apply".

6. Minn. R. pt. 7050.0220. Reformat tables of standards in 64 character width maximum, and move the title of Minn. R. pt. 7050.0220, subp. 6. to above the table to be consistent with the style used for the other tables in this part. [Note: If reformatting consistent with the Revisor's Office word processing limitations is not possible, the tables will be left as is]

7. Minn. R. pt. 7050.0220. Add to note no. 8 (silver) for Class 2A waters: "the MS and the FAV shall be no less than 0.12 ug/l".

8. Minn. R. pt. 7050.0220 and pt 7050.0222. Add "*" after the "none" listed for the MSs and FAVs in tables in

   Di-2-ethylhexyl phthalate
   Hexachlorobenzene
   Vinyl chloride

   Minn. R. pt. 7050.0222, subp. 7 item E. Add language to the effect; "...or if there is no MS and FAV...".

9. Minn. R pt. 7050.0220, subp. 6. Delete the aquatic life chronic chloride standard of 230 mg/L listed for Class 7 waters.

10. Minn. R. pt. 7050.0221, subp. 4. Revise the ending to the first sentence.
    Current wording: "...and the turbidity standard shall be 25 mg/l."
    Proposed new wording: "...and the turbidity standard shall be 25 NTU."

11. Minn. R. pt. 7050.0222. Add "CS", "MS" and "FAV" over the examples of metal toxicity with a hardness relationship in various locations.

12. Minn. R. pt. 7050.0222, subp. 4. Correct omission in the hardness equation for the silver FAV and MS.
    Current wording.
    The MS shall not exceed: exp. (1.72 [ln(total hardness and
    The FAV shall not exceed: exp. (1.72 [ln (total hardness mg/l)]-6.52) provided that the MS and FAV shall be no less than 1.0 ug/l.
    Proposed new wording.
    The MS shall not exceed: exp. (1.72 [ln (total hardness mg/l)]-7.2156) and
    The FAV shall not exceed: exp (1.72[ln (total hardness mg/l)]-6.52) provided that the MS and FAV shall be no less than 1.0 ug/l.

13. Minn. R. pt. 7050.0224, subp. 2 . Add "at 25 degrees C" to the specific conductance standard of 1000 micromhos per centimeter.

14. Minn. R. pt. 7050.0224, subp. 2. Revise title:
    Current wording: "Class 4 waters; agriculture and wildlife."
    Proposed new wording: "Class 4A waters."

15. Minn. R. parts 7050.0220, subp. 6 (note # 2) and 7050.0227, subp. 2. Change "logarithmic mean to geometric mean for the fecal coliform standard, to be consistent with other parts of the rule.

16. Minn. R. pt. 7050.0420. Revise last sentence.
    Current wording: "All trout waters are classified as Class 1B, 2A, 3B, 3C, 4A, 4B, 5 and 6 waters."
    Proposed new wording: "All waters listed in part 7050.0470 as Class 1B, 2A, and 3B waters are also classified as Class 3C, 4A, 4B, 5 and 6."

17. Minn. R. pt. 7050.0470, subp. 1, item A. (125). Add alternative name to entry.
    Current wording: Leppanen Creek
    Proposed new wording: Leppanen Creek (Leskinen Creek)

18. Minn. R. pt. 7050.0470, subp. 1, item A. (163). Revise entry name.
    Current wording: Nicadoo Creek
    Proposed new wording: Nicado Creek

19. Minn. R. pt. 7050.0470, subp. 3, item A. (11) and (68) Add cross references.
    Current wording: (11) County Ditch No. 6A-2, Rothsay and (68) Unnamed Creek, Rothsay
    Proposed change: add " see subitem 68; and see subitem 11 to the respective entries.

20. Minn. R. pt. 7050.0470, subp. 4, item A. (109) (110). *Mississippi River. Add to the description: "... applies to those portions of the Mississippi River from Lake Itasca to the southerly boundary of Morrison County that are included in the January 1981 Management Plan for the Upper Mississippi River adopted by the Mississippi Headwaters Board on February 12, 1981." This will make the description consistent with pt. 7050.0180, subp. 6, item B.

21. Minn. R. pt. 7050.0470, subp. 5, item A. (73) Revise entry name.
    Current wording: Hazel Run
    Proposed new wording: Hazel Creek (County Ditch No. 9). Also add cross reference entry for County Ditch No. 9.

22. Minn. R. pt. 7050.0470, subp. 5, item B. (15) Add alternative entry name.
    Current wording: Unnamed swamp
    Proposed new wording: Unnamed swamp (Skauby Lake)

23. Minn. R. 7050.0470, subp. 6, item A. (17). Kettle River. Change the location reference point from the dam to appropriate Twp/Range/Sec., because the dam no longer exists.

24. Minn. R. pt. 7050.0470, subp. 7, item A (62) Clarify location of watercourse. This trout stream is not shown on the USGS quad map.
    Current wording: (62) Hamilton Creek, (T.103, R.13, S.6; T.103, R.14, S.1
    Proposed new wording: (62) Hamilton Creek, (T.103, R.13, NW1/4 S.6; T.103, R.14,NE1/4 S.1

25. Minn. R. pt. 7050.0470, subp. 7, item A (56). Revise
    Current wording: "R.8, R.14."
    Proposed new wording: "R.8, S.14."

26. Minn. R. pt. 7050.0470, subp. 8, item A (21) Add alternative entry name.
    Current wording: Soldier Creek
    Proposed new wording: Soldier Creek (unnamed stream and Co. Ditch No. 53). Also, add cross reference entries.

The following housekeeping changes can only be accomplished after the rule is finalized because they are affected by the final format of the rule.

1. Minn. R. ch. 7050. Add table of contents.

2. Minn. R. pt. 7050.0222. Correct the headings at the top of each page in the table of Class 2 standards.

3. Minn. R. pt. 7050.0466, Map. Add page numbers in each watershed for the beginning page in pt. 7050.0470 of the listings of waters for that watershed. Increase the size of the county names.

4. Minn. R. pt. 7050.0470. Add to the top of each page of pt. 7050.0470 the name of the watershed, such as, "Lake Superior Basin, continued"

(18) Odor - Units: TON

2A CS	2A MS	2A FAV	1B DC	3A/3B IC	4A IR	4B LS	5 AN
-	-	-	3(S)	-	-	-	-

(19) Oil - Units: µg/l

2A CS	2A MS	2A FAV	1B DC	3A/3B IC	4A IR	4B LS	5 AN
500	5000	10000	-	-	-	-	-

(20) pH, low - Units: su

6.5	none	none	6.5(S)	6.5/6.0	6.0	6.0	6.0
2A	**2A**	**2A**	**1B**	**3A/3B**	**4A**	**4B**	**5**
CS	**MS**	**FAV**	**DC**	**IC**	**IR**	**LS**	**AN**

(21) pH, high - Units: su

2A CS	2A MS	2A FAV	1B DC	3A/3B IC	4A IR	4B LS	5 AN
8.5	none	none	8.5(S)	8.5/9.0	8.5	9.0	9.0

(22) Radioactive materials - See Note No. 2 below

(23) Salinity, total - Units: mg/l

2A CS	2A MS	2A FAV	1B DC	3A/3B IC	4A IR	4B LS	5 AN
-	-	-	-	-	-	1000	-

(24) Sodium - Units: meq/l

2A CS	2A MS	2A FAV	1B DC	3A/3B IC	4A IR	4B LS	5 AN
-	-	-	-	-	60% of total cations	-	-

(25) Sulfate - Units: mg/l

2A CS	2A MS	2A FAV	1B DC	3A/3B IC	4A IR	4B LS	5 AN
-	-	-	250(S)	-	-	-	-

(26) Sulfates, wild rice present - Units: mg/l

2A CS	2A MS	2A FAV	1B DC	3A/3B IC	4A IR	4B LS	5 AN
-	-	-	-	-	10	-	-

(27) Specific conductance, at 25°C - Units: µmhos/cm

2A CS	2A MS	2A FAV	1B DC	3A/3B IC	4A IR	4B LS	5 AN
-	-	-	-	-	1000	-	-

(28) Temperature - Units: °F - No material increase

(29) Total dissolved salts - Units: mg/l

2A CS	2A MS	2A FAV	1B DC	3A/3B IC	4A IR	4B LS	5 AN
-	-	-	-	-	700	-	-

(30) Total dissolved solids - Units: mg/l

2A CS	2A MS	2A FAV	1B DC	3A/3B IC	4A IR	4B LS	5 AN
-	-	-	500(S)	-	-	-	-

(31) Turbidity - Units: NTU

2A CS	2A MS	2A FAV	1B DC	3A/3B IC	4A IR	4B LS	5 AN
10	none	none	1-5	-	-	-	-

B. METALS AND ELEMENTS SUBSTANCE OR CHARACTERISTIC

4/18/1994' SR Adopt: Year

ATTACHMENT 10

STATE OF MINNESOTA
POLLUTION CONTROL AGENCY

18 SR 2195

IN THE MATTER OF THE PROPOSED REVISIONS TO THE RULES GOVERNING THE CLASSIFICATION AND STANDARDS FOR WATERS OF THE STATE, MINNESOTA RULES CHAPTER 7050

STATEMENT OF NEED AND REASONABLENESS

April 27, 1993

ATTACHMENT 10

A few drinking water standards are relevant to ground water but not to the raw surface water supplies. These standards, fecal coliform bacteria and two water treatment additives, are not included in the tables. The current rule addresses this situation for fecal coliform by including the term "bacteriological standard" in the standards normally restricted to ground waters (Class 1A), but excludes the bacteriological standard from the subclasses that include surface waters (Classes 1B through 1D). The total coliform bacteria standard is excluded by the purposeful omission of "bacteriological standards" in the last line in part 7050.0220, subpart 2, item B which reads: "The physical and chemical standards quoted above for Class 1A waters shall also apply to these [Class 1B] waters in the untreated state". No surface waters are classified 1A currently. Therefore, the total coliform standard does not currently apply to surface waters protected for drinking, and it is not included in the proposed tables under Class 1.

Two water treatment additives have EPA drinking water standards which are not in the tables. These chemicals, acrylamide and epichlorohydrin, may be added to the water as part of the treatment process before it is distributed to the consumer. These chemicals are not likely to be found in the raw surface water supplies.

The primary drinking water standards for copper and lead consist of required treatment techniques including corrosion control treatment, source water treatment, lead service line replacement, and public education rather than the usual numbers. These treatment standards for copper and lead are not included in the tables.

The EPA drinking water standards for radioactivity are excluded from the tables due to the space limitations.

Two pollutants, fluoride and hexachlorocyclopentadiene, have both primary and secondary drinking water standards. In both cases the secondary standard is the lower of the two standards and the lower secondary standard would be the applicable standard for compliance and enforcement purposes. The primary standards are listed to be complete and for the benefit of the reader.

Should any discrepancy occur between a standard listed in the proposed tables (part 7050.0220, subparts 3 through 6) and the standards listed under each use class separately (parts 7050.0221 through 7050.0227), the latter, class by class listings of standards, will be considered the correct standards for application and compliance determinations. This includes the drinking water standards in the Code of Federal Regulations.

R. Part 7050.0221 SPECIFIC STANDARDS OF QUALITY AND PURITY FOR CLASS 1 WATERS OF THE STATE, DOMESTIC CONSUMPTION.

This part was created from part 7050.0220 as follows:

Proposed rules	Current rules
Subpart 2	7050.0220, subpart 2, item A
Subpart 3	7050.0220, subpart 2, item B
Subpart 4	7050.0220, subpart 2, item C

Water quality standards applicable to use Classes 1B, 2A, 3A or 3B, 4A and 4B, and 5 continued.

SUBSTANCE OR CHARACTERISTIC	UNITS	STANDARDS FOR USE CLASSES							
		2A CHRONIC	2A MAXIMUM	2A FAV	1B DRINKING WATER	3A/3B INDUST. CONSUMPT.	4A IRRIGA-TION	4B LIVESTOCK	5 AESTHETIC
MISCELLANEOUS continued									
Sulfate	mg/l				250(S)				
Sulfates, wild rice present	mg/l						10		
Specific conductance	umhos/cm						1000		
Temperature	F	no material increase							
Total dissolved salts	mg/l						700		
Total dissolved solids	mg/l				500(S)				
Turbidity	NTUs	10	none	none	1-5				
METALS AND ELEMENTS									
Aluminum	ug/l	87	748	1496	50-200(S)				
Antimony	ug/l	5.5	90	180	6				
Arsenic	ug/l	2.0	360	720	50				
Barium	ug/l				2000				
Beryllium	ug/l				4.0				
Boron	ug/l						500		
Cadmium	ug/l	See note No. 3 below			5				
Chromium, +3	ug/l	See note No. 4 below							
Chromium, +6	ug/l	11	16	32					
Chromium, total	ug/l				100				
Cobalt	ug/l	2.8	436	872					
Copper	ug/l	See note No. 5 below			1000(S)				
Iron	ug/l	~~221~~	~~243~~	~~485~~	300(S)				
Lead	ug/l	See note No. 6 below							
Manganese	ug/l	~~138~~	~~4643~~	~~9285~~	50(S)				
Mercury	ug/l	0.0069	2.4*	4.9*	2				
Nickel	ug/l	See note No. 7 below			100				

Approved
by Revisor ______________

MINNESOTA
OFFICE OF ADMINISTRATIVE HEARINGS

PO Box 64620
Saint Paul, MN 55164-0620
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PH (651) 361-7900
TTY (651) 361-7878
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January 10, 2018

VIA EFILING ONLY
Carol Nankivel
Minnesota Pollution Control Agency
Resource Management and Assistance
Division
520 Lafayette Rd N
Saint Paul, MN 55155
carol.nankivel@state.mn.us

Re: ***In the Matter of the Amendment of the Sulfate Water Quality Standard Application to Wild Rice and Identification of Wild Rice Waters***
OAH 80-9003-34519; Revisor R-4324

Dear Ms. Nankivel:

Enclosed please find the Report of the Chief Administrative Law Judge in the above-entitled matter and the Report of Administrative Law Judge LauraSue Schlatter. The Agency may resubmit the rule to the Chief Administrative Law Judge for review after changing it, or may request that the Chief Administrative Law Judge reconsider the disapproval.

If the Agency chooses to resubmit the rule to the Chief Administrative Law Judge for review after changing it, or request reconsideration, the Agency must file the documents required by Minn. R. 1400.2240, subps. 4 and 5.

If you have any questions regarding this matter, please contact Katie Lin at (651) 361-7911 or katie.lin@state.mn.us.

Sincerely,

LauraSue Schlatter

LAURASUE SCHLATTER
Administrative Law Judge

Enclosure
cc: Office of the Governor
Office of the Revisor of Statutes
Legislative Coordinating Commission

MINNESOTA
OFFICE OF ADMINISTRATIVE HEARINGS

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January 11, 2018

Representative Tim O'Driscoll
Chair
Committee on Government Operations
and Elections Policy
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100 Rev. Dr. Martin Luther King Jr. Blvd.
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rep.tim.odriscoll@house.mn

Senator Mary Kiffmeyer
Chair
State Government Finance and Policy
and Elections Committee
95 University Avenue W
Minnesota Senate Bldg Room 3103
St. Paul, MN 55155
sen.mary.kiffmeyer@senate.mn

Re: In the Matter of the Amendment of the Sulfate Water Quality Standard Application to Wild Rice and Identification of Wild Rice Waters
OAH 80-9003-34519; Revisor R-4324

Dear Representative O'Driscoll and Senator Kiffmeyer:

Pursuant to Minn. Stat. § 14.26, the Office of Administrative Hearings is required to send to the legislative policy committees with primary jurisdiction over state governmental operations a copy of the statement of reasons for disapproval of agency rules. Enclosed please find the Report of the Chief Administrative Law Judge and Administrative Law Judge LauraSue Schlatter's Report on review of rules and memorandum for the above-referenced rules.

Under Minnesota law, the Agency may resubmit the rule to the Chief Administrative Law Judge for review after changing it, or may request that the Chief Administrative Law Judge reconsider the disapproval. If the Agency does not wish to follow the suggested actions of the Chief Administrative Law Judge to correct the defects found, the Agency may follow the process outlined in Minn. Stat. § 14.26, subd. 3(c).

Sincerely,

KATIE J. LIN
State Program Administrator Intermediate
Telephone: (651) 361-7911

Enclosure
cc: Carol Nankivel

STATE OF MINNESOTA
OFFICE OF ADMINISTRATIVE HEARINGS
ADMINISTRATIVE LAW SECTION
PO BOX 64620
600 NORTH ROBERT STREET
ST. PAUL, MINNESOTA 55164

CERTIFICATE OF SERVICE

In the Matter of the Amendment of the Sulfate Water Quality Standard Application to Wild Rice and Identification of Wild Rice Waters	OAH Docket No. 80-9003-34519 R-4324

Lisa Armstrong certifies that on January 11, 2018, she served a true and correct copy of the attached **REPORT OF THE CHIEF ADMINISTRATIVE LAW JUDGE** and **REPORT OF THE ADMINISTRATIVE LAW JUDGE** by courier service, by placing it in the United States mail with postage prepaid, or by electronic mail, as indicated below, addressed to the following individuals:

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OAH 80-9003-34519
Revisor R-4324

STATE OF MINNESOTA
OFFICE OF ADMINISTRATIVE HEARINGS

In the Matter of the Proposed Rules of the Pollution Control Agency Amending the Sulfate Water Quality Standard Applicable to Wild Rice and Identification of Wild Rice Rivers, Minnesota Rules parts 7050.0130, 7050.0220, 7050.0224, 7050.0470, 7050.0471, 7053.0135, 7053.0205, and 7053.0406

REPORT OF THE CHIEF ADMINISTRATIVE LAW JUDGE

This matter came before the Chief Administrative Law Judge pursuant to the provisions of Minn. Stat. § 14.15, subd. 3 (2016), and Minn. R. 1400.2240, subp. 4 (2017). These authorities require that the Chief Administrative Law Judge review an Administrative Law Judge's findings that a proposed agency rule should not be approved.

Based upon a review of the record in this proceeding, the Chief Administrative Law Judge agrees with and hereby **CONCURS** with all disapprovals contained in the Report of the Administrative Law Judge dated January 9, 2018.

1. The Chief Administrative Law Judge **CONCURS** that the following proposed rules are **DISAPPROVED:**

a. Proposed **Minn. R. 7050.0220, subps. 3a, 4a, 5a, 6a**
b. Proposed **Minn. R. 7050.0224, subp. 2**
c. Proposed **Minn. R. 7050.0224, subp. 5, A**
d. Proposed **Minn. R. 7050.0224, subp. 5, B (1)**
e. Proposed **Minn. R. 7050.0224, subp. 5, C**
f. Proposed **Minn. R. 7050.0224, subp. 6**
g. Proposed **Minn. R. 7050.0471, subps. 3 through 9**

2. The following changes to rules as originally proposed are **DISAPPROVED:**

a. Proposed changes to **Minn. R. 7050.0224, subp. 5, B (1)**
b. Proposed changed to **Minn. R. 7050.0224, subps. 5, E, F**

c. Proposed changes to **Minn. R. 7050.0224, subp. 5, B (2)**

The changes or actions necessary for approval of the disapproved rules and repeals are as identified in the Administrative Law Judge's Report.

If the Department elects not to correct the defects associated with the repeal of the existing rules and the defects associated with the proposed rules, the Department must submit the proposed rules to the Legislative Coordinating Commission and the House of Representatives and Senate policy committees with primary jurisdiction over state governmental operations, for review under Minn. Stat. § 14.15, subd. 4 (2016).

Dated: January 11, 2018

TAMMY L. PUST
Chief Administrative Law Judge

OAH 80-9003-34519
Revisor R-4324

STATE OF MINNESOTA
OFFICE OF ADMINISTRATIVE HEARINGS

In the Matter of the Proposed Rules of the Pollution Control Agency Amending the Sulfate Water Quality Standard Applicable to Wild Rice and Identification of Wild Rice Rivers, Minnesota Rules parts 7050.0130, 7050.0220, 7050.0224, 7050.0470, 7050.0471, 7053.0135, 7053.0205, and 7053.0406

REPORT OF THE ADMINISTRATIVE LAW JUDGE

Administrative Law Judge LauraSue Schlatter conducted several public hearings on this rulemaking proceeding at various locations throughout the state. The hearings were held on the following dates at the following locations: the Harold Stassen Building in St. Paul, Minnesota, on October 23, 2017; the Mesabi Range College in Virginia, Minnesota, on October 24, 2017; Bemidji State University in Bemidji, Minnesota, on October 25, 2017; the Fond du Lac Tribal Community College in Cloquet, Minnesota, on October 26, 2017; and Central Lakes Community College in Brainerd, Minnesota, on October 30, 2017. Judge Schlatter held an additional hearing at the offices of the Minnesota Pollution Control Agency (MPCA or Agency) in St. Paul, Minnesota, on November 2, 2017. This hearing was also broadcast via interactive video conference to the MPCA's regional offices in Detroit Lakes, Duluth, Mankato, Marshall, and Rochester. All of the hearings continued until everyone present had an opportunity to be heard concerning the proposed rules.[1]

The MPCA proposes to amend the rules governing Minnesota's water quality standard to protect wild rice from excess sulfate. The existing standard limits sulfate to 10 milligrams per liter in water used for the production of wild rice. The proposed amendments would establish an equation to determine the protective level of sulfate in each "wild rice water" based on the concentration of iron and organic carbon in the sediment. When sulfate in the water interacts with iron and organic carbon in the sediment, they can form sulfide, which the MPCA has determined is toxic to wild rice.[2] The proposed rules would limit sulfide in the sediment of a wild rice water to 120 micrograms per liter; identify approximately 1,300 lakes, rivers, and streams as wild rice waters; establish a process for the future identification of wild rice waters; and describe

[1] Throughout this Report, the terms "rule" and "rules," as well as the terms "standard" and "standards," are used interchangeably and in a manner intended to reflect typical usage while encompassing the fact that the rulemaking proceeding addresses a proposed rule made up of various identified parts.
[2] Ex. D (SONAR) at 12.

the sampling and analytical methods to characterize sediment and determine porewater sulfide.[3]

The public hearings and this Report are part of a rulemaking process governed by the Minnesota Administrative Procedure Act.[4] The Minnesota Legislature designed the rulemaking process to ensure that state agencies meet all of the requirements that Minnesota law specifies for adopting rules.[5] The rulemaking process also includes a hearing when 25 or more persons request one or when ordered by the agency.[6]

The hearings were conducted to allow the Agency representatives and the Administrative Law Judge reviewing the proposed rules to hear public comment regarding the impact of the proposed rules and what changes might be appropriate.[7] Further, the hearing process provided the general public an opportunity to review, discuss, and critique the proposed rules.

The Agency must establish that the proposed rules are within the Agency's statutory authority; necessary and reasonable; follow from compliance with the required procedures; and that any modifications that the Agency made after the proposed rules were initially published in the *State Register* are within the scope of the matter that was originally announced.[8]

Adonis Neblett, General Counsel, represented the MPCA at the hearing. The members of the MPCA's hearing panel (Agency Panel) included Carol Nankivel, Rulemaking Coordinator; Shannon Lotthammer, Division Director for the Environmental Analysis and Outcomes Division; Ed Swain, Research Scientist with the Environmental Analysis and Outcomes Division; Catherine Neuschler, Water Assessment Section Manager; Gerald Blaha, Research Scientist with the Water Quality Standards Unit; Elizabeth Kaufenberg, Research Scientist with the Effluent Limits Unit; Phillip Monso, Research Scientist with the Water Quality Standards Unit; Scott Kyser, Engineer with the Effluent Limits Unit; and Debra Klooz, a Paralegal in the Legal Services unit.

The MPCA received thousands of written comments on the proposed rules between August 21, 2017 and November 2, 2017. Approximately 57 people attended the first public hearing on October 23rd in St. Paul, Minnesota and signed the hearing register. Fourteen members of the public provided oral comments regarding the proposed rules during the October 23rd hearing and one public exhibit was received during that hearing.[9]

Approximately 88 people attended the October 24th hearing in Virginia, Minnesota and signed the hearing register. Twenty-five members of the public provided oral

[3] Porewater is the water present in saturated sediment between the solid particles of minerals and organic matter.
[4] Minn. Stat. §§ 14.131-.20 (2016).
[5] *See* Minn. Stat. §§ 14.05-.20 (2016); Minn. R. 1400.2000-.2240 (2017).
[6] See Minn. Stat. § 14.25 (2016).
[7] *See* Minn. Stat. § 14.14; Minn. R. 1400.2210-.2230.
[8] Minn. Stat. §§ 14.05, 14.23, 14.25, 14.50 (2016).
[9] Exhibit (Ex.) 1000.

comments regarding the proposed rules during the October 24th hearing. Twelve public exhibits[10] and two Agency exhibits[11] were received during the October 24th hearing.

Approximately 44 people attended the October 25th hearing in Bemidji, Minnesota, and signed the hearing register. Fourteen members of the public provided oral comments regarding the proposed rules during the October 25th hearing and two public exhibits were received during that hearing.[12]

Approximately 89 people attended the October 26th hearing in Cloquet, Minnesota, and signed the hearing register. Twenty-seven members of the public provided oral comments regarding the proposed rules during the October 26th hearing and nine written public exhibits were received during that hearing.[13]

Approximately 53 people attended the October 30th hearing in Brainerd, Minnesota, and signed the hearing register. Twenty members of the public provided oral comments regarding the proposed rules during the October 30th hearing and nine public exhibits were received during that hearing.[14]

Approximately 26 people attended the November 2nd hearing in St. Paul, Minnesota, or watched via interactive video conference at one of the MPCA's regional offices in Detroit Lakes, Duluth, Mankato, Marshall, and Rochester. Eight members of the public provided oral comments regarding the proposed rules during the November 2nd hearing and three public exhibits were received during that hearing.[15]

In total, 38 exhibits were received during the public hearings.[16]

After the close of the last of the hearings, the Administrative Law Judge kept the rulemaking record open for an additional 20 calendar days, until November 22, 2017, to allow interested persons and the Agency to submit written comments. Thereafter, the record remained open for an additional five business days, until December 1, 2017, to allow interested persons and the Agency to file written responses to any comments received during the initial comment period.[17]

Approximately 1,500 written comments were received from members of the public after the hearings, along with two responses from the Agency.[18] To aid the public in participating in this matter, all comments were posted at the Office of Administrative

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[10] Exs. 1001-1012.
[11] Exs. 1013-1014.
[12] Exs. 1015-1016.
[13] Exs. 1017-1024A.
[14] Exs. 1025-1033.
[15] Exs. 1033-1036.
[16] Exs. 1000-1036, which includes Exs. 1024 and 1024A.
[17] *See* Minn. Stat. § 14.15, subd. 1.
[18] MPCA Response to Public Comments (Nov. 22, 2017) and MPCA Rebuttal Response to Public Comments (Dec. 1, 2017).

Hearings' Rulemaking eComments website. In total, the Administrative Law Judge received more than 4,500 written comments on the proposed rule amendments.[19]

The hearing record closed for all purposes on December 1, 2017.[20]

NOTICE

The Agency must make this Report available for review by anyone who wishes to review it for at least five working days before the Agency takes any further action to adopt final rules or to modify or withdraw the proposed rules. If the Agency makes changes in the rules other than those recommended in this report, it must submit the rules, along with the complete hearing record, to the Chief Administrative Law Judge for a review of those changes before it may adopt the rules in final form.

Because the Administrative Law Judge has determined that the proposed rules are defective in certain respects, state law requires that this Report be submitted to the Chief Administrative Law Judge for her approval. If the Chief Administrative Law Judge approves the adverse findings contained in this Report, she will advise the Agency of actions that will correct the defects, and the Agency may not adopt the rules until the Chief Administrative Law Judge determines that the defects have been corrected. However, if the Chief Administrative Law Judge identifies defects that relate to the issues of need or reasonableness, the Agency may either adopt the actions suggested by the Chief Administrative Law Judge to cure the defects or, in the alternative, submit the proposed rules to the Legislative Coordinating Commission for the Commission's advice and comment. The Agency may not adopt the rules until it has received and considered the advice of the Commission. However, the Agency is not required to wait for the Commission's advice for more than 60 days after the Commission has received the Agency's submission.

If the Agency elects to adopt the actions suggested by the Chief Administrative Law Judge and make no other changes; and the Chief Administrative Law Judge determines that the defects have been corrected, it may proceed to adopt the rules. If the Agency makes changes in the rules other than those suggested by the Administrative Law Judge and the Chief Administrative Law Judge, it must submit copies of the rules showing its changes, the rules as initially proposed, and the proposed order adopting the rules to the Chief Administrative Law Judge for a review of those changes before it may adopt the rules in final form.

After adopting the final version of the rules, the Agency must submit them to the Revisor of Statutes for a review of their form. If the Revisor of Statutes approves the form of the rules, the Revisor will submit certified copies to the Administrative Law Judge, who will then review them and file them with the Secretary of State. When they are filed with

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[19] Of these comments, the vast majority were form letters, form postcards, or petitions. *See* https://minnesotaoah.granicusideas.com/discussions/minnesota-pollution-control-agency-environmental-assessment-and-outcomes-division.

[20] Pursuant to Minn. Stat. § 14.15, subd. 2, a one week extension was granted for the preparation of this Report. *See* Order Extending Deadline for Rule Report (Dec. 28, 2017).

the Secretary of State, the Administrative Law Judge will notify the Agency, and the Agency will notify those persons who requested to be informed of their filing.

SUMMARY OF CONCLUSIONS

The MPCA has established that it has the statutory authority to adopt the proposed rules and that it followed the legal requirements to promulgate the rules.

The Administrative Law Judge **DISAPPROVES** the proposed repeal of the 10 mg/L sulfate standard at **Minn. R. 7050.0220, subps. 3a, 4a, 5a, 6a** and **Minn. R. 7050.0224, subp. 2,** due to the Agency's failure to establish the reasonableness of the repeal, and because the repeal conflicts with the requirements 33 U.S.C. § 1313(c), 40 C.F.R. § 131.10(b) (2015) and Minn. R. 7050.0155 (2017).

The Administrative Law Judge **DISAPPROVES** the proposed equation-based sulfate standard at **Minn. R. 7050.0224, subp. 5, B (1)** because the proposed rule fails to meet the definition of a rule under Minn. Stat. § 14.38 (2016) and Minn. R. 1400.2100.G (2017). In addition, the proposed equation-based sulfate standard is not rationally related to the Agency's objective in this proceeding, and is unconstitutionally void for vagueness.

The Administrative Law Judge **DISAPPROVES** the proposed list of approximately 1,300 wild rice waters at **Minn. R. 7050.0471, subps. 3 through 9** because it violates 40 C.F.R. §§ 131.3 and .11(h)(1).

In addition, the Administrative Law Judge **DISAPPROVES** the following proposed rules because the Agency failed to demonstrate that the proposed rules meet the required legal standards:

a. Proposed **Minn. R. 7050.0224, subp. 5, A** – to the extent the language incorporates the standard in items B(1) and (2) the language violates Minn. Stat. § 14.38 and Minn. R. 1400.2100.B and G (2017).

b. Proposed **Minn. R. 7050.0224, subp. 5, A** – to the extent the language incorporates the standard in item C, the language violates Minn. R. 1400.2100.D (2017).

c. Proposed **Minn. R. 7050.0224, subp. 5, C** – violates Minn. R. 1400.2100D.

d. Proposed **Minn. R. 7050.0224, subp. 6** – fails to establish need or reasonableness for rule. No reason for distinguishing between [WR], which are provided additional protection of narrative standard, and other wild rice waters listed at Minn. R. 7050.0471 violates 1400.2100.B.

The Administrative Law Judge finds that the Agency failed to provide adequate regulatory analyses as required by Minn. Stat. § 14.131 (1), (5), (7), and (8). While the Agency made the cost determination required by Minn. Stat. § 14.127, the Administrative

Law Judge concludes that this determination is not adequately supported in the rulemaking record.[21]

Based upon all the testimony, exhibits, and written comments the Administrative Law Judge makes the following:

FINDINGS OF FACT

I. Background to the Proposed Rules

1. This rulemaking concerns amendments to Minnesota's water quality standard to protect wild rice from adverse impacts due to sulfate pollution. Wild rice is an important natural resource in Minnesota. In addition to providing food to people and waterfowl generally, it has spiritual, cultural, and nutritional significance to the Dakota and Ojibwe people.

2. Under the federal regulations implementing the Clean Water Act (CWA), the MPCA is responsible for establishing, reviewing, and revising water quality standards.[22]

3. Federal law defines "water quality standards" to "consist of a designated use or uses for the waters of the United States and water quality criteria for such waters based upon such uses. Water quality standards are intended to protect the public health or welfare, enhance the quality of water and serve the purposes of the Act."[23]

4. Water quality standards "must be based on sound scientific rationale and must contain sufficient parameters or constituents to protect the designated use."[24]

5. Minnesota Rules, chapter 7050 (2017) establishes water quality standards for "all waters of the state, both surface and underground."[25] This chapter sets out a classification system for the beneficial uses of waters, establishes numeric and narrative water quality standards, and provides nondegradation provisions, and other provisions to protect the physical, chemical, and biological integrity of waters of the state.[26] Water use classifications, and their accompanying narrative and numeric standards and antidegradation provisions, make up the state's set of water quality standards.

6. In Minnesota, the wild rice resource is protected with a unique water quality standard. The existing wild rice standards, found at Minn. R. 7050.0224, consist of a narrative standard in subpart 1 applicable to selected wild rice waters specifically identified in rule, and a numeric standard in subpart 2 that establishes a sulfate standard

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[21] *See Builders Ass'n. of Twin Cities v. Minnesota Dept. of Labor and Industry*, 872 N.W. 2d 263 (Minn. Ct. App. 2015).
[22] 40 C.F.R. § 131.4(a) (2017). Under state and federal law, the MPCA is charged with the administration and enforcement of the CWA. *See* 33 U.S.C. §§ 1251-1387 (2016); 40 C.F.R. § 123.25(a) (2017); Minn. Stat. § 115.03, subds. 1, 5 (2016).
[23] 40 C.F.R. § 131.3(i) (2017).
[24] 40 C.F.R. § 131.11(a)(1) (2017); *see also* 40 C.F.R. § 131.5(a)(2) (2017).
[25] Minn. R. 7050.0110.
[26] *Id.*

applicable to "water used for production of wild rice." The purpose of a designated use of a water body to protect wild rice is described as "the harvest and use of grains from this plant serve as a food source for wildlife and humans."[27]

7. Minnesota first adopted a sulfate standard to protect wild rice in 1973.[28] The sulfate standard was based on research conducted in the 1930s and 1940s that found that higher levels of sulfate in water correlated with reduced presence of wild rice.[29] Based on this research, the MPCA set the numeric standard at 10 mg/L of sulfate applicable to "water used for production of wild rice during periods when the rice may be susceptible to damage by high sulfate levels."[30]

8. Over the years, the MPCA has received comments and questions about the appropriateness of the sulfate standard and the meaning of the phrase "waters used for production of wild rice."[31] In 2011, the Minnesota Legislature directed the MPCA to undertake further study of the wild rice sulfate water quality standard and to revise the standard as necessary.[32] This rulemaking proceeding is the result of that legislative directive.[33]

9. In 2011, the Minnesota Legislature provided the MPCA with a $1.5 million appropriation from the Clean Water Fund to conduct a Wild Rice Sulfate Study to gather additional information about the effects of sulfate and other substances on the growth of wild rice.[34] The Legislature also directed the MPCA to undertake rulemaking to identify wild rice waters and to make any other needed changes to the standards following completion of the study.[35] The rulemaking was to be completed by January 15, 2018.[36]

10. The Minnesota Legislature also directed the MPCA to create an advisory group comprised of tribal government representatives and a variety of other stakeholders to provide input on the research and the development of future rule amendments.[37] The legislation further directed the MPCA to establish criteria for waters containing natural beds of wild rice after consulting Minnesota tribes, the Minnesota Department of Natural Resources (DNR), and stakeholders.[38]

11. In 2017, the MPCA received $180,000 from the Legislative Citizens Commission on Minnesota Resources to analyze wastewater treatment alternatives to

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[27] Minn. R. 7050.0224, subp. 1.
[28] Ex. D SONAR at 11-12, 33-34.
[29] Ex. D at 11.
[30] Minn. R. 7050.0224, subp. 2.
[31] Ex. D at 11-12.
[32] 2011 Minn. Laws 1st Spec. Sess. ch. 2, art. 4, § 32.
[33] Ex. D. at 13.
[34] Ex. D at 13; 2015 Minn. Laws 1st Spec. Sess. ch. 4, art. 4, § 136.
[35] Ex. D at 13.
[36] 2015 Minn. Laws 1st Spec. Sess. ch. 4, art. 4, § 136.
[37] 2011 Minn. Laws 1st Spec. Sess. ch. 2, art. 4, § 32.
[38] *Id.*

inform the development of the proposed rules. The analysis is expected to be completed by May of 2018.[39]

12. In 2017, the Minnesota Legislature extended the deadline for completing this rulemaking by one year to January 15, 2019.[40]

II. Rulemaking Authority

13. The MPCA relies upon its general rulemaking authority under Minn. Stat. § 115.03, subd. 1 (2016), as its statutory authority to adopt these proposed rules. This statute provides that the Agency is given and charged with the following powers and duties:

> (a) to administer and enforce all laws relating to the pollution of any of the waters of the state;
>
> (b) to investigate the extent, character, and effect of the pollution of the waters of this state and to gather data and information necessary or desirable in the administration or enforcement of pollution laws, and to make such classification of the waters of the state as it may deem necessary;
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> (c) to establish and alter such reasonable pollution standards for any waters of the state in relation to the public use to which they are or may be put as it shall deem necessary for the purposes of this chapter and, with respect to the pollution of waters of the state, chapter 116;
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> (d) to encourage waste treatment, including advanced waste treatment, instead of stream low-flow augmentation for dilution purposes to control and prevent pollution; and
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> (e) to adopt, issue, reissue, modify, deny, or revoke, enter into, or enforce reasonable orders, permits, variances, standards, rules, schedules of compliance, and stipulation agreements, under such conditions as it may prescribe, in order to prevent, control, or abate water pollution, or for the installation or operation of disposal systems or parts thereof, or for other equipment and facilities.[41]

14. The MPCA also relies upon its general authority to "group the designated waters of the state into classes, and adopt classifications and standards of purity and quality" under Minn. Stat. § 115.44, subd. 2 (2016), as a source of statutory authority to adopt the proposed rules. Minn. Stat. § 115.44, subd. 2, provides in part:

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[39] Ex. 1015; Letter from Iron Range Legislative Delegation (Nov. 2, 2017); Testimony (Test.) of Rep. Matt Bliss at Tr. 85 (Oct. 25, 2017); Test. of Rep. Rob Ecklund at 69-72 (Oct. 30, 2017).
[40] 2017 Minn. Laws, ch. 93, art. 2, § 149.
[41] Minn. Stat. § 115.03, subd. 1.

> In order to attain the objectives of sections 115.41 to 115.53, the agency after proper study, and after conducting public hearing upon due notice, shall, as soon as practicable, group the designated waters of the state into classes, and adopt classifications and standards of purity and quality therefor.

15. Additionally, the MPCA cites the specific legislative authorities that require it to initiate a process to amend the state water quality standards in Minn. R. ch. 7050,[42] and that extended the deadline for completing the mandated rule revisions.[43]

16. The Administrative Law Judge concludes that the Agency has the statutory authority to adopt the proposed rules.

III. Procedural Requirements of Chapter 14 (2016)

A. Publications

17. On October 26, 2015, the Agency published a Request for Comments in the *State Register* seeking comments on "its planned changes to rules governing water quality standards, Minnesota Rules chapter 7050 (Waters of the State)."[44]

18. On August 3, 2017, the Agency requested review and approval of its Notice of Hearing and Additional Notice Plan.

19. On August 8, 2017, Administrative Law Judge Eric Lipman issued an Order on behalf of Administrative Law Judge LauraSue Schlatter approving the Additional Notice Plan and Hearing Notice.

20. On August 21, 2017, the Agency published a Notice of Hearing in the State Register stating its intention to adopt rules following the receipt of input from the public.[45] In the Notice, the Agency announced a series public hearings scheduled for October 23, 24, 25, 30, and November 2, 2017.[46]

21. On August 21, 2017, the Agency sent via electronic mail the Notice of Hearing to all persons and associations who had registered their names with the Agency for the purpose of receiving such notice.[47] The Agency also provided a copy of the Notice of Hearing to all persons and associations identified in the Agency's Additional Notice Plan.[48]

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[42] 2011 Minn. Laws 1st Spec. Sess, ch. 2, art. 4, § 32.
[43] 2017 Minn. Laws ch. 93, art. 2, § 149.
[44] Ex. A; 40 *State Register* 477-78 (Oct. 26, 2015).
[45] Ex. F; 42 *State Register* 171-172 (Aug. 21, 2017).
[46] *Id*.
[47] Ex. G.
[48] Ex. H1.

22. On September 18, 2017, the Agency sent via electronic mail the Notice of Additional Hearing to all persons and associations who had registered their names with the Agency for the purpose of receiving such notice and to all persons and associations identified in the Agency's Additional Notice Plan.[49] In the Notice, the Agency announced an additional public hearing to take place in Cloquet, Minnesota, on October 26, 2017.[50]

23. The Agency published the Notice of Additional Hearing in the *State Register* on September 18, 2017.[51]

24. At the hearing on October 23, 2017, the MPCA filed copies of the following documents as required by Minn. R. 1400.2220 (2017):

a. MPCA's Request for Comments as published in the *State Register* on October 26, 2015;[52]

b. A Petition for Rulemaking submitted by the Minnesota Chamber of Commerce on December 17, 2010, and a Memorandum in Support of the Minnesota Chamber of Commerce's Petition for Rulemaking dated December 6, 2010;[53]

c. Proposed rules dated July 24, 2017, including the Revisor's approval;[54]

d. The MPCA's Statement of Need and Reasonableness (SONAR);[55]

e. The Certificate of Mailing the SONAR to the Legislative Reference Library on August 21, 2017;[56]

f. The Notice of Hearing as mailed and as published in the *State Register* on August 21, 2017; and the Notice of Additional Hearing as mailed and as published in the *State Register* on September 18, 2017;[57]

g. Certificate of Mailing the Notice of Hearing to the rulemaking mailing list and Certificate of Accuracy of the Mailing List dated August 21, 2017, and Certificate of Mailing the Notice of Additional Hearing to the rulemaking list and Certificate of Accuracy of the Mailing List dated September 18, 2017;[58]

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[49] Ex. H2.
[50] *Id*.
[51] Ex. F; 42 *State Register* 369-370 (Sept. 18, 2017).
[52] Ex. A; 40 *State Register* 477-478 (Oct. 26, 2015).
[53] Ex. B.
[54] Ex. C.
[55] Ex. D.
[56] Ex. E.
[57] Ex. F.
[58] Ex. G.

h. Certificate of Providing Additional Notice of the August 21, 2017, Notice of Hearing[59] and Certificate of Providing Additional Notice of the September 18, 2017, Notice of Additional Hearings;[60]

i. Written comments received during the prehearing comment period and a link to the Minnesota Office of Administrative Hearings' rulemaking eComments website, where written comments on the proposed rules received by the Agency prior to the hearing were posted;[61]

j. Chief Judge's authorization to omit from the notice of hearing published in the *State Register* the text of the proposed rules (not applicable);

k. Other documents or evidence to show compliance with any other law or rule which the agency is required to follow in adopting this rule:

K1 – Certificate of Sending the Notice of Hearing and SONAR to legislators and the Legislative Coordinating Commission on August 21, 2017;[62]

K2 – Notice to Department of Agriculture of Agency's intent to adopt rules as required by Minn. Stat. § 14.111, dated July 19, 2017;[63]

K3 – Notice to the Minnesota Department of Management and Budget and a September 17, 2017, memorandum from the Minnesota Department of Management and Budget;[64]

K4 – Notices sent to affected municipalities as required by Minn. Stat. § 115.44, subd. 7 (2016).[65]

l. Additional documents submitted at the hearing:

Peer-reviewed articles on sulfur processes and sulfate treatment;[66] the MPCA's rule hearing presentation; errata correcting minor errors in the SONAR; and MPCA Changes to Specific Water Identification Numbers (WID). [67]

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[59] Ex. H1.
[60] Ex. H2.
[61] Ex. I.
[62] Ex. K1.
[63] Ex. K2.
[64] Ex. K3.
[65] Ex. K4.
[66] Exs. L1–L5 and L8.
[67] Exs. L6, L7, and L9.

B. Additional Notice Requirements

25. Minn. Stat. §§ 14.131 and 14.23 require that an agency include in its SONAR a description of its efforts to provide additional notification to persons or classes of persons who may be affected by the proposed rule or, alternatively, the agency must detail why these notification efforts were not made.

26. The MPCA states that the proposed revisions have been in development for many years and that it has made extensive efforts to inform and engage specific stakeholders and the general public. In April of 2011, the MPCA created a webpage to provide background about the existing wild rice sulfate standard and its plan to evaluate the standard. Since 2011, the MPCA has also used the GovDelivery system to share information about the wild rice standard with subscribers. In addition, pursuant to a 2011 legislative directive, the MPCA established an advisory committee to provide input to the Commissioner on various topics related to the wild rice scientific study and proposed rulemaking. The MPCA also made a special effort to communicate and consult with Minnesota tribes, given their sovereign status and the great importance of wild rice to the Ojibwe and Dakota people.[68]

27. The MPCA also held numerous meetings over the course of developing the proposed revisions to engage interested persons and obtain feedback.[69] The MPCA released a draft proposal of the proposed wild rice water quality standard in March 2015, along with a draft list of waters where the standard would apply. The MPCA sent notice of the availability of the draft proposal to the MPCA's GovDelivery mailing list of people who had registered their interest in this topic and posted the draft proposal on its rulemaking webpage.[70] Before officially proposing the rules, the MPCA held a series of three open house meetings to provide an informal opportunity for the public to review the proposal and ask questions.[71]

28. Pursuant to the Additional Notice Plan approved by the Office of Administrative Hearings, on August 8, 2017, the Agency:

a. posted the Notice of Hearing, SONAR, SONAR attachments, proposed rule language, documents incorporated by reference, information about how to file comments, and the times and locations of hearings on an Agency webpage established to provide information about the proposed rule amendments;

b. Published the Notice of Hearing on the MPCA's Public Notice webpage;

c. issued a press release via the GovDelivery system to 534 news media contacts and more than 3,400 media contacts and persons

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[68] Ex. D at 126-128.
[69] *Id*. at 128.
[70] *Id*. at 129.
[71] *Id*.

registered to be notified of news releases to provide information about the proposed rule amendments and how to comment;

d. provided an extended comment period to allow additional time for review of the proposed rule amendments;

e. held multiple public hearings in various locations throughout the state and provided daytime and evening opportunities for people to attend and comment;

f. provided notice to a series of nonprofit organizations that represent and serve Native American communities in Minnesota; trade associations that serve mining communities and mining companies; and municipalities that operate wastewater treatment facilities and associations that represent them;

g. provided an electronic copy of the Notice of Hearing to more than 2,600 interested parties as certified in the MPCA's Certificate of Mailing Notice;

h. provided an electronic copy of the Notice of Hearing to municipalities as required by Minn. Stat. § 115.44, subd. 7;

i. posted the Notice of Hearing with links to the SONAR and proposed rule language on the Agency's public notice website for the term of the public notice comment period; and

j. posted the Notice of Hearing, SONAR, and proposed rule language on an Agency webpage established to provide information about the proposed amendments.[72]

29. The Administrative Law Judge finds that the Agency has fulfilled its additional notice requirements.

C. Notice Practice

1. Notice to Stakeholders

30. On August 21, 2017, the Agency provided a copy of the Notice of Hearing to its official rulemaking list (maintained under Minn. Stat. § 14.14) and to stakeholders identified in its Additional Notice Plan.[73]

31. On September 18, 2017, the Agency provided a copy of the Notice of Additional Hearing to its official rulemaking list (maintained under Minn. Stat. § 14.14) and to stakeholders identified in its Additional Notice Plan.[74]

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[72] Exs. H1 and G. *See also* Ex. D at 131-132.
[73] Exs. G and H1.
[74] Exs. G and H1.

32. Hearings on the proposed rules were held on October 23, 24, 25, 26, 30, and November 2, 2017.[75]

33. There are 62 days between August 21, 2017 and October 23, 2017, the date of the first hearing in this matter. There are 37 days between September 18, 2017 and October 26, 2017, which was the date of the additional hearing.

34. The Administrative Law Judge concludes that the Agency fulfilled its responsibility to mail the Notice of Hearing and Notice of Additional Hearing "at least 33 days before the . . . start of the hearing."[76]

2. Notice to Legislators

35. On August 21, 2017, the Agency sent a copy of the Notice of Hearing and the SONAR to legislators and the Legislative Coordinating Commission as required by Minn. Stat. § 14.116.[77]

36. Minn. Stat. § 14.116(b) requires the agency to send a copy of the Notice of Hearing and the SONAR to certain legislators on the same date that it mails its Notice of Hearing to persons on its rulemaking list and pursuant to its additional notice plan.

37. The Administrative Law Judge concludes that the MPCA fulfilled the requirements of Minn. Stat. § 14.116(b).[78]

3. Notice to the Legislative Reference Library

38. On August 21, 2017, the MPCA mailed a copy of the SONAR to the Legislative Reference Library.[79]

39. Minn. Stat. § 14.23 requires the agency to send a copy of the SONAR to the Legislative Reference Library when the Notice of Intent to Adopt is mailed.

40. The Administrative Law Judge concludes that the Agency met the requirement of Minn. Stat. § 14.23 that it send a copy of the SONAR to the Legislative Reference Library when the Notice of Intent is mailed.

D. Impact on Farming Operations

41. Minn. Stat. § 14.111 imposes additional notice requirements when the proposed rules affect farming operations. The statute requires that an agency provide a copy of any such changes to the Commissioner of Agriculture at least 30 days prior to publishing the proposed rules in the *State Register*.

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[75] Ex. G.
[76] Minn. R. 1400.2080, subp. 6.
[77] Ex. K1.
[78] Minn. R. 1400.2080, subp. 6.
[79] Ex. E.

42. The MPCA provided the Commissioner of Agriculture with a copy of the proposed rules and notice of its intent to adopt the rules. This notice was provided on July 19, 2017, 32 days prior to the publication of the Notice of Hearing in the State Register.[80]

43. The Administrative Law Judge concludes that the MPCA fulfilled its responsibilities under Minn. Stat. § 14.111.

E. Statutory Requirements for the SONAR

44. The Administrative Procedure Act obliges an agency adopting rules to address certain factors in its SONAR.[81] Those factors are:

> (1) a description of the classes of persons who probably will be affected by the proposed rule, including classes that will bear the costs of the proposed rule and classes that will benefit from the proposed rule;
>
> (2) the probable costs to the agency and to any other agency of the implementation and enforcement of the proposed rule and any anticipated effect on state revenues;
>
> (3) a determination of whether there are less costly methods or less intrusive methods for achieving the purpose of the proposed rule;
>
> (4) a description of any alternative methods for achieving the purpose of the proposed rule that were seriously considered by the agency and the reasons why they were rejected in favor of the proposed rule;
>
> (5) the probable costs of complying with the proposed rule, including the portion of the total costs that will be borne by identifiable categories of affected parties, such as separate classes of governmental units, businesses, or individuals;
>
> (6) the probable costs or consequences of not adopting the proposed rule, including those costs or consequences borne by identifiable categories of affected parties, such as separate classes of government units, businesses, or individuals;
>
> (7) an assessment of any differences between the proposed rule and existing federal regulations and a specific analysis of the need for and reasonableness of each difference; and

[80] Ex. K2.
[81] Minn. Stat. § 14.131.

(8) an assessment of the cumulative effect of the rule with other federal and state regulations related to the specific purpose of the rule.

1. The Agency's Regulatory Analysis

(1) A description of the classes of persons who probably will be affected by the proposed rule, including classes that will bear the costs of the proposed rule and classes that will benefit from the proposed rule.

45. The MPCA's analysis focuses on regulated facilities that discharge wastewater to certain waters containing beds of natural wild rice, and on people interested in enjoying the beneficial uses that the water quality standards protect. The Agency states that the beneficial uses includes fishing, swimming, boating, and harvesting wild rice.

a. Classes that will bear costs.

46. The Agency points out that effluent limits imposed on regulated facilities as a result of the proposed rules will be applied through National Pollutant Discharge Elimination System/State Disposal System (NPDES/SDS) permits. These permits are reviewed and re-issued every five years. Any facility that discharges sulfate directly to, or is located upstream of, a wild rice water governed by the rules has the potential to be affected by the proposed rules. These facilities are generally either industrial facilities, or municipal water or wastewater treatment plants.[82]

47. The MPCA describes the process for adopting the proposed equation-based water quality standards as follows:

> In the case of this wild rice sulfate standard, this implementation process will begin with data collection. As noted . . . , the data required will be sediment data to calculate the sulfate standard (or porewater sulfide data to establish an alternate standard), surface water sulfate data, and effluent sulfate data. The MPCA plans to collect the sediment data over time, largely in conjunction with its regular ten-year cycle of intensive watershed monitoring, focusing first on wild rice waters that are most likely to be impacted by high levels of sulfate. The exception would be that where a new or expanded discharge is proposed, the proposer may be required to collect the sediment data following the procedures proposed to be incorporated into the rule.[83]

48. The Agency notes that regulated facilities that are not already monitoring their sulfate effluent data will probably have to do so for their first five-year permit due to the fact that the permit will be reissued following adoption of the rule. Facilities will also be impacted by an effluent limit review, which involves analysis of site-specific variables

[82] Ex. D (SONAR) at 145-146.
[83] *Id.*

to determine whether the facility's permit must include a limit to ensure that the sulfate standard is not exceeded.[84]

49. The variables include specifics of the facility as well as the receiving water, including the level of the receiving water's sulfate pollutant The MPCA estimates that, for facilities that already monitor their effluent's sulfate discharge, the effluent limit review will likely occur in the first five-year permit reissuance after the rule is adopted. For facilities that do not, the effluent review will likely not occur until the second five-year permit reissuance after the rule is adopted.[85]

50. Another necessary variable for this analysis is a numeric sulfate standard for at least one wild rice water which is affected by the facility's discharge. To calculate the numeric sulfate standard in accordance with the proposed rule, certain data must be obtained, including the amount of organic carbon and extractable iron in the wild rice water sediment.[86]

51. By identifying the industrial and municipal waste water treatment plants (WWTPs) within a specified distance of a regulated wild rice water, the MPCA was able to estimate "the universe of affected dischargers."[87]

52. Based on an analysis of 2015 NPDES/SDS permit information, the Agency estimated that there are approximately 745 discharge stations upstream of at least one wild rice water to be regulated pursuant to the proposed rules, ranging in distance between one mile to 413 river miles from the nearest regulated wild rice water. About 319 of the stations are within 60 miles of a proposed regulated wild rice water, and about 135 are within 25 miles of a proposed regulated wild rice water. While noting that "25 miles is not a definite predictor for impact . . . ,"[88] the MPCA focuses on the 135 WWTPs as those most likely to be affected by the proposed rule. These facilities are most likely to require an effluent limit review and possibly to incur the treatment costs needed to meet an applicable water quality standard. But, the Agency notes, "[s]everal factors will affect a facility's potential to impact a wild rice water and those factors cannot be determined in advance of establishing the numeric sulfate standard and evaluating the specific circumstances associated with each discharge and each wild rice water."[89] The new standards could result in costs, if more treatment is needed to meet a standard that is more stringent than the current 10 mg/L standard, or in cost savings, if the standard is more relaxed than the current standard.[90]

53. The Agency states that industrial WWTPs are likely to pass along the costs of new treatment equipment or technologies to their customers and municipal WWTPs are likely to pass along similar costs to their residential, commercial, and industrial system

[84] Ex. D at 146.
[85] *Id.*
[86] Ex. C (proposed rule 7050.0224, subp. 5, B) at li. 7.25-8.12.
[87] *Id.* at 147.
[88] *Id*.
[89] *Id.*
[90] *Id.* at 148.

users. The Agency speculates that, to the extent the market will not support increased industrial costs, such costs may have to be absorbed, and will thus reduce profits, making the industry less competitive in the marketplace, negatively impacting shareholders and employees, and possibly resulting in a company ceasing operations rather than investing in the expensive technology needed to meet a new standard. The Agency acknowledges that employment is a particularly key issue for the mining economy of Minnesota's Iron Range, but it is unable to predict whether the consequences of adopting the proposed rule will be "as minor as a small increase in the price of the product, or may be as extensive as the consequences to an entire community when a company ceases operations."[91]

54. Adopting the standards through the MPCA's water assessment cycle will, in itself, take up to ten years:

> The MPCA's current Intensive Watershed Monitoring plan includes intensive data collection across the state following a 10-year cycle. The MPCA is working with field staff to incorporate data collection needs for the proposed sulfate wild rice standard into that effort. In most cases, the MPCA will integrate the collection of sediment data in wild rice waters into our regular monitoring work around the state. The agency will prioritize data collection for wild rice waters most likely to be affected by discharges, and some work may be prioritized outside the regular monitoring schedule.[92]

55. In its Rebuttal to Comments following the rule hearings, the Agency explains:

> [E]valuating the need for and (as needed) determining a water quality based effluent limit requires data specific to the discharge being evaluated and the receiving water(s) being discharged to. Data needs unique to the proposed rule revisions are the sediment iron and carbon (or porewater sulfide) data. Collecting all the data necessary to calculate all effluent limits statewide would take at least ten to fifteen years, even if the sediment data were not needed. Necessary steps such as gathering five years of effluent data to evaluate and set effluent limits combined with the 10-year surface water monitoring schedule to gather surface water data cumulatively add up to the necessary data not being available for some permitted discharges until at least ten to fifteen years after rule promulgation. The MPCA does plan to prioritize data collection based on factors such as those mentioned in the EPA comments, Appendix 2 – the likelihood of sulfate impacts (because of type and location of dischargers) and permitting schedules. It is unreasonable to delay this rulemaking for ten to fifteen years to provide total certainty regarding future effluent limits for specific facility discharges and the exact future costs. In addition, every facility is unique and detailed engineering is needed to estimate the costs of installing any treatment

[91] Ex. D. at 148.
[92] MPCA Response to Comments, Cover Memorandum at 10 (Nov. 22, 2017) (Response Cover Memo).

system. This is why the MPCA provided general effluent limit considerations and the range of costs detailed in the SONAR. A delay such as would be necessary to gather data and estimate the cost for all potentially affected facilities is particularly unreasonable given that while the rulemaking would be delayed the existing sulfate standard would remain in place and need to be addressed as required by the Clean Water Act and federal regulations.[93]

56. The Administrative Law Judge concludes that the Agency has correctly described the various types of WWTPs that discharge sulfate directly to, or that are located upstream of, wild rice waters governed by the proposed rules as classes that will bear the cost of the proposed rules. However, the Administrative Law Judge further concludes that the Agency omitted to include, in its discussion of the WWTPs' possible costs, the Agency's SONAR-based expectation, which is not set forth in the rule, that regulated parties will bear the cost of conducting sediment sampling for a new or expanded discharge.[94]

57. The Agency's predictions about the number of dischargers likely to be affected is unreliable because "[s]everal factors will affect a facility's potential to impact a wild rice water and those factors cannot be determined in advance of establishing the numeric sulfate standard and evaluating the specific circumstances associated with each discharge and each wild rice water."[95]

58. The Agency did not identify Minnesota Indian tribes or individual Native Americans as classes of persons who would bear a burden under the proposed rules because the Agency believes that the proposed new sulfate standards will be protective of wild rice.[96]

59. Wild rice is not only a food source for Native American communities, but a source of deep spiritual importance and, for some, a life-giving being.[97] Many in the Native American communities who submitted comments, testified at the public hearings, and worked with the MPCA during the development of this rule do not believe that the rule will be protective of wild rice. Among the reasons that some of the representatives of Native American communities presented as their concerns about the rule are:

a. A higher sulfate standard will be harmful to the rice because the higher levels of iron underlying the higher sulfate standard cause plaque to form on the roots of the wild rice plants, interfering with the ability of the plant to absorb nutrients and ultimately leading to barren seeds;[98]

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[93] MPCA Rebuttal Memo at 40-41.
[94] Ex. D at 146.
[95] *Id.* at 147.
[96] *Id.*at 145.
[97] Exs. 1000 and 1020; Tr. at 142-145 (Oct. 24, 2017); Comments from Fond du Lac Band of Lake Superior Chippewa (filed Nov. 22, 2017).
[98] Comments from 1854 Treaty Authority (filed Nov. 21, 2017); Comments from Fond du Lac Band of Lake Superior Chippewa (filed Nov. 22, 2017).

b. A higher sulfate standard will lead to higher levels of methylmercury in fish, which in turn leads to serious health concerns for Native American and other populations who rely heavily on fish for food;[99]

c. The list of wild rice waters excludes a number of waters identified by the 1854 Exclusionary Act Treaty as well as the Minnesota DNR's 2008 wild rice waters list;[100] and

d. The MPCA's inclusion, in the wild rice waters listed in the proposed rule, of waters that are within the boundaries of the Fond du Lac and Grand Portage reservations despite requests that those waters be excluded.[101]

60. While the MPCA had responses to each of these concerns, the volume and nature of the comments from the Native American community demonstrated that the Agency has not succeeded in building an atmosphere of trust regarding this proposed rule, or in making the Minnesota Native American community feel that it has been heard.

61. Implementation of the rule as proposed is a burden to the Minnesota Indian tribes, and many Native American individuals, whose testimony and written comments during the rulemaking process demonstrate that they are compelled to continue to challenge the rule because they believe that the long-term survival of wild rice is in peril and do not believe that the Agency understands the importance of wild rice in Native American culture and life.[102]

62. The Administrative Law Judge concludes that the Agency failed to recognize the proposed rule's burden on the Native American community in its discussion of classes of people who will be burdened by adoption of the proposed rule.

b. Classes that will benefit from the new standard.

63. The MPCA states generally that any person who uses Minnesota waters for drinking, swimming, boating, fishing, commerce, scientific, educational, or cultural purposes, or general aesthetic enjoyment will benefit from the proposed rules. Specifically, the Agency states that any person who harvests wild rice for food or who eats wild rice will benefit. The Agency emphasizes that many Native Americans, especially members of the Ojibwe and Dakota tribes, will benefit from the proposed rule. The Agency states that tribal rights to harvest wild rice are protected in treaties and that harvesting, preparing, sharing, and selling wild rice is important culturally, spiritually, and socially to Native American Minnesotans.[103]

[99] Tr. at 65-68 (Oct. 25, 2017).
[100] Exs. 1000 and 1020; Comments from 1854 Treaty Authority (filed Nov. 21, 2017); Comments from Fond du Lac Band of Lake Superior Chippewa (filed Nov. 22, 2017).
[101] Ex. 1020; Comments from 1854 Treaty Authority (filed Nov. 21, 2017); Comments from Fond du Lac Band of Lake Superior Chippewa (filed Nov. 22, 2017).
[102] Exs. 1000 and 1020; Comments from Fond du Lac Band of Lake Superior Chippewa (filed Nov.22, 2017); eComments Nicolette Slagle on behalf of Honor the Earth (Nov. 22, 2017); eComments from George Crocker on behalf of North American Water Office (Nov. 22, 2017).
[103] Ex. D at 149.

64. The Agency asserts that the varied benefits of wild rice include the following:

> Transactions and activities associated with the wild rice harvest benefit individuals and local economies. Some tribal members have shared stories about how money from ricing paid for each year's school supplies. Many people place a high value on wild rice as food, especially for its availability, flavor, and health benefits. For persons who have limited incomes or a cultural connection, wild rice can be an important subsistence food.[104]

65. In addition, the MPCA states that wildlife, especially the migratory waterfowl that depend on wild rice as a food source, along with the people who hunt waterfowl, engage in bird watching and other wildlife-related activities, plus businesses that support those activities, will benefit from the proposed rules. The Agency adds that businesses that benefit from tourism and people who derive a value from ecosystem services generally will also benefit from the proposed rules.[105]

66. The Agency explains that, where the proposed rule will require ambient sulfate levels to be less than 10 mg/L, the equation-based standard will be more protective of the wild rice than the current standard and thus provide a benefit to those who use and value wild rice.[106]

67. To the contrary according to the MPCA, where the proposed rule will permit ambient sulfate levels to be higher than 10 mg/L while still maintaining a protective level of sulfide to the wild rice, the equation-based standard will potentially reduce treatment costs. In addition, the proposed alternate standard, which can be used in certain cases where the equation is not appropriate, could also allow sulfate levels to be higher than that calculated by the equation-based standard.[107]

68. The proposed rules may thus allow some municipal or industrial dischargers to reduce or eliminate sulfate treatment, or the need for a variance, to operate at a lower level of sulfate treatment. This could permit dischargers to avoid paying for a higher level of wastewater treatment, or applying for, and justifying, a variance request. In addition to the monetary costs of wastewater treatment, the MPCA notes that wastewater treatment for sulfate involves energy use and the generation of by-products, both of which could be lessened or avoided through application of the proposed rules. [108]

69. The Agency does not analyze how less-protective standards of wild rice waters that neighbor wild rice waters on tribal lands will affect waters on tribal lands. Nor does the Agency explain how it will insure that increased sulfate levels will not add to mercury methylation.

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[104] *Id.* at 150.
[105] *Id.*
[106] *Id.* at 151.
[107] *Id.* In its Rebuttal, the Agency proposes to change the way in which the Alternate Standard is established from the rule as originally proposed. MPCA Rebuttal Response to Public Comments (MPCA Rebuttal) at 6-7 (Dec. 1, 2017). *See* Ex. C. (proposed rule 7050.0224, subp. 5, B (2)) at li. 8.18-8.25.
[108] Ex. D at 151.

70. The Administrative Law Judge concludes that, to the extent the proposed rule fails to maintain a level of water quality that provides for the attainment and maintenance of the water quality standards of downstream waters, including waters on tribal lands, the proposed rule will not benefit wildlife, or the Objibwe, Dakota or other people who harvest or depend on wild rice for food, spiritual or cultural nourishment, or as a means of earning money.

c. Classes that will benefit from clarity regarding how and where the standard applies.

71. The MPCA states that the proposed rule may benefit dischargers "in the form of the benefit of regulatory certainty, prompt permit renewal, and protection from litigation."[109] By "regulatory certainty," the MPCA means "the general ability of permittees to know and anticipate environmental regulations and reasonably plan for compliance. . . ."[110]

72. The MPCA identifies two areas of difficulty for dischargers of sulfate: (1) a lack of duration or averaging time in the current sulfate rule, leading to uncertainty regarding whether the standard applies at all times or is to be averaged over some period of time; and (2) a lack of clear criteria for determining whether a given water is used for production for wild rice, resulting in case-by-case decisions regarding the applicability of the sulfate standards.[111]

73. According to the MPCA, it is this lack of clarity concerning waters used for the production of wild rice that has resulted in delayed issuance of new or renewed NPDES/SDS permits. Because the proposed rule specifically identifies wild rice waters and provides more details about the standard, the proposed rule provides dischargers with more certainty regarding "whether their effluent may impact a wild rice water and whether they will need to take actions because of the standard – from monitoring their effluent to undergoing an effluent limit review to installing treatment."[112]

74. The MPCA predicts that the proposed rule will speed permitting, reduce permitting backlogs, and reduce the risk of litigation. In addition, the Agency states that the proposed rule will "allow existing facilities to implement improvements and innovations that are currently stalled."[113] According to the Agency, industries and taxpayers will benefit because dischargers will be able to obtain and update their permits more effectively under the proposed rule.[114]

75. Finally, the MPCA envisages that greater clarity about how and where the wild rice sulfate standard applies will also allow the development of a clear process of

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[109] *Id.*
[110] *Id*. at 151, n.24.
[111] *Id*. at 151-152.
[112] Ex. D at 152.
[113] *Id.*
[114] *Id.*

assessing wild rice waters to determine attainment of the standard. This is important both for assessment and identifying impaired waters and for developing point source permit limits to ensure compliance with the standard. In this way, a clearer, more effective standard will also benefit those concerned about the effective protection of wild rice waters.[115]

76. The tribal representatives and the WaterLegacy and other environmental organizations disagreed strongly with the exclusion of water bodies where wild rice is an existing use under the CWA as demonstrated by their inclusion on the 1854 Treaty list and the Minnesota Department of Natural Resources' (MDNR) 2008 list of Minnesota wild rice waters.[116] While not identifying specific reasons for excluding individual water bodies, the Agency acknowledges that it excluded from the proposed rule some water bodies where wild rice has been an existing use.[117]

77. The Administrative Law Judge concludes that because the proposed rule listing wild rice waters is not in compliance with the CWA it will not improve the permitting process by providing certainty as to the water bodies which are identified. Therefore, the proposed rule will not provide the benefit of clarity regarding identification of wild rice waters to WTTP owners and operators.

78. Because the Agency has not sampled the affected waters before proposing the rules, it cannot state what the standard will be for any given discharger, or whether that discharger's effluent will exceed a new standard, and what treatment may be needed to meet the standard, once it is ascertained.[118]

79. Regulated parties predict extremely large costs for wastewater sulfate treatment and express frustration at the lack of specific information which would allow them to accurately predict and plan for water treatment requirements or variance requests.[119]

80. The Administrative Law Judge concludes that the Agency's decision to promulgate this rule without defining a standard applicable to each regulated wild rice water undermines many of the potential benefits the rule could provide to WWTP owners and operators, including improvements in their ability to plan, certainty about regulated waters, and efficiency in the regulated environment.

81. The Administrative Law Judge concludes that the proposed rule may continue to give rise to litigation regarding the identification of wild rice waters subject to the sulfate standard. In addition, the rule as proposed is more likely to give rise to litigation

[115] *Id.*
[116] Comments from 1854 Treaty Authority (filed Nov. 21, 2017); Comments from WaterLegacy (filed Nov. 22, 2017).
[117] Ex D at 58.
[118] *Id*. at 145-149, 165, 182-186.
[119] See, e.g., Exs. 1009, 1029, U.S. Steel Corporation comments (filed Nov. 22, 2017); Comments from Hibbing Chamber of Commerce (filed Nov. 2, 2017); Comments from Alexandria Lake Area Sanitary District (filed Nov. 20, 2017).

regarding the standard itself.[120] Therefore, the Administrative Law Judge concludes that the Agency incorrectly determined that the proposed rule will lead to less litigation concerning the water quality standards for wild rice waters.

82. The Administrative Law Judge finds that the Agency performed an analysis of classes of persons who probably will be affected by the proposed rule, including classes that will bear the costs of the proposed rule and classes that will benefit from the proposed rule as required by Minn. Stat. § 14.131(1). However, the Administrative Law Judge finds that the Agency's determinations as a result of that analysis are not supported by the record.

(2) The probable costs to the Agency and to any other agency of the implementation and enforcement of the proposed rule and any anticipated effect on state revenues.

83. The MPCA implements water quality standards primarily through permitting and assessment. The Agency states that it will continue its activities related to permit applications, variance requests, assessments, impaired water identification, and compliance enforcement using the revised standard instead of the previous standard.[121]

84. The MPCA predicts that it will incur the following additional costs if the proposed rules are adopted:

a. Updating the list of wild rice waters (data gathering and rulemaking);

b. Conducting sediment and surface water sampling and analysis;

c. Processing permit applications;

d. Reviewing variance requests; and

e. Responding to possible litigation.[122]

85. In this rulemaking, the Agency is proposing to identify approximately 1,300 waters as wild rice waters. While the Agency expects that these waters make up most of the wild rice waters in Minnesota, it expects it will be need to amend the rule within three years to add newly identified wild rice waters.[123]

86. The MPCA presumes that it will be able to gather information leading to the identification of additional wild rice waters through its existing triennial standards review process and its routine water assessment activities. Therefore, the MPCA does not expect to incur additional costs to obtain wild rice information.[124]

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[120] *See* discussion in this Report at 55-58.
[121] Ex. D SONAR at 152.
[122] Ex. D at 152-153.
[123] Ex. D at 153.
[124] *Id.*

87. The MPCA estimates the cost of a rulemaking including a hearing in three years will be approximately $129,000. The Agency projects that future amendments may not be controversial and may either be adopted without the need for a hearing, making them less costly, or may be combined with other rulemaking projects at no additional cost.[125]

88. Another cost of implementing the proposed rule will be calculating the new sulfate standard pursuant to the proposed equation-based standard or the alternative standard at each of the approximately 1,300 identified regulated wild rice waters. The MPCA plans to conduct analyses of the sediment of wild rice waters as part of its permitting process for new or expanding discharge sources, and its regular 10-year cycle of intensive watershed monitoring. The MPCA plans to initially focus its efforts to calculate the sulfate standard on wild rice waters associated with existing permitted dischargers.[126]

89. According to the MPCA, between 1,050 and 1,100 of the wild rice waters identified in the proposed rule are not currently impacted by a discharge, leaving approximately 200-250 waters for the MPCA to prioritize. The MPCA's plan to collect and sample the sediment, in order to calculate the standard under the proposed rule, is spelled out in the SONAR but not in the rule:

> [D]uring the existing process of preparation for each year's lake and stream monitoring, the MPCA will review how many wild rice waters are in the watershed, and the resources to collect and sample sediment. Waters to be sampled, if there are more than resources allow, will be prioritized based on factors such as the distance from dischargers, type of discharger, and timeline for permit reissuance.[127]

90. Using procedures for collection and analysis of the sediment according to the methods prescribed in its document entitled "Sampling and Analytical Methods for Wild Rice Waters,"[128] the MPCA determined that an average cost to conduct the necessary sampling analysis of a wild rice water in order to calculate the numeric sulfate standard will be approximately $1,200 per regulated wild rice water, including laboratory services.[129]

91. The MPCA separately calculated that the costs for porewater sampling and analysis to establish an alternate sulfate standard will be approximately $1,050 per

[125] *Id.*
[126] As stated above, the MPCA expects that, for new or expanded discharge sites, the permittee will be responsible for the cost of characterizing sediment total extractable iron and sediment total organic carbon. Ex. D at 154. This expectation is not stated in the rule.
[127] Ex. D at 154.
[128] The MPCA incorporated the Sampling and Analytical Methods for Wild Rice Waters by reference into the proposed rule. Ex. C. at lines 9.8-9.12 (part 7050.0224, subp. 5, E). However, as discussed later in this Report, the MPCA's December 1, 2017 Rebuttal comments include a proposal to allow people to use methods consistent with its methods, rather than strictly conforming to the methods as written. In addition, the MPCA mentions that it may make changes to the Sampling and Analytical Methods document. MPCA Rebuttal at 6-7.
[129] Ex. D at 154.

regulated wild rice water, including laboratory analysis of 10 porewater samples. For the alternate standard, the $1,050 is in addition to the initial $1,200 for calculating the numeric sulfate standard, resulting in a total of $2,250.[130]

92. The MPCA was unable to estimate the costs for establishing a site-specific standard, except to state that they will be highly variable:

> In addition to the cost of sediment sampling, and possibly porewater sampling, there will be other costs unique to the situation. It is likely that more extensive sampling and analysis will be needed and additional costs will be incurred to determine the factors affecting the wild rice beneficial use in that water body.[131]

93. The MPCA predicts that, while the complexity of the proposed wild rice sulfate standard will require increased staff time and costs to review permit applications, that increase will be balanced by a decrease in time required to resolve questions about whether the sulfate standard applies to a particular receiving water. Only those waters listed as wild rice waters in the proposed rule will be subject to the rule's sulfate standard. The MPCA states that the determination of "whether a water is a 'water used for production of wild rice' has been a significant obstacle to efficiently applying the existing sulfate standard, requiring time from multiple staff to make a determination."[132]

94. Because such determinations will no longer be required under the proposed rule, the MPCA anticipates that the proposed rule will not result in significant changes to the Agency's current administrative costs to review permit applications.[133]

95. Similarly, the Agency states it does not believe that it will incur significant increases in costs to process variance requests as a result of the proposed rule. The Agency acknowledges that a revised standard will likely result in requests for variances from the new standard, but states "it is difficult to predict how many, when they will be received, and the degree of complexity of those requests."[134] Nonetheless, the MPCA concludes that, as with permitting costs, it "does not expect that the costs associated with increased variance reviews will exceed the costs associated with the complicated and time consuming process required to implement the current rules."[135]

96. The MPCA recognizes that the portion of the proposed rule allowing for an exemption from the fees for municipal WWTPs seeking a variance from a wild rice standard or effluent limit will entail a cost to the MPCA.[136] The MPCA forecasts that the fee waiver will not have a significant impact on its resources because it is developing a streamlined variance application and review process specifically for the sulfate standard.

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[130] *Id*. at 154-155.
[131] *Id*. at 154.
[132] *Id*. at 155.
[133] *Id.*
[134] Ex. D at 156.
[135] *Id.*
[136] *Id.* Ex. C. at 67.20-67.21 (proposed rule 7053.0406, subp. 2, C).

The Agency expects that the streamlined process will result in a reduced level of staff effort required to review applications for variances from the proposed sulfate standards.[137]

97. The Agency stated frequently during public hearings that it expects WWTPs that are required to meet higher sulfate standards to apply for variances from those standards.[138] The cost analysis does not reflect an anticipated increase in variance requests, or a discussion of whether the Agency expects variance requests to increase as a result of expected higher standards for some dischargers under the proposed rules.

98. The MPCA anticipates litigation costs regardless of whether the proposed rules are adopted. It is not able to estimate what the costs will be, but surmises that the costs will be higher if the new standard is not adopted than if it is adopted. This is based on the MPCA's assumption that legal challenges under the existing standard will have to do with the identification of waters used for the production of wild rice, and that legal challenges under the proposed standard will be to permits issued under the revised standard.[139]

99. The MPCA does not include in its litigation estimate any possible challenges from one or more of the many groups that have vigorously opposed this rule. Those groups include Native American communities, environmental groups, mining companies, power companies, municipal WWTPs, and a variety of governmental entities. The Administrative Law Judge concludes the MPCA may have underestimated litigation costs that could follow if the rule is adopted.

100. Explaining that other state agencies incur costs if they have permitted projects or operations required to comply with water quality standards, the MPCA states that other agencies, especially the Minnesota Department of Transportation (MnDOT), and the Minnesota Department of Natural Resources (MDNR) may incur additional costs under the proposed rules. MnDOT operates highway rest areas and MDNR operates campgrounds and fish hatcheries, all of which generate wastewater. The wastewater treatment systems associated with these activities are often subsurface sewage treatment systems that do not discharge. However, the MPCA has determined that eight MnDOT or MDNR facilities operate WWTPs that discharge to proposed wild rice waters.[140]

101. Another situation that could result in costs to MnDOT will arise if MnDOT conducts road construction in an area of high sulfate rock, resulting in increased sulfate storm water runoff to nearby regulated wild rice waters. The MPCA explains that state agency costs "in these situations will vary based on the treatment facility and receiving water characteristics and may be incurred regardless of the adoption of the proposed

[137] Ex. D at 109, 156.
[138] *See* Tr. at 51-54 (Oct. 23, 2017); Tr. at 47-48 (Oct. 24, 2017); Tr. at 59-60 (Oct. 30, 2017).
[139] Ex. D at 156.
[140] Ex. D at 157.

rules."[141] The MPCA concludes that it is unable to provide a reasonable estimate of possible costs without considering the site-specific factors.[142]

102. The MPCA predicts that the proposed sulfate rule's greater protection for regulated wild rice will increase the value provided by the wild rice, including tourism dollars related to increased wild rice harvesting and related activities, and sales tax on more abundant marketed wild rice. The MPCA predicts that if the proposed rules are not adopted these benefits to state revenue will be lost.[143]

103. The MPCA theorizes that the proposed rule, if adopted, may inhibit industrial growth or expansion due to the added costs of complying with more stringent sulfate standards. This could result in lost jobs and reduced state tax revenue. Conversely, the MPCA posits that, to the extent that the new standard requires less treatment of wastewater, there could be additional investment in new and existing industrial facilities, with added jobs and financial benefits to the state. The MPCA also points out that where additional treatment is required at existing facilities, the costs of new treatment systems, and the installation and operation of those systems, could provide additional employment, increased income, and equipment purchases with resulting increases in income and sales tax revenue for the state.[144]

104. Ultimately, the Agency concludes that, while the proposed rule change will likely affect state revenues, it cannot predict the direction or magnitude of the impact on revenues.[145]

105. The Administrative Law Judge concludes that the Agency performed the analysis required regarding probable costs to itself, and to any other agency, of the implementation and enforcement of the proposed rule and any anticipated effect on state revenues to the extent that it was able to do so with incomplete information.

(3) The determination of whether there are less costly methods or less intrusive methods for achieving the purpose of the proposed rule.

106. The Agency combined its response to this statutory requirement with its response to statutory requirement (4) below.

[141] *Id.*
[142] *Id.*
[143] *Id.*
[144] Ex. D at 157-158.
[145] *Id*. at 158.

(4) A description of any alternative methods for achieving the purpose of the proposed rule that were seriously considered by the agency and the reasons why they were rejected in favor of the proposed rule.

107. The MPCA notes that the determination of whether there are less costly or less intrusive methods to protect wild rice waters depends on what level of protection is desired. A less protective sulfate standard may result in lower treatment costs for some dischargers, but may be less beneficial for the groups who value wild rice. Similarly, a more narrow definition of what constitutes a wild rice water may be deemed a benefit to some, but overly restrictive to others.[146]

108. The MPCA considered a number of possible alternatives to the proposed rule including: (1) adopting a narrative standard; (2) adopting a higher protective sulfide value; (3) maintaining the existing 10 mg/L sulfate standard or adopting a different fixed numeric standard instead of the proposed equation; and (4) adopting an alternative equation standard other than the proposed equation.[147]

109. After reviewing the possible alternatives, the MPCA concluded that its proposed equation standard, which tailors the sulfate standard to the naturally variable environmental conditions, represents the best current scientific understanding of the effect of sulfate and sulfide on wild rice and provides the most precise protection of wild rice water's beneficial use.[148] The MPCA concluded that a narrative standard would not represent a significant improvement over the current fixed standard and could not be effectively implemented through permitting or assessment.[149] The MPCA also maintains that fixed numeric standards ignore current scientific information correlating wild rice viability with sulfide resulting from the interaction of sulfate with other compounds in the sediment.[150] According to the MPCA, the most accurate fixed standard is still much less accurate than the proposed equation-based standard.[151] The MPCA states that it considered other equation standards but ultimately concluded that its proposed equation standard is appreciably more accurate (misclassification rate of 16 to 19 percent) than the other modeling it analyzed.[152]

110. The MPCA also considered applying the current 10 mg/L standard or adopting an interim standard for all wild rice waters where no equation-based sulfate value has been calculated. Commenters expressed concern that it will take the MPCA many years to calculate a standard for the 1,300 wild rice waters identified in this rulemaking.[153] The MPCA acknowledges the validity of the concern about the length of time it will take to characterize 1,300 wild rice waters it proposes to list in the rule.

[146] Ex. D at 159.
[147] *Id*. at 160-161.
[148] Ex. D at 159-163; MPCA's Response to Public Comments Attachment 1 at 3 (Nov. 22, 2017).
[149] Ex. D at 160.
[150] *Id*. at 161.
[151] *Id*.
[152] *Id*.
[153] Ex. D at 162.

However, it maintains it plans to prioritize those wild rice waters that receive or may receive a discharge from a permitted facility.[154] According to the MPCA, approximately 250-350 of the identified wild rice waters receive a discharge and it has developed an implementation plan to prioritize the sampling needed to calculate a numeric sulfate standard for those waters.[155]

111. The MPCA considered applying a "no net increase" in sulfate discharges to wild rice waters until a numeric standard is determined. But this proved to be difficult to create in rule and the Agency concluded it was unnecessary as no new discharges will be permitted without a sulfate standard being first calculated.[156]

112. The Agency also considered a number of alternatives to its criteria for identifying wild rice waters. The MPCA proposes to identify a wild rice water using the unique numeric identification it assigns to streams, rivers, and lakes.[157] This numeric identification is referred to as a water ID or WID.[158] Commenters expressed concern that identifying an entire large body of water as a wild rice water would not be reasonable if wild rice was only located in a small portion of the water body.[159] In response to these concerns, the MPCA considered identifying as a wild rice water only the specific area within a water where wild rice beds are found.[160] The MPCA concluded, however, that such an approach would be unreasonable because: (1) it would create a completely new system to identify a water, and (2) wild rice beds are known to move within a stream reach from one year to the next depending on hydrology and other factors.[161] According to the MPCA, a new form of identification would be inconsistent with the MPCA's many other data collection uses and would result in information that could not be effectively or efficiently compared and shared.[162]

113. The MPCA also received comments that its process of identifying wild rice waters was based on consideration of either too little or too much wild rice.[163] The MPCA maintains that the process it uses to identify wild rice waters reasonably characterizes them in regard to both the beneficial use of a Class 4D water (use of the grain as a food source by wildlife and humans) and the statutory mandate to consider the acreage and density of wild rice.[164] Under the proposed rules, the Commissioner is required to consider information about wild rice waters in the regular triennial water quality standards review process, which includes a public notice and comment period.[165]

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[154] *Id.*
[155] *Id.*
[156] *Id.*
[157] Ex. D at 40.
[158] *Id*. at 39.
[159] *Id*. at 162.
[160] *Id*. at 40.
[161] *Id*. at 40,162.
[162] *Id*. at 40-41.
[163] *Id*. at 162.
[164] *Id*.
[165] Ex. D at 163.

114. The MPCA considered alternatives for future identification of wild rice waters based on water bodies meeting specific stem densities or observation of wild rice over several growing seasons.[166] Ultimately, the MPCA decided that a specific threshold for determining wild rice waters was too limiting.[167] The MPCA maintains it is better to evaluate adding water bodies based on their unique factors as they relate to the beneficial use, which is the process the MPCA employed to identify the 1,300 wild rice waters being proposed.[168] The MPCA notes that, because each addition to the list of wild rice waters will be required to go through rulemaking, the specific factors demonstrating the beneficial use necessary to establish the water as a wild rice water will be considered in the SONAR and can be evaluated in that rulemaking.[169]

115. The MPCA also considered alternatives to the application of the proposed equation-based sulfate standard.[170] The MPCA contemplated applying averaging periods other than the annual average proposed. Some commenters suggested that a monthly average would be more protective of wild rice during critical growth periods.[171] Ultimately, the MPCA rejected shorter averaging periods. The MPCA maintains that its research supports the conclusion that porewater sulfide is a function of long-term (at least one year) average concentrations of sulfate, rather than short-term changes in surface water sulfate.[172]

116. The MPCA also considered alternatives for sediment sampling and analytical results in the equation-based standard.[173] The proposed rule establishes how many sediment samples must be taken and analyzed for iron and carbon and how the resulting values are used in the equation.[174] The MPCA proposes that the sediment of a wild rice water can be adequately characterized by a composite of five sediment cores from each of five different areas within the water body.[175] The MPCA proposes to designate the lowest of the five calculated sulfate concentrations as the sulfate standard for that wild rice water.[176]

117. Some commenters suggested taking the average value of the five sulfate concentrations, rather than the lowest.[177] Others suggested calculating the 10th or 20th percentile concentration from the data.[178] The MPCA considered these alternatives and concluded that taking the lower value would be the best approach. The MPCA contends that an average value would not be protective of the entire wild rice population and is susceptible to biasing high if the analysis yields one unusually high value that is

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[166] *Id*.
[167] *Id*.
[168] *Id*.
[169] *Id*.
[170] Ex. D at 164.
[171] *Id*.
[172] *Id*.
[173] *Id.*
[174] *Id*.
[175] *Id*.
[176] Ex. D at 165.
[177] *Id*.
[178] *Id.*

incorporated into the average.[179] Using the lowest value is also easier to implement than calculating a percentile value. The MPCA maintains that using the lowest value from the set of calculated sulfate concentrations is a reasonable method to produce a protective sulfate concentration for a wild rice water.[180]

118. Both Representative Rob Ecklund (Minnesota House District 3A) and Representative Matt Bliss (Minnesota House District 5A) noted that the MPCA had received $180,000 from the Legislative Citizens Commission on Minnesota Resources to analyze wastewater treatment alternatives to inform the development and analysis of wild rice, sulfate, and other water quality standards.[181] That analysis will be completed in May of 2018.[182] Both Representatives Ecklund and Bliss were critical of the MPCA for proposing the new sulfate standard before the analysis of wastewater treatment alternatives was completed. Representative Bliss stated that the legislature moved the deadline for completing this rulemaking to January of 2019 specifically so the MPCA could use the results of the study to further inform its new wild rice standard.[183]

119. The Iron Range Legislative Delegation[184] commented in a joint letter pointing out that, during the 2017 Legislative Session, the legislature provided the MPCA with an additional year, until January, 2019, to adopt a new wild rice water quality standard. The letter states that "[t]he proposed rules are premature . . ." because the sulfate treatment cost analysis is not complete. The letter also expressed concerns about the relative untested nature of the science underlying the proposed standard, and supported eliminating the 10 mg/L standard.[185]

120. WaterLegacy opposes the MPCA's proposed equation standard.[186] It contends that the MPCA's assumption that iron protects wild rice from the harmful effects of sulfate loading is premature and inconsistent with both laboratory experiments and field experience.[187] According to WaterLegacy, the proposed equation standard will neither provide effective protection of wild rice nor clarify implementation.[188]

121. WaterLegacy also opposes the MPCA's proposed identification of wild rice waters.[189] According to WaterLegacy, the MPCA's proposal to restrict the water bodies in which any wild rice sulfate standard would apply is arbitrary and would remove a

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179 *Id*.
180 *Id*.
181 Tr. at 87 (Oct. 25, 2017); Tr. at 69-72 (Oct. 30, 2017); Ex. 1015.
182 Ex. 1015.
183 *Id.*
184 Letter from Iron Range Legislative Delegation (Senators David Tomassoni, Thomas Bakk, and Justin Eichorn, and Representatives Jason Metsa, Rob Ecklund, Julie Sandstede, Dale Lueck, and Sandy Layman) (Nov. 2, 2017).
185 *Id.* at 1.
186 WaterLegacy comments (filed Nov. 22, 2017).
187 *Id*. at 18.
188 *Id*.
189 WaterLegacy comments (filed Nov. 22, 2017) at 30.

designated use and de-list wild rice waters identified by Minnesota state agencies, including waters downstream of existing and potential mining discharge.[190]

122. Similarly, both the Friends of the Boundary Waters and the Fond du Lac Band complained that the MPCA was removing a designated use when it failed to identify certain waters as wild rice waters.[191] The comments referred to all waters listed in Appendix B of the MDNR's 2008 *Natural Wild Rice in Minnesota* report and the 1854 Treaty Authority's 2016 and 2017 lists of wild rice waters.[192]

123. The MPCA maintains that not all surface waters in the state are class 4A waters used for the production of wild rice. The MPCA points out that the existing sulfate standard is applicable only to "water used in the production of wild rice" and that this modifying language clearly demonstrates that not all Class 4A waters are wild rice waters.[193] The MPCA also contends that the presence of a waterbody in the MDNR's 2008 inventory[194] is not sufficient to demonstrate beneficial use.[195]

124. Other commenters, like Mining Minnesota, complained that the MPCA was over-designating waters as wild rice waters.[196]

125. The Administrative Law Judge concludes that the MPCA provided the analysis required by Minn. Stat. § 14.131(4).

(5) The probable costs of complying with the proposed rules, including the portion of the total costs that will be borne by identifiable categories of affected parties, such as separate classes of governmental units, businesses, or individuals.

126. The MPCA states that, because many of the variables affecting costs cannot be determined until the standard is actually implemented at a specific location it has limited information about the probable costs of complying with the proposed rules.[197]

127. The MPCA acknowledges that if a facility needs to treat its wastewater discharge to comply with the revised water quality standard, the design, construction, installation, and operation of the treatment system will be a major cost.[198]

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[190] *Id*.
[191] *See* MPCA's Rebuttal Response to Public Comments Submitted during the Post-Hearing Public Comment Period at 12 (filed Dec. 1, 2017).
[192] *Id*.
[193] *Id*.
[194] MDNR's 2008 *Natural Wild Rice in Minnesota – A Wild Rice Report Study Report to the Legislature* (2008), Appendix B.
[195] *Id*.
[196] *See* Comments from Mining Minnesota (filed Nov. 22, 2017) and MPCA's Rebuttal Response to Public Comments Submitted during the Post-Hearing Public Comment Period at 13 (filed Dec. 1, 2017).
[197] *Id*.
[198] Ex. D at 166.

128. In addition to municipal WWTPs, the MPCA permits nearly 520 industrial wastewater discharges under its NPDES/SDS permitting program.[199] The MPCA permits a variety of types of industrial wastewater discharge, including discharges from non-contact cooling water systems, ethanol producers, manufacturing facilities, food processors, paper mills, and power plants. Industrial wastewater dischargers also include sand/gravel/stone mining, peat mining, and taconite mining operations.[200]

129. The MPCA acknowledges that treatment for sulfate can be extremely expensive.[201] According to the MPCA, reverse osmosis (RO) membrane filtration is the most practical sulfate treatment technology currently available for removing sulfate from wastewater discharges.[202] However, the MPCA states that there are significant design uncertainties that make it difficult to estimate costs for RO treatment of sulfate.[203] According to the MPCA, a design engineer would need to perform extensive site-specific analysis and engineering testing in order to get the correct parameters to design and cost a full-scale plant capable of removing sulfate and meeting all potential permit limits.[204] The MPCA states that, if bench or pilot testing of operations is required to obtain design parameters, it will add well over a year to the full-scale plant design time and hundreds of thousands of dollars to the design costs.[205]

130. The MPCA states that treating municipal wastewater using RO followed by evaporation and crystallization is likely to have high capital costs associated with sulfate-polishing costs that are above the costs of conventional WWTPs.[206] There will also be high operation and maintenance costs associated with concentrate management.[207] Energy and disposal costs are the primary drivers of concentrate management operations and maintenance costs.[208] The MPCA notes that RO is an energy intensive process but evaporation with crystallization is much more so.[209] In addition, the crystalized salts must be disposed of at a landfill and the tipping and hauling fees will add cost.[210] The MPCA cites to the Barr report that found five to ten percent of operations and maintenance costs were associated with disposal fees.[211]

131. RO membrane treatment with evaporation and crystallization also has significant secondary costs such as high carbon emissions, advanced operator training requirements, and an increased need for operator labor hours.[212] According to the MPCA, when evaporators and crystalizers are operated in conjunction with a RO plant,

[199] Ex. D at 169.
[200] *Id*.
[201] Ex. D at 182.
[202] *Id*. at 181-182.
[203] *Id*. at 181.
[204] *Id.*
[205] *Id.*
[206] Ex. D at 183.
[207] *Id*.
[208] *Id*.
[209] *Id*.
[210] Ex. D at 184.
[211] *Id*. citing SONAR Ex. 42.
[212] Ex. D at 184.

four to eight additional labor hours per eight-hour shift are normally required.[213] The MPCA acknowledges that the combination of these secondary considerations could prove prohibitively burdensome for affected communities.[214]

132. The MPCA notes that, with respect to municipal dischargers, there are some state programs available to mitigate the cost of activities necessary to comply with the proposed sulfate standard.[215]

133. With respect to taconite mine dischargers, the MPCA states that it is impossible to estimate the costs for treatment of taconite mine wastewater with a high degree of certainty as it will vary depending on the volume, concentration, level of treatment, and process used.[216] A mining company's 2012 estimate of costs associated with mining wastewater treatment to achieve the current wild rice sulfate standard of 10 mg/L identified total capital costs at over $20 million and annual operation and maintenance costs at nearly $3 million.[217]

134. The MPCA notes that the identification of 1,300 wild rice waters in the proposed rule will expand the number of permittees required to address sulfate treatment in their discharges.[218] This requirement will likely increase the cost of preparing a permit application for these permittees and the fees associated with the review of the application.[219]

135. In addition, the MPCA includes approximately $1,200 per body of wild rice water for taking samples to characterize the sediment and collecting and analyzing porewater for sulfide in order to develop the numeric standard.[220]

136. The record indicates that some industries and cities will incur substantial costs in complying with the proposed rules.

137. Many commenters expressed concern about the potential significant costs to municipal and industrial dischargers associated with achieving a revised sulfate standard. For example, the Duluth Area Chamber of Commerce indicated its opposition to the proposed rule revisions citing the prohibitively expensive treatment options.[221] Likewise, Nancy McReady with Conservationists with Common Sense (CWCS) predicted the proposed rules could bankrupt cities and businesses and result in large increases to residential sewer and water bills.[222]

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[213] *Id.*
[214] *Id.*
[215] Ex. D at 188.
[216] *Id*. at 184.
[217] Ex. D at 185, Table 18.
[218] Ex. D at 186.
[219] *Id*.
[220] *Id.*
[221] Rulemaking eComment from David Ross (filed Nov. 6, 2017).
[222] Rulemaking eComment from Nancy McReady (filed Nov. 4, 2017).

138. State Representative Mike Sundin (Minnesota House District 11A) echoed the Western Lake Superior Sanitary District's concern that implementation of RO treatment could require a $500 million investment, resulting in residential sewer bills increasing upwards of five times.[223] Gerard Bettendorf, mayor of the city of Foley, commented that the proposed rule could have a devastating economic impact on Foley and other cities throughout Minnesota.[224]

139. In its Response to Public Comments, the MPCA states that the conclusions made by some commenters regarding the extensive costs of implementing the proposed standard are premature.[225] The MPCA asserts that it intends to make use of available tools and "pursue creative strategies" to avoid impacts to municipalities and industries that would affect jobs, affordability of municipal services, and economic vitality.[226] According to the MPCA, economic and environmental health are not mutually exclusive.[227]

140. The Administrative Law Judge concludes that the MPCA has attempted to engage in the analysis required by Minn. Stat. § 14.131 but that the record does not support an adequate analysis.

(6) The probable costs or consequences of not adopting the proposed rule, including those costs borne by individual categories of affected parties, such as separate classes of governmental units, businesses, or individuals.

141. The MPCA asserts that there are two primary problems with the existing standard that would not be resolved if the proposed revisions are not adopted.[228] The first problem is the difficulty of determining how the standard applies and defining the waters to which the existing standard applies.[229] The existing standard has no clear information about duration and frequency and implementing the current standard requires a detailed case-by-case analysis to determine whether the wild rice beneficial use exists.[230]

142. According to the MPCA, failing to adopt the proposed revisions will result in continued uncertainty and the attendant need for case-by-case interpretation as to whether or not a water used for the production of wild rice is downstream of a discharge.[231] This confusion results in delays in the permitting process and increased costs of permit design and review.[232]

[223] Rulemaking eComment from Rep. Mike Sundin (filed Nov. 21, 2017).
[224] Ex. 1029.
[225] MPCA's Response to Public Comments at 11 (filed Nov. 22, 2017).
[226] *Id*.
[227] *Id*.
[228] Ex. D at 189.
[229] *Id*.
[230] *Id*.
[231] *Id*.
[232] *Id*.

143. The MPCA states that the second problem is the existing numeric sulfate standard's lack of accuracy in protecting wild rice beneficial use.[233] The MPCA maintains that current scientific understanding of sulfate toxicity means that the existing standard may be, depending on the circumstances, either over-protective or under-protective.[234] By retaining the existing standard and not adopting the proposed equation-based approach, the MPCA believes there will be higher misclassification rates and less accurate and effective protection of wild rice.[235]

144. The MPCA also contends that failing to adopt the proposed equation-based standard will result in less effective protection of wild rice, negatively impacting the economic, ecological, and cultural benefits provided by wild rice waters.[236]

145. Many commenters urged the MPCA to not adopt the proposed rule and to instead retain the existing 10 mg/L standard.[237] These commenters noted that keeping the existing 10 mg/L standard would be easier to enforce and more cost effective than trying to implement the proposed equation.[238]

146. Many commenters also agreed that the sulfate standard should be enforced year-round as proposed in the rule, rather than just during the wild rice growing season as required by the existing rule.[239]

147. The Administrative Law Judge concludes that the Agency conducted the analysis required by Minn. Stat. § 14.131(6).

(7) An assessment of any differences between the proposed rules and existing federal regulation and a specific analysis of the need for and reasonableness of each difference.

148. The MPCA states that there is no federal counterpart to the equation-based sulfate standard for wild rice waters or the process for identifying wild rice waters.[240] Therefore, it is not possible to assess any differences between the proposed rule revisions and existing federal regulations. The MPCA maintains, however, that the proposed revisions are consistent with the intent of the CWA as well as reasonable interpretations of federal guidance and the federal expectation that states develop state-specific water quality standards.[241]

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[233] Ex. D at 190.
[234] *Id*.
[235] *Id*.
[236] Ex. D at 193.
[237] *See, e.g.,* Rulemaking eComment from Kris Wegerson (filed Nov. 21, 2017).
[238] *Id*.
[239] Ex. 1020.
[240] Ex. D at 197.
[241] *Id.*

149. No other state has established a beneficial use class for wild rice or established a sulfate standard applicable to wild rice.[242]

150. The Grand Portage and Fond du Lac Bands of the Minnesota Chippewa Tribe have each established a water quality standard for wild rice.[243] The water quality standards for both tribes generally define wild rice areas as bodies of water that "presently has or historically had the potential to sustain the growth of wild rice." Both also establish a numeric sulfate standard of 10 mg/L.[244]

151. The MPCA's current wild rice sulfate standard and proposed revisions to the wild rice sulfate standard differ from the tribal standards as follows:

a. The proposed revisions clarify the existing beneficial use to "the use of the grain of wild rice as a food source for wildlife and humans."

b. The proposed rule revisions apply the standard to identified wild rice waters based on supporting the beneficial use. The tribal standards apply the standards more broadly to waters on the basis of past, present, or future potential to sustain growth of wild rice.

c. The existing state rules apply the sulfate standard "during periods when the rice may be susceptible to damage by high sulfate levels." The proposed revisions apply the sulfate standard as an annual average that can be exceeded once in ten years. The Grand Portage tribal standards do not specify when the standard applies. The Fond du Lac sulfate standard is an instantaneous maximum limit.

d. The proposed revisions to the state sulfate standard establish the protective sulfate value through an equation rather than a fixed 10 mg/L standard. Both tribal sulfate standards are fixed numeric standards of 10mg/L.[245]

152. The Administrative Law Judge finds that the Agency failed to discuss the definition of "existing use" under the CWA, and how its decision to exclude certain waters previously identified as wild rice waters corresponds with the CWA's definition of "existing use." Therefore, the Administrative Law Judge determines that the Agency has not met its obligation under Minn. Stat. § 14.131(7) to assess the differences between the proposed rule and federal regulations and the reasonableness of each difference.

153. The Administrative Law Judge notes that the Agency failed to address the potential conflict between the 10 mg/L sulfate standard on the Fond du Lac and Grand Portage Indian Reservations and the proposed equation-based sulfate standard. While this failure may not technically violate the requirements of Minn. Stat. § 116.07, subd. 2(f) (2016), the Administrative Law Judge views this as a violation of the underlying purpose of this statutory requirement.

[242] *Id.*
[243] Id.; SONAR Exs. 45 and 46.
[244] Ex. D at 197; SONAR Exs. 45 and 46.
[245] Ex. D at 197-198; SONAR Exs. 45 and 46.

154. The Administrative Law Judge finds that the Agency has met its special obligations under Minn. Stat. § 116.07, subd. 2(f), to assess the impact of the proposed rule and the approaches taken by neighboring states.

(8) Assessment of the cumulative effect of the rule with other federal and state regulations related to the specific purpose of the rule.

155. "Cumulative effect" means the incremental impact of the proposed rule in addition to other rules, regardless of what state or federal agency has adopted the other rules. Cumulative effects can result from individually minor, but collectively significant, rules adopted over a period of time.[246]

156. As noted above, there is no federal counterpart to the wild rice sulfate standard. Therefore, there is no cumulative effect to assess with respect to other federal regulations.

157. The MPCA maintains that, because it is replacing the existing water quality standard and not proposing an additional standard, the revised standard does not create cumulative impacts.[247] According to the MPCA, an assessment of whether a regulation has a cumulative effect is "whether the proposed revisions duplicate an existing rule that achieves the same purpose."[248]

158. The Administrative Law Judge disagrees that this is the proper analysis for the question of cumulative effect. The Administrative Law Judge looks first to the plain language of the word "cumulative." The first dictionary definition of "cumulative" is "increasing by successive additions."[249] "Duplicative," in contrast, means "consisting of or existing in two corresponding or identical parts or examples."[250]

159. The legislative history of Minn. Stat. § 14.131(8) demonstrates that Minnesota legislators were not concerned with agencies promulgating rules that were duplicative. They were concerned with regulations that have an increasing effect on regulated parties. At a hearing before the Senate Committee on Finance when the "cumulative effect" language was under consideration, the MPCA's legislative director spoke to the committee:[251]

> One example [is] our agency deals with hazardous waste, medical waste. As we deal on the disposal side of it, once it gets to a landfill. However, up the chain of control of that issue that is handled by a number of additional

[246] Minn. Stat. § 14.131.
[247] Ex. D at 199.
[248] *Id.*
[249] Merriam-Webster online dictionary, https://www.merriam-webster.com/dictionary/cumulative.
[250] Merriam-Webster online dictionary, https://www.merriam-webster.com/dictionary/duplicative.
[251] Testimony of Kirk Koudelka, legislative director, MPCA before Senate Comm. On Finance, S.F. 1922 (Mar. 29, 2012).

agencies that could have an impact on that. Us then having to do a cumulative effect on how a hospital handles their medical waste or how MnDOT regulates how they transport medical waste before it gets to the landfill.

160. In response to the Committee Chair Robling's concern that the MPCA was not considering the cumulative effect of regulations, and that legislators were hearing from constituents that the cumulative effect was overwhelming,[252] Mr. Koudelka replied:[253]

> For instance, right now we are working on some mercury rules for facilities and their mercury emissions. We do look at what other requirements are on the federal level on that. . . . . The way this is written, all other rules that affect that waste, through its chain of command, even though we may not personally have any authority over it, would have to be looked at. There is some concern on what that does to the scope from a number of agencies . . . .

161. The Administrative Law Judge finds that the MPCA has not met its obligation to assess the cumulative effect of the rule with other federal and state regulations related to the specific purpose of the proposed rule.

2. Performance-Based Regulation

162. The Administrative Procedure Act[254] also requires an agency to describe how it has considered and implemented the legislative policy supporting performance based regulatory systems. A performance-based rule is one that emphasizes superior achievement in meeting the agency's regulatory objectives and maximum flexibility for the regulated party and the agency in meeting those goals.[255]

163. The Agency asserts that the proposed rules meet the state's objectives for flexible, performance-based standards. It maintains that the existing WQS are a performance-based regulatory system. The WQS identify, using the best-available science, the conditions that must exist in Minnesota's water bodies to support each waters' designated uses. Because the proposed rules do not dictate how a regulated party must achieve the wild rice beneficial use or prescribe how they must operate to ensure compliance with the WQS, the Agency maintains they allow regulated parties maximum flexibility in meeting the standard. The Agency concedes, however, that, in the case of sulfate treatment, there are limited alternatives and options available to meet the standard. Nonetheless, the Agency contends that, by not dictating a single course of action and by allowing for variances, the proposed rules meet the requirement of emphasizing maximum flexibility for the regulated parties.[256]

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[252] Chair Claire A. Robling, Senate Comm. On Finance, S.F. 1922 (Mar. 29, 2012).
[253] Testimony of Kirk Koudelka, legislative director, MPCA before Senate Comm. On Finance, S.F. 1922 (Mar. 29, 2012).
[254] Minn. Stat. § 14.131.
[255] Minn. Stat. § 14.002.
[256] Ex. D at 201.

164. The Administrative Law Judge finds that the Agency has met the requirements set forth in Minn. Stat. § 14.131 for consideration and implementation of the legislative policy supporting performance-based regulatory systems.

3. Consultation with the Commissioner of Minnesota Management and Budget (MMB)

165. By memorandum dated September 7, 2017, Sean Fahnhorst, an Executive Budget Officer with MMB, responded to the MPCA's request to evaluate the fiscal impact and benefit of the proposed rules on local units of government, as required by Minn. Stat. § 14.131.[257] The MPCA estimates that the 62 municipal wastewater treatment plants that discharge into or within 25 miles upstream of identified wild rice waters are most likely to incur major costs to upgrade their treatment processes to comply with these revised standards.[258] The MPCA provided a "preliminary analysis of the costs" in its SONAR and indicated that it expects to complete further analysis of the costs and alternatives of sulfate treatment by May 2018.[259]

166. MMB reviewed the proposed rules and the Agency's SONAR. MMB noted that municipal wastewater treatment plants are generally not designed to remove sulfate and that upgrades to existing facilities will be non-standard and require site-specific analysis and engineering testing. MMB noted further that few options exist for removing sulfate from wastewater, and the methods available can be very expensive. MMB concluded that cost estimates for upgrades are only possible with detailed wastewater treatment plant design information.[260]

167. MMB also noted that the MPCA expects to grant variances to some municipal wastewater treatment facilities, which would exempt them from discharge limits related to this standard if they demonstrate that economic or technological factors prevent their compliance. Local governments would incur administrative costs applying for the variance, but the MPCA proposes to reduce some of these expenses by waiving the variance application fee and assisting municipalities with the application process.[261]

168. Finally, MMB noted that, in terms of fiscal impacts, the proposed rules may benefit some local governments by identifying nearby wild rice waters, clarifying wastewater regulations and standards, and attracting tourists.[262]

169. The purpose of the consultation with MMB required by Minn. Stat. § 14.131 is "to help evaluate the fiscal impact and fiscal benefits of the proposed rule on units of local government." [263] In this case, given the scarcity of information available about the

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[257] Ex. K3.
[258] *Id.*
[259] *Id.*
[260] *Id*.
[261] Ex. K3.
[262] *Id*.
[263] Minn. Stat. § 14.131.

actual costs and benefits that are likely to accrue to local governments, the MMB memorandum reaches no conclusions regarding the adequacy of the information and analysis provided by the Agency. Nor is MMB provided with enough information to engage in its own evaluation of the fiscal impacts and benefits of the proposed rule on units of local government.

170. The Administrative Law Judge finds that the Agency consulted with MMB as required under Minn. Stat. § 14.131, but failed to provide adequate information to help MMB evaluate the fiscal impacts and benefits of the proposed rule on units of local government.

4. Cost to Small Businesses and Cities under Minn. Stat. § 14.127

171. Minn. Stat. § 14.127 requires the Agency to "determine if the cost of complying with a proposed rule in the first year after the rule takes effect will exceed $25,000 for: (1) any one business that has less than 50 full-time employees; or (2) any one statutory or home rule charter city that has less than ten full-time employees." The Agency must make this determination before the close of the hearing record, and the Administrative Law Judge must review the determination and approve or disapprove it.[264]

172. The Agency concludes that a small business or city within the definition of Minn. Stat. § 14.127 may incur expenses in excess of $25,000 to comply with the proposed rule in the first year after the rule takes effect. However, the Agency believes that such a circumstance is unlikely to occur within a year after the rule takes effect.[265]

173. The Agency discusses the criteria it developed that are necessary to determine which small businesses and cities could potentially be included in an analysis pursuant to Minn. Stat. § 14.127. The criteria identified by the Agency are as follows:

a. The business or city must discharge to a surface water.

b. The surface water receiving the discharge must be a wild rice water or within a certain range of a wild rice water. For purposes of this evaluation, the MPCA selected a range of 25 miles.

c. The discharge must contain sulfate.

d. The affected business must have fewer than 50 full-time employees. Affected cities must have fewer than 10 full time employees.

e. The business or city must need to obtain a new or re-issued permit within the first year after the rules are adopted.

f. The MPCA must have sufficient information available to develop an effluent limit – including sediment data to set the numeric standard

[264] Minn. Stat. § 14.127, subds. 1 and 2.
[265] Ex. D at 202.

for the receiving wild rice water, sulfate levels in the receiving water, and data on sulfate concentrations in the business or city's effluent.

g. The application of the adopted sulfate standard must result in effluent limits that are more stringent.

h. The business or city must incur costs of more than $25,000 in the first year following adoption of the proposed revisions for planning, installation, or operation activities specifically to meet the revised standard.[266]

174. Using these criteria, the Agency calculates that, of the 135 dischargers within 25 miles of a regulated wild rice water, there are approximately 75 small businesses and cities that may be affected by the proposed revisions and currently have permits. Because the MPCA issues permits to dischargers on a five-year schedule, fewer than 75 will be required apply for a permit under the new standard in the first year. Nonetheless, assuming the rule is adopted in mid-2018,[267] the MPCA estimates that more than 60 dischargers will at least begin the process of updating their existing permits in 2018.[268]

175. According to the Agency, permit issuance or renewal involves "setting effluent limits, developing and reviewing plans and specifications, permit notice and approval, and construction activities."[269] In addition, the Agency recognizes that "dischargers may have to make a significant initial investment in planning and preliminary design work in advance of receiving the permit."[270]

176. The Agency explains that the cost driver for dischargers is the implementation of a sulfate effluent limit in a permit, which requires the discharger to take action to either limit the sulfate in its discharge or to request a variance. Before a discharger can be assigned an effluent limit, the MPCA must know the numeric sulfate standard applicable to the receiving wild rice water. In addition, the discharger's sulfate effluent concentrations must be available.[271]

177. The Agency states that a majority of dischargers do not have current effluent monitoring for sulfate. For these dischargers, the Agency estimates that sulfate limits could not be implemented before 2023.[272]

178. According to the Agency, only if a small business or city receives a more stringent effluent limit than was required under the existing standard will it have higher treatment costs than it would have had under the 10 mg/L standard, or incur the costs of applying for a variance.[273] However, a facility will not know whether its effluent limit is

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[266] Ex. D at 204.
[267] *Id*. at 202.
[268] *Id*. at 206.
[269] *Id.*
[270] *Id.*
[271] *Id*. at 207.
[272] *Id.*
[273] *Id.*

more or less than it would be under the existing standard until the new standard has been set for the receiving wild rice water.[274]

179. The Agency does not explain why it estimates that it will take dischargers five years to monitor their own sulfate discharges.

180. Furthermore, the Agency states that it expects to take up to ten years to sample the 1,300 regulated wild rice waters identified in the proposed rule for the purpose of setting new standards.[275]

181. Nonetheless, for purposes of the rulemaking evaluation, the MPCA assumes that all the identified dischargers will have to either meet more stringent sulfate discharge limits or apply for variances. The cost to treat wastewater to remove sulfate is extremely high. The MPCA recognizes that the most effective treatment option at this time to remove sulfate from wastewater is an RO membrane treatment system.[276] The cost of designing, building and operating an RO system will certainly exceed $25,000. However, the MPCA expects permittees will not incur the full cost of treatment or design/build in the first year after adoption of the proposed rules.[277]

182. The MPCA expects that WWTPs that meet the above criteria may incur costs in the first year after the rules are adopted. Costs could include retaining a contractor or designer to begin the process of evaluating discharge and treatment options, among other items. The WTTP could also begin the process of bench-scale studies and facility design, although the MPCA believes a variance application is more likely. The MPCA notes that the cost of a variance alone could exceed $25,000, especially for an industrial facility for which there is no variance fee waiver in the rule. However, the MPCA does not presume that the cost of a variance for a municipality would necessarily be less than $25,000.[278]

183. The MPCA cannot estimate the cost of these activities "because of the extent of the variables,"[279] but the Agency concludes that such costs will "be significant" and "may exceed $25,000"[280] for some small businesses and cities in the first year after adoption of the proposed revisions.[281]

184. While the MPCA's analysis pursuant to Minn. Stat. § 14.127 discusses the question of whether small businesses and cities will spend more than $25,000 to comply with the proposed rule within one year after the rule is adopted, the statutory language

[274] Ex. D at 207.
[275] Response Cover Memo at 10.
[276] Ex. D at 207.
[277] *Id.*
[278] Ex. D at 208.
[279] *Id.*
[280] *Id.*
[281] *Id.*

requires this analysis to focus on the "cost of complying with a proposed rule in the first year after the rule takes effect . . . ."[282]

185. Because MPCA predicts that it will likely take five to ten years to sample the regulated wild rice waters identified in the proposed rule for the purpose of setting new standards that will provide the basis for new effluent limits, the Administrative Law Judge finds that the rule cannot take effect for purposes of the Agency's analysis under Minn. Stat. § 14.127 until the necessary sediment and porewater sampling have been completed and new sulfate standards calculated pursuant to the equation standard in the proposed rule.

186. Any attempt to perform the analysis required by Minn. Stat. § 14.127 is based on conjecture regarding whether and to what extent any given small business or city that meets the criteria outlined by the MPCA will be subject to a more stringent effluent limit once a new standard is determined for receiving waters subject to the wild rice sulfate rules.

187. The legislature's purpose in enacting Minn. Stat. § 14.127 was to better understand the impact of its regulatory delegations. For example, in its 1993 review of Minnesota's rulemaking process, the State Commission on Reform and Efficiency observed that the legislature is often "not aware of the specific costs of preparing and adopting the rules it authorizes or requires" and "lacks cost information when considering bills authorizing rulemaking."[283] In this context, the provisions of Minn. Stat. § 14.127 operate as a check against the legislature misjudging the cost of regulatory programs when it delegates rulemaking authority.

188. The structure and text of the exemptions in Minn. Stat. § 14.127, subd. 4, confirm this conclusion. Subdivision 4 provides that there is no safe harbor from regulatory compliance for small cities and small businesses when:

a. the legislature has appropriated sufficient funds for the costs of complying with the proposed rule;

b. the proposed rule follows from "a specific federal statutory or regulatory mandate";

c. the rules were promulgated under the limited exemption of the "good cause exempt" rulemaking procedure;

d. the legislature exempted the proposed rules from compliance with Chapter 14 rulemaking procedures;

e. the rules were promulgated by the Public Utilities Commission; or

[282] Minn. Stat. § 14.127 (emphasis added).
[283] *See* Finding 6, *Reforming Minnesota's Administrative Rulemaking System* (State Commission on Reform and Efficiency, 1993.).

f. the Governor waives the safe-harbor provisions by filing a notice with both houses of the legislature and publishing the same in the *State Register*.

189. These exemptions reflect an underlying legislative assumption that delegated rulemaking authority will not result in compliance costs of more than $25,000 for a small city or small business during the first year. If that cost assumption is not generally true for a particular agency (such as the Public Utilities Commission), or untrue with respect to a particular program (such that appropriation accompanies the rulemaking delegation), one of the listed exemptions will apply. In all other cases, the legislature offers the affected stakeholders the opportunity to revisit the question of compliance costs with the legislature and the agency.[284]

190. The Agency's application of the statute significantly narrows the protections for small businesses and small cities. Under Minn. Stat. § 14.127, a qualifying small city or small business may opt out of costly regulatory programs by filing "a written statement with the agency claiming a temporary exemption from the rules"[285] until "the rules are approved by a law enacted after the agency determination or administrative law judge disapproval."[286] Because, according to the MPCA, the small businesses and cities it has identified as potentially affected by $25,000 limitation in Minn. Stat. § 14.127 will not know for certain whether their effluent limits will be more or less stringent until the new sulfate standards are calculated, it is not technically possible for any small city or business to claim that it must spend $25,000 in order to comply with the new sulfate standards. Thus, the Agency's attempt to implement a rule without definite standards runs afoul of the statutory language of Minn. Stat. § 14.127, despite the Agency's finding that some small businesses and cities may spend $25,000 within a year after the proposed rule is adopted.

191. The Administrative Law Judge finds that the Agency has made a determination required by Minn. Stat. § 14.127, but that determination is not adequately supported in the rulemaking record. The hearing record does not establish that the compliance costs for any one qualifying small city or small business will be more than $25,000 in the first year following the adoption of the proposed rule because the hearing record does not establish that the compliance costs for any one qualifying small city or small business will be known within one year of adoption of the proposed rule.

192. The cost determination under Minn. Stat. § 14.127 is disapproved.

193. The result of this cost determination disapproval would usually be that any small business or city that must spend more than $25,000 to comply with this rule can file a statement with the Agency pursuant to Minn. Stat. § 14.127, subd. 3, claiming a temporary exemption pending further action by the legislature. Because the basis for the disapproval is that the Agency has failed to provide the information required to make a

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[284] Minn. Stat. § 14.127, subd. 3.
[285] *Id.*
[286] *Id.*

finding under Minn. Stat. § 14.127, it is not possible for a small city or business to claim a temporary exemption at this time without further action by the Agency.

5. Adoption or Amendment of Local Ordinances

194. Under Minn. Stat. § 14.128 (2016) the Agency must determine if a local government will be required to adopt or amend an ordinance or other regulation to comply with a proposed agency rule. The Agency must make this determination before the close of the hearing record, and the Administrative Law Judge must review the determination and approve or disapprove it.[287]

195. The Agency states that, because state water quality standards are not implemented at the local level, no changes will be required to local ordinances or regulations in response to the proposed rule revisions. The Agency notes, however, that local units of government that own or operate a WWTP may be subject to additional conditions on discharges due to the proposed revisions. For example, a city may require pre-treatment of high sulfate wastewater or charge a higher fee for discharge of sulfate to the municipal WWTP. These conditions may be in the form of an ordinance or regulation, but they are not specifically required by the proposed rules.[288]

196. The Administrative Law Judge finds that the Agency has made the determination required by Minn. Stat. § 14.128 and approves that determination.

6. Economic Analysis and Identification of Cost-Effective Permitting

197. Pursuant to a 2015 Minnesota Session Law,[289] the MPCA is required to consider the effect the proposed revisions will have on MPCA's permit process for industrial and municipal dischargers.[290]

198. The MPCA states that it considered the effects its proposed revisions will have on the permit process and it recognizes that, for some dischargers, the proposed rules may result in substantial costs.[291]

199. The MPCA expects that, in most cases, dischargers can only meet the proposed sulfate standard by using membrane treatment. The MPCA recognizes that the current options for treating sulfate are costly and complex.[292]

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[287] Minn. Stat. § 14.128, subd. 1. Moreover, a determination that the proposed rules require adoption or amendment of an ordinance may modify the effective date of the rule, subject to some exceptions. Minn. Stat. § 14.128, subds. 2 and 3.
[288] Ex. D at 201.
[289] 2015 Minn. Laws 1st Spec. Sess. ch. 4, art. 3, § 2, subd. 2 (authorizing funds for "enhanced economic analysis in the water quality standards rulemaking process, including more specific analysis and identification of cost-effective permitting.").
[290] Ex. D at 209-213.
[291] *Id*. at 209.
[292] *Id*.

200. The MPCA states that industrial dischargers could encounter substantial treatment costs if sulfate effluent limits are included in NPDES/SDS permits. The industries most likely to be affected include ethanol producers, food processors, power plants, ferrous (taconite) mining and processing, and any potential non-ferrous mining. The taconite industry on the Mesabi Iron Range is likely to be the most affected of the industrial categories because of the prevalence of wild rice in that region, the amount of sulfate generated by mining and processing, the aggregate volume of water discharged, and the elevated sulfate concentrations from legacy mining.[293]

201. The MPCA notes that variances from water quality standards are a permitting tool that may be used to temporarily address uncertain or costly treatment alternatives.[294] The MPCA expects variances to become an increasingly necessary component of the permit process as more stringent water quality-based effluent limits are implemented.[295] In considering a variance, the MCPA must determine the point at which costs would result in substantial and widespread negative economic and social impact such that compliance with the standard is not feasible.[296] All variances from a water quality standard are subject to final approval by the United States Environmental Protection Agency (EPA).[297]

202. Because the proposed sulfate effluent limits may prompt an increase in variance requests, the MPCA is considering implementing a streamlined variance process. According to the MPCA, the streamlined process will define the information required for obtaining final approval from the EPA and allow ample time for a discharger to consider its permitting options. The MPCA maintains that the streamlined process will reduce permitting uncertainty and application review time and result in more cost-effective permitting.[298]

203. The Administrative Law Judge concludes the Agency has made the analysis required under 2015 Minn. Laws 1st Spec. Sess. ch. 4, art. 3, § 2, subd. 2, given the limited information available.

7. External Review Panel

204. The Agency is required to convene an external review panel during the promulgation or amendment of a water quality standard, or state in the SONAR why such a panel was not convened.[299]

205. The MPCA conducted an external peer review on the state-sponsored wild rice study in 2014.[300] The report of the peer review panel was released in September

[293] *Id*. at 209-210.
[294] Ex. D at 210.
[295] *Id*.
[296] *Id*.
[297] *Id*.
[298] Ex. D at 216.
[299] *See* Minn. Stat. § 115.035 (2016).
[300] Ex. D at 217.

2014.[301] The names and affiliations of the peer reviewers are provided in Table 19 of the SONAR.[302] The MPCA states that the report of the peer review panel informed its analysis and interpretation of data regarding the effect of sulfate on wild rice and that analysis is reflected in its March 2015 draft proposal.[303]

206. The Administrative Law Judge finds that the Agency met the requirement of Minn. Stat. § 115.035 regarding external review panels.

IV. Rulemaking Legal Standards

207. The Administrative Law Judge must make the following inquiries: whether the agency has statutory authority to adopt the rule; whether the rule is unconstitutional or otherwise illegal; whether the agency has complied with the rule adoption procedures; whether the proposed rule grants undue discretion to government officials; whether the rule constitutes an undue delegation of authority to another entity; and whether the proposed language meets the definition of a rule.[304]

208. Under Minn. Stat. § 14.14, subd. 2 and Minn. R. 1400.2100 (2017), the agency must establish the need for, and reasonableness of, a proposed rule by an affirmative presentation of facts. In support of a rule, the agency may rely upon materials developed for the hearing record,[305] "legislative facts" (namely, general and well-established principles that are not related to the specifics of a particular case but which guide the development of law and policy),[306] and the agency's interpretation of related statutes.[307]

209. A proposed rule is reasonable if the agency can "explain on what evidence it is relying and how the evidence connects rationally with the agency's choice of action to be taken."[308] By contrast, a proposed rule will be deemed arbitrary and capricious where the agency's choice is based upon whim, devoid of articulated reasons or "represents its will and not its judgment."[309]

210. An important corollary to these standards is that when proposing new rules an agency is entitled to make choices between different possible regulatory approaches, so long as the alternative that is selected by the agency is a rational one.[310] Thus, while reasonable minds might differ as to whether one or another particular approach

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[301] *Id*.; SONAR Ex. 9.
[302] Ex. D at 217.
[303] *Id*; SONAR Ex. 10.
[304] *See* Minn. R. 1400.2100.
[305] *See Manufactured Housing Institute v. Pettersen*, 347 N.W.2d 238, 240 (Minn. 1984); *Minnesota Chamber of Commerce v. Minnesota Pollution Control Agency*, 469 N.W.2d 100, 103 (Minn. Ct. App. 1991).
[306] *Compare generally United States* v. *Gould,* 536 F.2d 216, 220 (8th Cir. 1976).
[307] *See Mammenga v. Agency of Human Services*, 442 N.W.2d 786, 789-92 (Minn. 1989); *Manufactured Manufactured Hous. Inst.*, 347 N.W.2d at 244.
[308] *Manufactured Hous. Inst.*, 347 N.W.2d at 244.
[309] *See Mammenga*, 442 N.W.2d at 789; *St. Paul Area Chamber of Commerce v. Minn. Pub. Serv. Comm'n,* 251 N.W.2d 350, 357-58 (Minn. 1977).
[310] *Peterson v. Minn. Dep't of Labor & Indus*., 591 N.W.2d 76, 78 (Minn. Ct. App. 1999).

represents "the best alternative," the agency's selection will be approved if it is one that a rational person could have made.[311]

211. Because both the Agency and the Administrative Law Judge suggested changes to the proposed rule language after the date it was originally published in the *State Register*, it is also necessary for the Administrative Law Judge to determine if this new language is substantially different from that which was originally proposed.

212. The standards to determine whether any changes to proposed rules create a substantially different rule are found in Minn. Stat. § 14.05, subd. 2(b). The statute specifies that a modification does not make a proposed rule substantially different if:

> (1) the differences are within the scope of the matter announced . . . in the notice of hearing and are in character with the issues raised in that notice;
>
> (2) the differences are a logical outgrowth of the contents of the . . . notice of hearing, and the comments submitted in response to the notice; and
>
> (3) the . . . notice of hearing provided fair warning that the outcome of that rulemaking proceeding could be the rule in question.

213. In reaching a determination regarding whether modifications result in a rule that is substantially different, the Administrative Law Judge must consider whether:

> (1) persons who will be affected by the rule should have understood that the rulemaking proceeding . . . could affect their interests;
>
> (2) the subject matter of the rule or issues determined by the rule are different from the subject matter or issues contained in the . . . notice of hearing; and
>
> (3) the effects of the rule differ from the effects of the proposed rule contained in the . . . notice of hearing.[312]

V. Analysis of the Proposed Rule

214. There were few sections of the proposed rule that were not opposed by any member of the public. This Report will first address the three portions of the rule that are central to its function and design: Minn. R. 7050.0224, subp. 2, which proposes to repeal the 10 mg/L sulfate standard; Minn. R. 7050.0224, subp. 5, B (1), which proposes to replace the 10 mg/L standard with the equation-based sulfate standard; and Minn. R. 7050.0471, subps. 3-9, which proposes the list of waters to be included as class 4D waters to be protected by the wild rice sulfate standard.

[311] *Minnesota Chamber of Commerce*, 469 N.W.2d at 103.
[312] *See* Minn. Stat. § 14.05, subd. 2.

A. Repeal of the 10 mg/L Sulfate Standard

215. Minn. R. 7050.0224, subp. 2, proposes to repeal the 10 mg/L sulfate standard applicable to wild rice waters, which are currently classified as Class 4A waters.[313]

216. Minn. R. 7050.0220, subps. 3a, 4a, 5a, and 6a, propose to delete references to the 10 mg/L sulfate wild rice water standard.[314]

217. A number of commenters support repeal of the 10 mg/L sulfate standard as it applies to wild rice waters, without regard to whether they are re-classified as Class 4D waters or remain classified as Class 4A waters.[315]

218. The MPCA responded that the decision to repeal the 10 mg/L standard "is not separate from moving forward with the proposed equation."[316] Because the MPCA has determined that sulfate negatively affects wild rice, albeit indirectly rather than directly, the MPCA determined that "[i]t is not scientifically defensible to conclude that simply eliminating the existing sulfate standard would protect" wild rice.[317]

219. The 1854 Treaty Authority, the Fond du Lac Band of Lake Superior Chippewa, the Grand Portage Band of Chippewa, WaterLegacy, and numerous individuals oppose repeal of the 10 mg/L sulfate standard.[318] These commenters and others express concerns that increases in sulfate could lead to increases in methyl mercury, which bio-accumulates in fish, has long-term serious health effects on humans, and is especially dangerous to developing fetuses.[319] Some commenters also question

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[313] Ex. C at 7.16, proposed Minn. R. 7050.0224, subp. 5.
[314] Ex. C at 3.16, 4.11, 5.7, 5.23, proposed Minn. R. 7050.0220, subps. 3a, 4a, 5a, and 6a.
[315] Test. of Rob Beranek, Oct. 23 Tr. at 91; eComment from Kurt Anderson on behalf of Minnesota Power at 7 (Minnesota Power comment) (Nov. 21, 2017); eComment from Elizabeth Wefel on behalf of Coalition of Greater Minnesota Cities at 1-2 (Coalition of Greater MN Cities comment) (Nov. 22, 2017); Test. of Chrissy Bartovich, Oct. 24, 2017 Tr. at 82; Test. of Jason Metsa, Oct. 24, 2017 Tr. at 104; Letter from Iron Range Mayors (Hoyt Lakes, Ely, Virginia, Nashwauk, Aurora, Biwakbik, Grand Rapids, Hibbing, Babbitt, Mountain Iron) at 1 (Nov. 6, 2017); Letter from Iron Range Legislative Delegation (Senators David Tomassoni, Thomas Bakk, and Justin Eichorn, and Representatives Jason Metsa, Rob Ecklund, Julie Sandstede, Dale Lueck, and Sandy Layman) (Nov. 2, 2017).
[316] MPCA Response, Att. 1 at 24.
[317] MPCA Response at 3.
[318] eComment from Paula Maccabee on behalf of WaterLegacy at 11-12, 55-56 (WaterLegacy comment), (eComment filed Nov. 22, 2017); Letter from Darren Vogt at 5 (Nov. 21, 2017); eComment from Nancy Schuldt at 25 (Nov. 22, 2017); Test. of Dennis Scymialis, Oct. 26, 2017, Tr. at 70; Test. of Tom Thompson, Oct. 26, 2017, Tr. at 75. Some commenters objected to the Agency's classification of wild rice waters as class 4 waters rather than class 2 waters. Test. of Margaret Watkins, Oct. 26, 2017, Tr. at 89-90, Hearing Ex. 1020 (Letter from Dennis Morrison on behalf of Grand Portage Tribal Reservation Council at 8 and Letter from Robert L. Larsen on behalf of Minnesota Indian Affairs Council at 2).
[319] Test. of Dave Zentner, Oct. 26 Tr. at 117; Test. of Dr. Emily Onello, Oct. 26, 2017, Tr. at 68; Test. of Margaret Watkins, Oct. 26, 2017, Tr. at 89-90, Hearing Ex. 1020 (Letter from Dennis Morrison on behalf of Grand Portage Tribal Reservation Council at 8 and Letter from Robert L. Larsen on behalf of Minnesota Indian Affairs Council at 2).

whether the extraordinary nutritional value – and health benefits – of wild rice will be degraded by increased surface water sulfate levels.[320]

220. In response to the concerns raised about the effect of increased sulfate concentrations on the methylation of mercury, the MPCA acknowledges that "increased concentrations of sulfate have been shown to increase the methylation of mercury in aquatic systems where organic carbon is available and especially where background sulfate concentrations are low." The MPCA agrees that "enhanced production of methylmercury is a significant concern."[321]

221. Despite these concerns, and while acknowledging that it is "very concerned about actions that might increase the mercury content of fish," the Agency notes that "in a formal sense," the scope of this rulemaking does not encompass the effects of sulfate on the methylation of mercury.[322] The MPCA reports that it is "conducting a significant separate study concerning the factors that control mercury in fish."[323] At this time, the Agency states that it has determined

> that the relationship between sulfate and mercury methylation is significantly more complicated than the relationship between sulfate and sulfide on which the proposed wild rice rule is based. Therefore, it would be even more challenging to develop a proposed sulfate standard that addresses the role of sulfate in the potential for production of methylmercury.[324]

For these reasons, the Agency states, it is not making "any decisions as how to proceed on the question of enhanced mercury methylation until the results of the ongoing major study are available."[325]

222. Both the Fond du Lac Band and the Grand Portage Band of Lake Superior Chippewa have wild rice water quality standards that limit sulfates to 10 mg/L. Each Band has authority to set water quality standards on its reservation, and the EPA has approved the standard for each Band.[326]

223. The CWA requires that, any time a state revises or adopts a new water quality standard, the standard "shall be such as to protect the public health or welfare, enhance the quality of water and serve the purposes of" the CWA.[327] Standards "shall

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[320] Test. of Dr. Emily Onello, Oct. 26, 2017, Tr. at 68-69; Test. of Dr. Debby Allert, Oct. 26, 2017, Tr. at 107-112, Hearing Ex. 1024 (Materials submitted by Dr. Allert on behalf of Minnesota Academy of Family Physicians).
[321] MPCA Response Att. 1 at 21 (Nov. 22, 2017).
[322] *Id.*
[323] *Id.*
[324] *Id.*
[325] *Id.*
[326] Hearing Ex. 1020 (Letter from Dennis Morrison on behalf of Grand Portage Tribal Reservation Council at 11; Test. of Nancy Schuldt at 96 (Oct. 26, 2017); eComment from Paula Maccabee on behalf of WaterLegacy at 15 (eComment filed Nov. 22, 2017).
[327] 33 U.S.C. § 1313 (c).

be established taking into consideration their use and value for public water supplies, propagation of fish and wildlife, recreational purposes, and agricultural, industrial, and other purposes . . . ."[328] The federal regulations also require the state to "take into consideration the water quality standards of downstream waters and . . . ensure that its water quality standards provide for the attainment and maintenance of the water quality standards of downstream waters."[329]

224. Minn. R. 7050.0155 requires that "[a]ll waters must maintain a level of water quality that provides for the attainment and maintenance of the water quality standards of downstream waters, including the waters of another state."

225. The MPCA has proposed that the maximum value of sulfate which could result in application of the proposed equation-based standard would be 838 mg/L,[330] a standard more than 80 times the current standard of 10 mg/L.

226. In the face of challenges raised by the public concerning increased mercury methylation, further harm to wild rice, and degradation of waters due to algae blooms as a result of elevated sulfate standards, the MPCA has failed to make an affirmative presentation of facts which demonstrate that, in establishing standards which would allow increased levels of sulfate in wild rice waters, it is protecting the public health or welfare, enhancing the quality of water, and ensuring that the proposed water quality standards provide for the attainment and maintenance of the water quality standards of downstream waters, as required by federal and state law.[331] Therefore, the Administrative Law Judge concludes that the proposed repeal of the 10 mg/L wild rice sulfate standard violates Minn. R. 1400.2100.D, prohibiting a rule that conflicts with other applicable law.

227. For the reasons set forth in the following section regarding the equation-based standard, the Administrative Law Judge further concludes that the MPCA has not presented facts adequate to support the reasonableness of the proposed repeal of the 10 mg/L sulfate standard without a replacement standard that is equally or more protective of wild rice waters. Therefore, the proposed rule repealing the 10 mg/L sulfate standard is defective because it violates Minn. R. 1400.2100.B.

[328] 33 U.S.C. § 1313 (c)
[329] 40 C.F.R. § 131.10(b) (2015).
[330] MPCA Rebuttal at 4.
[331] The Fond du Lac Band of the Minnesota Chippewa Tribe asserts that the Chippewa retain usufructuary rights to gather wild rice under the Treaties of 1837 and 1854. *Minnesota v. Mille Lacs Band of Chippewa Indians*, 526 U.S. 172, 196 (1999). The Fond du Lac Band, along with the entire Minnesota Indian Affairs Council, believes that equation-based sulfate standard is not proven to be protective of wild rice waters. Hearing Ex. 1020 (Letter from Dennis Morrison on behalf of Grand Portage Tribal Reservation Council at 8 and Letter from Robert L. Larsen on behalf of Minnesota Indian Affairs Council at 2). Therefore, the Fond du Lac Band argues, the State has an obligation under the 1837 and 1854 Treaties to insure that wild rice is not degraded or contaminated. The Fond du Lac Band contends that the proposed equation-based standard will not adequately protect wild rice or, by extension, the Band's Tribal treaty rights. eComment from Nancy Schuldt at 1,4-5 (Nov. 22, 2017). Because the Administrative Law Judge finds that repeal of the 10 mg/L violates federal and state law, this Report need not reach the treaty-rights arguments.

228. Should the Agency proceed with this rulemaking, it may cure the defect by retaining the 10 mg/L wild rice sulfate standard either by returning to the current wild rice classification as 4A waters, or by applying the 10 mg/L wild rice sulfate standard to wild rice in the 4D classification.

229. The Administrative Law Judge finds that the suggested changes would be needed and reasonable and would not constitute a substantially different rule under Minn. Stat. § 14.05, subd. 2(b).

B. Equation-based Sulfate Standard

230. **Part 7050.0224, subp. 5, B (1).** As stated above, the MPCA proposed the equation-based sulfate standard to replace the 10 mg/L sulfate standard.

231. Because the Administrative Law Judge has determined that the proposed repeal of the 10 mg/L sulfate standard is not needed or reasonable, the equation-based standard cannot be implemented as part of this rulemaking. Nonetheless, for purposes of the Agency's consideration in future rulemaking procedures, the Administrative Law Judge provides a review of the equation-based standard.

232. **Part 7050.0224, subp. 5, B (1)** contains the equation for the calculated sulfate standard as proposed by the Department. The standard is expressed as milligrams of sulfate ion per liter, as follows:[332]

$$\text{Calculated sulfated standard} = 0.0000121 \times \frac{\text{Iron}^{1.923}}{\text{Organic carbon}^{1.197}}$$

Where:

(a) organic carbon is the amount of organic matter in dry sediment. The concentration is expressed as percentage of carbon, as determined ~~using~~ consistent with the method for organic carbon analysis in Sampling and Analytical Methods for Wild Rice Waters, which is incorporated by reference in item E;

(b) iron is the amount of extractable iron in dry sediment. The concentration is expressed as micrograms of iron per gram of dry sediment, as determined ~~using~~ consistent with the method for extractable iron in Sampling and Analytical Methods for Wild Rice Waters, which is incorporated by reference in item E;

(c) sediment samples are collected ~~using~~ consistent with the procedures established in Sampling and Analytical Methods for Wild Rice Waters; and

[332] Ex. C at lines 7.25-7.26 and 8.1-8.17.

(d) the calculated sulfate standard is the lowest sulfate value resulting from the application of the equation to each pair of organic carbon and iron values collected and analyzed in accordance with units (a) to (c).[333]

233. Many of the commenters rejected the proposed equation-based standard. Concerns about the equation-based standard focused on the implementation of the standard and on the science underlying the equation.

1. Implementation of the Equation-based Standard

234. The equation will require measurements of iron and carbon to be taken from the sediment in each of the 1,300 or more identified wild rice waters. The data will then be inserted into the equation to calculate the equation-based sulfate standard for that particular water.[334] As stated above, the Agency estimates that it will take approximately ten years for agency staff to calculate the standards for the approximately 1,300 waters identified in the proposed rule.[335]

235. A number of commenters express concerns that it will take approximately ten years for the Agency to establish the standards under the proposed rule. Some of the concerns are that the Agency's delayed ability to implement the new standards will create confusion, and will defer enforcement of the water quality standards for wild rice waters.[336] Regulated parties assert that they lack the information they need to properly plan for compliance with the standards once they are implemented.[337] Others observe that the Agency has not enforced the 10 mg/L standard for most of the years the existing standard has been in place, and that the Agency, with its limited resources, has not shown that it will have the means to develop the 1,300 individual standards which must be calculated before they can be enforced.[338]

236. Cleveland Cliffs, which owns and operates United Taconite and Northshore Mining Company and partially owns and operates Hibbing Taconite, is a major employer on Minnesota's Iron Range. Cleveland Cliffs employs over 1,700 individuals and claims it has a total economic impact to the region of nearly $900 million.[339] In its post-hearing comments, Cleveland Cliffs asserts that the MPCA's implementation plan for the equation-based standard is unreasonable. Cleveland Cliffs contends that it is unreasonable that the MPCA cannot notify any potentially affected WWTP what revised standard will apply to it because the MPCA has not calculated sulfate standards in

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[333] Ex. C at 8.5-8.17; MPCA Rebuttal Response to Public Comments at 5.
[334] MPCA Rebuttal at 44.
[335] Ex. D at 153-154; MPCA's Response to Public Comments at 10-11 (Nov. 22, 2017).
[336] Comments of Lea Foushee, Oct. 23 Hearing Tr. at 93; (MCEA eComment) at 6-8 (Nov. 22, 2017).
[337] Comments of Chrissy Bartovich, Oct. 24 Hearing Tr. at 82.
[338] Comments of Matt Tuchel, Oct. 24 Hearing Tr. at 151-152; Paula Maccabee letter at 7-11 (Nov. 22, 2017); Dorie Reisenweber, Oct. 26 Hearing Tr. at 106; Dave Zentner, Oct 26 Hearing Tr. at 114; Allen Richardson, Oct. 26 Hearing Tr. at 129; Barbara Cournyea, Oct. 30 Hearing Tr. at 88; Sydney Evans (eComment) (Oct. 23, 2017); Jeff Williams (eComment) (Nov. 2, 2017).
[339] Letter from Rob Beranek at 1 (Nov. 22, 2017) (Beranek Letter).

individual wild rice waters under the proposed rule.[340] To demonstrate the inadequacy of the MPCA's regulatory cost analysis,[341] Cleveland Cliffs cites the MPCA's statements in the SONAR that "sulfate treatment is prohibitively expensive for many dischargers"[342] and that "companies might choose to stop operations rather than invest in the treatment needed to meet a revised standard."[343]

237. The Agency's response to comments regarding implementation of the equation-based standard is that this water quality rule is not unique:

> With any standard, resources are required to collect a sufficient amount of data for implementation. In fact, the MPCA is not convinced that the resources needed to implement the proposed standard revision exceed those needed to implement the existing 10 mg/L sulfate standard if this rulemaking were not to proceed.[344]

238. In response to commenters' concerns regarding the time needed to develop the individual sulfate limits, the Agency states: "[i]t is not uncommon for data gathering to be necessary before a standard can be fully implemented in permits."[345]

239. The Agency explains that implementing the current 10 mg/L standard takes time, both because wild rice waters have to be identified and because surface waters have to be analyzed to see whether the 10 mg/L standard is being met.[346]

240. The Agency plans to make efficient use of its resources by collecting sediment iron and carbon data to develop the new sulfate standards using its existing 10-year intensive watershed monitoring program.[347]

241. The MPCA acknowledges that, because it does not have the data available to calculate the proposed equation-based standard, it does not know "how many dischargers will be required to install additional treatment"[348] or "how many wild rice waters need a standard more stringent than the existing 10 mg/L."[349] Similarly, the Agency states in the SONAR, "[b]ecause the number of dischargers who must meet a different limit (either more or less stringent) is not known, it is difficult to quantify the change in environmental costs or benefits based on this rule revision."[350]

242. In its rebuttal comments, the MPCA states:

[340] Beranek Letter at 25-26.
[341] Beranek Letter at 23.
[342] Ex. D at 107.
[343] Ex. D at 148.
[344] MPCA Response at 10 (Nov. 22, 2017).
[345] MPCA Response, Att. 2 at 39.
[346] MPCA Response at 10-11 (Nov. 22, 2017).
[347] MPCA Response at 10 (Nov. 22, 2017).
[348] Ex. D at 144.
[349] Ex. D at 143.
[350] *Id.*

> [T]he MPCA understands that dischargers want clarity about how the standard will affect them, and we are sensitive to comments that the MPCA should strive to fully understand and articulate the implementation details of a rule prior to adopting the rule. In the case of water quality standards, the impact on permitted facilities comes through development of an effluent limit specific to a facility that ensures the permitted facility will not cause or contribute to a violation of the water quality standard. Effluent limit setting requires evaluating multiple factors as described beginning on page 96 of the SONAR.
>
> There are approximately 1000 facilities in Minnesota that hold water discharge permits. Site-specific data is required to evaluate the need for an effluent limit at each facility, and these issues are addressed in an individualized permitting process. This data is not immediately available for all facilities and it takes time to gather this data.
>
> This time and data need is inherent to the difference between water quality standards and effluent limits, and is not unique to the proposed revisions to the wild rice sulfate standard. As explained in Part 6G, pp. 96-99 of the SONAR, evaluating the need for and (as needed) determining a water quality based effluent limit requires data specific to the discharge being evaluated and the receiving water(s) being discharged to. Data needs unique to the proposed rule revisions are the sediment iron and carbon (or porewater sulfide) data.
>
> Collecting all the data necessary to calculate all effluent limits statewide would take at least ten to fifteen years, even if the sediment data were not needed. Necessary steps such as gathering five years of effluent data to evaluate and set effluent limits combined with the 10-year surface water monitoring schedule to gather surface water data cumulatively add up to the necessary data not being available for some permitted discharges until at least ten to fifteen years after rule promulgation. The MPCA does plan to prioritize data collection based on factors such as those mentioned in the EPA comments, Appendix 2 – the likelihood of sulfate impacts (because of type and location of dischargers) and permitting schedules.[351]

243. The rule, as proposed, gives regulated parties no notice of the numeric sulfate standard they will be expected to comply with, because it repeals the existing 10mg/L standard and replaces it with an equation based on variables that lack values. WWTPs will not know, until there is a final decision regarding the new water quality standards applicable to their discharge facilities, whether and to what extent they will have to treat their wastewater discharge for sulfate.

244. During the public hearings, MPCA staff distinguished between the process of setting standards and the permitting process. In her introductory remarks, Shannon Lotthammer, Division Director for the MPCA's Environmental Analysis and Outcomes

[351] MPCA Rebuttal Memo at 40.

Division, stated, “So one thing I want to point out is that the permitting process is not the same thing as establishing a water quality standard.”[352] Ms. Lotthammer made similar comments during her introductory remarks at each public hearing.[353]

245. To the extent that the Agency claims that the delay in setting standards does not disadvantage the WWTPs because the permitting process can also take years, that claim is undermined by the Agency’s own statements that setting water quality standards and permitting are two completely separate processes. The additional step of establishing a water quality standard before effluent limits can be established will prevent the WWTPs from planning, with any certainty, how to approach what will, at that point, be unknown compliance obligations.

246. The Administrative Law Judge finds that Part 7040.0224, subp. 5, B (1) violates Minn. R. 1400.2100.B. The equation-based sulfate standard is not rationally related to the Agency's objective. The Agency states that its objective in this proceeding is "[t]o amend the state water quality standards and the rules implementing those standards to protect wild rice from the impact of sulfate, so that wild rice can continue to be used as a food source by humans and wildlife."[354] The equation-based sulfate standard does not update the standards because, while the rule repeals the existing sulfate standard of 10 mg/L,[355] it fails to provide the values necessary to insert into the proposed equation to calculate individualized standards for each wild rice water body. Therefore, if the rule is enacted as proposed, there will be no standards when the rule becomes effective. Regulated parties will not know what standards will apply to them, or even whether any sulfate standard applies to them. Therefore, the rule as proposed will not protect wild rice from the impact of sulfate, and is not rationally related to the Agency’s objective.

247. The Administrative Law Judge finds that Part 7040.0224, subp. 5, B (1) violates Minn. R. 1400.2100.E because it is unconstitutionally void for vagueness. “A rule, like a statute, is void for vagueness, if it fails to give a person of ordinary intelligence a reasonable opportunity to know what is prohibited or fails to provide sufficient standards for enforcement.”[356]

248. The Administrative Law Judge finds that Part 7040.0224, subp. 5, B (1) violates 1400.2100.G. By its own terms, the equation-based sulfate standard cannot have the force and effect of law. The equation lacks values to insert in the place of the iron and organic carbon variables, and thus cannot be calculated. Therefore, the proposed equation-based sulfate standard will not have the force and effect of law within five working days after notice of its adoption and violates the requirements of Minn. Stat. § 14.38.

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[352] Comments of Shannon Lotthammer, Tr.at 49 (Oct. 23, 2017).
[353] Comments of Shannon Lotthammer, Tr.at 44-45 (Oct. 24, 2017); Tr. at 44 (Oct. 25, 2017); Tr. at 58 (Oct. 26, 2017); Tr. at 57 (Oct. 30, 2017); Tr. at 47-48 (Nov. 2, 2017).
[354] Ex. D at 1.
[355] Ex. C. at lines 7.8-7.10 (proposed Minn. R. 7050.0224, subp. 2).
[356] *In re N.P.*, 361 N.W. 2d 386, 394 (Minn. 1985), *citing Grayned v. City of Rockford*, 408 U.S. 104, 108-09, 92 S. Ct. 2294, 2298-99 (1972).

249. The Agency could cure the defects identified in this section only by conducting the sampling process necessary to provide the values for the equation proposed in the rule for each water identified in the rule, before proposing the rule. However, because the Agency cannot repeal the 10 mg/L sulfate standard for the reasons explained in section V. A., above, the Agency cannot implement the equation-based sulfate standard.

2. Science-based Objections to the Equation

250. The basis for many of the objections were disagreements with the scientific underpinnings of the equation. The science-based objections fall primarily into the following categories:

a. Disagreement with the MPCA's conclusion that sulfate harms wild rice.[357]

b. Disagreement with the MPCA's conclusion that the proposed sulfide standard will be protective of wild rice.[358]

c. Concerns that permitting higher sulfate levels will result in increased methyl mercury in fish.[359]

d. Criticisms of MPCA's research based on its decision to exclude from consideration stressors on wild rice growth other than sulfate or sulfide.[360]

e. Disagreement with the MPCA's conclusion that a level as low as 120 micrograms per liter of sulfide is the maximum level that is protective of wild rice. [361]

f. Criticisms of the MPCA's research on porewater sulfide.[362]

g. Criticisms of the MPCA's use of field data.[363]

h. Criticisms of the MPCA's choice of data sets.[364]

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[357] eComment from Tom Scott (Nov. 22, 2017); Kurt Anderson, Tr. at 116 (Oct. 23, 2017); Sen. David Tomassoni Tr. at 53-55 (Oct. 24, 2017); Larry Sutherland, Tr. at 73 (Oct. 24, 2017).
[358] eComment from John Coleman on behalf of Great Lakes Indian Fish and Wildlife Commission at 3-7 (Nov. 22, 2017); eComment from Nancy Schuldt on behalf of Fond du Lac Band of Chippewa at 26-88 (Nov. 22, 2017).
[359] Jennifer Lang, Tr. at 61 (Oct. 23, 2017); Ex. 1000, Letter from Lea Foushee on behalf of North American Water Office at 1; eComment from Nancy Schuldt on behalf of Fond du Lac Band of Chippewa at 33 (Nov. 22, 2017); Test. of Dave Zentner on behalf of Izaak Walton League, Tr. at 116-117 (Oct. 26, 2017); E- comment from Kristin Blann on behalf of The Nature Conservancy (Nov. 22, 2017).
[360] Test. of O'Neill Tedrow, Tr. at 89-95 (Oct. 24, 2017) and Ex. 1008; Test. of Chrissy Bartovich, Tr. at 80 (Oct. 24, 2017).
[361] Test. of Kurt Anderson, Tr. at 113-116 (Oct. 23, 2017); Test. of Mike Bock, Tr. at 76-80 (Oct. 23, 2017); Test. of Mike Hansel, Tr. at 82 (Oct. 23, 2017); Test. of Rob Beranek, Tr. at 90 (Oct. 23, 2017); Tom Rukavina, Tr. at 134-148 (Oct. 24, 2017); Sen. Justin Eichorn, Tr. at 59-60 (Oct. 24, 2017).
[362] Test. of Mike Hansel, Tr. at 83 (Oct. 23, 2017).
[363] Test. of Mike Bock, Tr. at 79 (Oct. 23, 2017); eComment from John Coleman on behalf of Great Lakes Indian Fish and Wildlife Commission at 3-7 (Nov. 22, 2017).
[364] Test. of Rob Beranek, Tr. at 90 (Oct. 23, 2017); eComment from John Coleman on behalf of Great Lakes Indian Fish and Wildlife Commission at 4-5 (Nov. 22, 2017).

i. Concerns that the equation assumes steady state in a water body.[365]

j. Questions about upwelling of ground water.[366]

k. Questions about the long-term effectiveness of the calculated sulfide levels.[367]

l. Concerns about error rates in the equation.[368]

m. Disagreement about the use of EC_{10} concentration standard.[369]

n. Effect of sulfate on different parts of the wild rice plant.[370]

o. Challenges to the MPCA's analysis of its research and data.[371]

p. Concerns about response to peer review criticisms.[372]

q. Issues with the structural equation model (SEM).

251. The Administrative Law Judge finds that the MPCA presented sufficient evidence to demonstrate that there is an adequate scientific basis to conclude that the proposed equation-based sulfate standard is supported by peer-reviewed science and is needed and reasonable.

252. With one notable exception, the MPCA responded to each of the arguments raised by the commenters with arguments that were supported by peer-reviewed research.[373]

253. The exception, for which the MPCA did not offer a convincing response, was raised by several parties, most notably Dr. John Pastor, one of the scientists on whose foundational research the MPCA relied for its conclusions that sulfide, rather than sulfate, is the direct cause of damage to naturally-occurring wild rice.[374] Dr. Pastor's continuing mecocosm research has indicated that, while increased iron may counter the toxicity of sulfide to wild rice seedlings in the springtime, iron sulfide plaques form and

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[365] John Pastor, PhD., Technical Review Comments on MPCA's Proposed Flexible Standard for Sulfate in Wild Rice Beds (Nov. 2017), submitted as attachment to WaterLegacy eComments (Nov. 22, 2017); eComment from Nancy Schuldt on behalf of Fond du Lac Band of Chippewa (Nov. 22, 2017); eComment from Miya Evans on behalf of Mesabi Nugget (Nov. 22, 2017).
[366] Test. of Meaghan Blair, Tr. at 117-119 (Oct. 24, 2017).
[367] John Pastor, PhD., Technical Review Comments on MPCA's Proposed Flexible Standard for Sulfate in Wild Rice Beds (Nov. 2017), submitted as attachment to WaterLegacy eComments (Nov. 22, 2017);
[368] Test. of Rob Beranek, Tr. at 91 (Oct. 23, 2017); Test. of Sen. David Tomassoni, Tr. at 55 (Oct. 24, 2017); Test. of Jack Croswell, Tr. at 99 (Oct. 24, 2017); Test. of Rep. Jason Metsa, Tr. at 102 (Oct. 24, 2017); Test. of Sen. Justin Eichorn, Tr. at 54, 61 (Oct. 25, 2017).
[369] eComment from Nancy Schuldt on behalf of Fond du Lac Band of Chippewa at 28-31 (Nov. 22, 2017); eComment from Rob Beranek at 12-13 (Nov. 22, 2017); eComment from John Coleman on behalf of Great Lakes Indian Fish and Wildlife Commission at 4-5 (Nov. 22, 2017).
[370] eComment from Rob Beranek at 6-8 (Nov. 22, 2017); Test. of Kurt Anderson, Tr. at 69-70 (Oct. 23, 2017).
[371] Test. of Mike Bock, Tr. at 78-79 (Oct. 23, 2017); Test. of Kurt Anderson, Tr. at 114 (Oct. 23, 2017).
[372] Test. of Kelsey Johnson, Tr. at 69 (Oct. 24, 2017).
[373] *See* MPCA Response Memorandum (Nov. 22, 2017) and Rebuttal Memorandum (Dec. 1, 2017).
[374] Ex. D at Ex. S-19.

precipitate on the plants' roots during the flowering and seed production phases of the wild rice life cycle. These plaques result in fewer and smaller seeds, with reduced nitrogen content, leading to extinction of the wild rice plant within 4 or 5 years at about 300 mg/L of sulfate, and greatly reducing wild rice plant population viability at lower concentrations of sulfate. Dr. Pastor hypothesizes that this occurs because the increased plaque appears to block uptake by the plant of nitrogen during the critical flowering and seed production portion of its life cycle.[375]

254. The MPCA's response to Dr. Pastor's reports about the plaque formation is, first, that "the only information the MPCA has on this issue is a four-page non-peer reviewed progress report . . . ." The MPCA also states that Dr. Pastor only presents evidence of nutrient uptake inhibition at 300 mg/L, asserting that this is "much higher than would be allowed using the MPCA's proposed equation."[376]

255. The Administrative Law Judge notes that the MPCA failed to mention the discussion of plaque formation in the peer-reviewed article which Dr. Pastor co-authored with MPCA staff, among others. The MPCA relies on this article, among others, to support the theory that increased iron in the porewater is protective against sulfide, permitting increased sulfate in the surface water.[377] This theory underlies, and is essential to, its equation-based sulfate standard. Furthermore, as discussed above, Dr. Pastor considered the effect of lower amounts of sulfate, as reported in his June 2017 article, concluding that, even at lower levels, sulfate greatly reduced plant viability when combined with increased iron.[378]

256. Nonetheless, Dr. Pastor's continued research regarding the harmful effects of increased sulfate with increased iron are not yet the subject of peer-reviewed publication. Therefore, the Administrative Law Judge finds that the MPCA demonstrated by an affirmative presentation of facts that it could rationally choose to proceed with the equation-based sulfate standard from a scientific standpoint.

257. The Administrative Law Judge finds that the MPCA's demonstration that the science underlying the equation-based standard is reasonable in that it describes a manner of calculating a sulfate level resulting in a level of sulfide in porewater protective of wild rice.

258. Nonetheless, because the MPCA failed to make an affirmative presentation of facts that implementation of the equation-based standard, or the alternate standard, would provide "for the attainment and maintenance of the water quality standards of downstream waters," the new proposed sulfate standards, even if based on science that a rational decision-maker could conclude is protective of wild rice, must be disapproved.

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[375] MPCA Response, Att. 5, N-34 at 3 (Pastor, Progress Report on Experiments on Effects of Sulfate and Sulfide on Wild Rice. June 28, 2017); eComment from John Coleman on behalf of Great Lakes Indian Fish and Wildlife Commission at 6 (Nov. 22, 2017).
[376] MPCA Rebuttal at 25.
[377] Ex. D at Ex. S-19.
[378] MPCA Response, Att. 5, N-34 at 3 (Pastor, Progress Report on Experiments on Effects of Sulfate and Sulfide on Wild Rice. June 28, 2017).

C. List at Minn. R. 7050.0471 of Proposed 4D (Naturally Occurring) Wild Rice Waters

259. **Part 7050.0471, subparts 3-9,** proposes to list the waters that will be protected as Class 4D wild rice waters. There are approximately 1,300 Minnesota water bodies in the list as proposed by the MPCA.[379]

260. In the SONAR, the MPCA explains that the current rules "apply the wild rice beneficial use to 'water used for production of wild rice,'" without identifying the waters to which the use applies.[380] The MPCA states that the case-by-case process of evaluating potential wild rice waters has posed a significant challenge to the implementation of the existing standard.[381]

261. The proposed rule is a response to a legislative mandate first passed in 2011:[382]

> (a) Upon completion of the research referenced in paragraph (d), the commissioner of the Pollution Control Agency shall initiate a process to amend Minnesota Rules, chapter 7050. The amended rule shall:
>
> > (1) address water quality standards for waters containing natural beds of wild rice, as well as for irrigation waters used for the production of wild rice;
> >
> > (2) designate each body of water, or specific portion thereof, to which wild rice water quality standards apply; and
> >
> > (3) designate the specific times of year during which the standard applies.
>
> Nothing in this paragraph shall prevent the Pollution Control Agency from applying the narrative standard for all class 2 waters established in Minnesota Rules, part 7050.0150, subpart 3.
>
> (b) "Waters containing natural beds of wild rice" means waters where wild rice occurs naturally. Before designating waters containing natural beds of wild rice as waters subject to a standard, the commissioner of the Pollution Control Agency shall establish criteria for the waters after consultation with the Department of Natural Resources, Minnesota Indian tribes, and other interested parties and after public notice and comment.

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[379] Ex. C at 11.16-11.17 and 12.7-66.8 (proposed Minn. R. 7050.0471, subps. 1 and 3-9). The original proposed list is slightly longer than the list as finally proposed by the MPCA, because the MPCA initially included waters within the boundaries of the Grand Portage and Fond du Lac reservations. The two tribes objected to inclusion of the waters within their reservations' boundaries, and the MPCA proposed to remove those waters from the proposed list. MPCA Response at 13.

[380] Ex. D at 38.

[381] *Id.*

[382] 2011 Minn. Laws, 1st Sp. Sess. ch. 2, art. 4, § 32(a)-(d).

The criteria shall include, but not be limited to, history of wild rice harvests, minimum acreage, and wild rice density.

(c) Within 30 days of the effective date of this section, the commissioner of the Pollution Control Agency must create an advisory group to provide input to the commissioner on a protocol for scientific research to assess the impacts of sulfates and other substances on the growth of wild rice, review research results, and provide other advice on the development of future rule amendments to protect wild rice. The group must include representatives of tribal governments, municipal wastewater treatment facilities, industrial dischargers, wild rice harvesters, wild rice research experts, and citizen organizations.

(d) After receiving the advice of the advisory group under paragraph (c), consultation with the commissioner of natural resources, and review of all reasonably available and applicable scientific research on water quality and other environmental impacts on the growth of wild rice, the commissioner of the Pollution Control Agency shall adopt and implement a wild rice research plan using the money appropriated to contract with appropriate scientific experts. The commissioner shall periodically review the results of the research with the commissioner of natural resources and the advisory group.

262. The proposed rule applies the sulfate standard only to waters specifically identified as Class 4D wild rice waters, which are listed in proposed Minn. R. 7050.0471.[383] Waters which are not listed in the rule are not subject to the sulfate standard.[384]

263. In determining which waters to include in the proposed rule, the MPCA relied on a number of sources, including:[385]

a. *Natural Wild Rice in Minnesota*) – A Wild Rice Study Report to the Legislature (2008) (Minnesota DNR) – MDNR Wild Rice Harvester Survey Report (2007);

b. Minnesota Wild Rice Management Workgroup List of 350 Important Wild Rice Waters (2010);

c. 1854 Treaty Authority List of wild rice waters (through March 2016 plus three additional waters since March 2016);

d. MDNR Aquatic Plant Management Database;

e. MPCA Biomonitoring Field Sites;

f. University of Minnesota/MPCA Wild Rice Study Field Survey Sites;

[383] Ex. C at li. 12.7-66.8 (proposed Minn. R. 7050.0471, subps. 3-9); Ex. D at 38.
[384] Test. of S. Lotthammer, Nov. 2, 2017 Tr. at 92.
[385] Ex. D at 42.

g. Minnesota Biological Survey Database;

h. MPCA Call for Data;

i. Permittee Monitoring Reports;

j. WR Waters (7050.0470);

k. Waters identified by MDNR in 2015 as wild rice waters; and

l. Waters Identified through MPCA Review of Various Water Surveys.

264. The MPCA found that it could not determine that certain waters were Class 4D wild rice waters based solely on the information it received from these sources. In some cases, the MPCA could not identify the location of the water from the information provided. In other cases, the MPCA could not correlate the location of a river or stream with a specific WID.[386]

265. The MPCA acknowledges that the MDNR's 2008 report "is widely considered the most comprehensive source of information regarding where rice may be found in Minnesota, and [the DNR report] was extensively reviewed."[387] The MDNR report represents the work of experts in the field from state, tribal, and federal governments, along with academia and the private sector.[388] However, the MPCA found the MDNR list insufficient on its face because it consolidated certain information on the location of natural wild rice stands, making it difficult for the MPCA to define the density or acreage of some rice stands. In addition, according to the MPCA, the MDNR report contains limited information about streams with wild rice.[389]

266. As part of this rulemaking, at proposed Minn. R. 7050.0471, subp. 2, the MPCA is proposing "[a]cceptable types of evidence"[390] that can be used in future rulemakings to add wild rice water bodies. The evidence must

> support a demonstration that the wild rice beneficial use exists or has existed on or after November 28, 1975, in the water body, such as by showing a history of human harvest or use of the grain as food for wildlife or by showing that a cumulative total of at least two acres of wild rice are present.[391]

267. The evidence the MPCA lists as acceptable evidence in its proposed Minn. R. 7050.0471, subp. 2, includes:

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[386] Ex. D at 45.
[387] *Id.*
[388] *Id.*
[389] Ex. D at 46.
[390] Ex. C at line11.24 (proposed Minn. R. 7050.0471, subp. 2).
[391] Ex. C at lines11.21-11.24 (proposed Minn. R. 7050.0471, subp. 2) and MPCA Rebuttal at 8. The reference to the Rebuttal reflects some fairly minor proposed changes to the language in subpart 2 which the MPCA set forth in its December 1, 2017 Rebuttal Memorandum.

A. written or oral histories that meet the criteria of validity, reliability, and consistency;

B. written records, such as harvest records;

C. photographs, aerial surveys, or field surveys; or

D. other quantitative or qualitative information that provides a reasonable basis to conclude that the wild rice beneficial use exists.[392]

268. The MPCA found the MDNR report sufficiently reliable to presume that water bodies included in the report "with wild rice acreage estimates of two acres or more meet the beneficial use."[393] For waters in the MDNR report with fewer than two acre estimates, the MPCA looked to other sources to identify "high quality, harvestable wild rice waters."[394]

269. Several commenters maintained that, in rejecting waters listed in MNDR's 2008 report and in the 1854 Treaty Authority's list, the MPCA is removing a designated use from waters that already had wild rice as an "existing use" under federal law.[395] Under federal law, states are delegated authority to establish "designated uses" of waters and to set water quality standards to protect the designated uses.[396] According to these commenters, this action by the MPCA violates the CWA's prohibition against removing a designated use if the designated use is an "existing use[], as defined in [40 C.F.R.] § 131.3, unless a use requiring more stringent criteria is added . . . ."[397]

270. A number of commenters object to the MPCA's proposed list of Class 4D wild rice waters.[398] WaterLegacy and others assert that the MPCA's use of the term "beneficial use" with regard to the classification of wild rice waters is an imprecise and confusing use of a term that is not defined in either existing or proposed rules.[399]

271. WaterLegacy argues that the MPCA's proposed list of Class 4D waters is "arbitrary and exclusive" and will "de-list wild rice waters identified by Minnesota state agencies, including waters downstream of existing and potential mining discharge."[400]

272. WaterLegacy points out that the existing rules, at Minn. R. 7050.0220, subps. 3a, 4a, 5a, and 6a, apply the current 10 mg/L sulfate standard where wild rice is

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392 Ex. C at lines 12.1-12.6 (proposed Minn. R. 7050.0471, subp. 2).
393 Ex. D at 46.
394 Ex. D at 46.
395 WaterLegacy eComment at 30. Hearing Ex. 1020, Written Comments of Dennis Morrison on behalf of Grand Portage Band of Chippewa (Grand Portage Comments) at 8 (Oct. 24, 2017). *See* eComment from Nancy Schuldt on behalf of Fond du Lac Band at 21-23 (Nov. 22, 2017).
396 WaterLegacy eComment at 31. 40 C.F.R. § 131.3.
397 40 C.F.R. § 131.11(h)(1).
398 eComment of Nancy Schuldt on behalf of Fond du Lac Band at 8-25 (Nov. 22, 2017), WaterLegacy eComment at 30-40; Hearing Ex. 1020, Grand Portage Comments at 4-8 (Oct. 24, 2017). eComment of Minnesota Center for Environmental Advocacy (MCEA eComment) at 2-5 (Nov. 22, 2017).
399 WaterLegacy eComment at 30. Fond du Lac eComment at 20-21.
400 WaterLegacy eComment at 30.

"present." Minn. R. 7050.0224, subp. 1, protects wild rice as a Class 4 water, "for wildlife designated public uses and benefits," recognizing it as a "food source for wildlife and humans." In addition, WaterLegacy cites Minn. R. 7050.0224, subp. 2, which limits sulfate to 10 mg/L in "water used for production of wild rice . . . ."[401]

273. WaterLegacy maintains that, while rescinding existing Minnesota rules that protect waters used for the production of wild rice and where wild rice is present, the proposed rules create a list of protected waters that excludes "many known and previously designated wild rice waters."[402]

274. WaterLegacy claims that the MPCA proposes to delist designated wild rice waters previously identified in consultation with the MDNR and Minnesota tribes. WaterLegacy contends that this delisting violates the CWA's prohibition on removing existing uses that have been attained at any time since November 28, 1975. In addition, according to WaterLegacy, the MPCA's proposed list fails to protect wild rice waters generally, and particularly fails to protect wild rice waters downstream of existing and proposed WWTPs.[403]

275. Other commenters disagree with the MPCA's proposed list of Class 4D waters for distinctly different reasons. Cleveland Cliffs focuses on the 2011 legislative requirement that the MPCA must consult "with the Department of Natural Resources, the Minnesota Indian tribes, and other interested parties and after public notice and comment"[404] to establish criteria for wild rice waters before the Agency designates such waters.[405] Cleveland Cliffs argues that this legislative language required the MPCA to engage in rulemaking to establish criteria for designating wild rice waters before it could designate such waters.[406]

276. In addition, Cleveland Cliffs contends that MPCA violated the language in the 2011 law requiring that "[t]he criteria shall include, but not be limited to, history of wild rice harvests, minimum acreage, and wild rice density" when it included waters in the Class 4D wild rice waters list, without regard to their failure to meet the MPCA's stated minimum acreage requirement or a known density of wild rice.[407]

277. U.S. Steel Corporation asserts the MPCA's listing of waters violates the 2011 legislation because the list does not contain information about wild rice density.[408]

[401] WaterLegacy eComment at 31.
[402] WaterLegacy eComment at 31. eComment of Nancy Schuldt on behalf of Fond du Lac Band at 8-25 (Nov. 22, 2017), Hearing Ex. 1020, Grand Portage Comments at 4-8 (Oct. 24, 2017).
[403] WaterLegacy eComment at 31.
[404] 2011 Minn. Laws, First Sp. Sess., Ch. 2, Art. 4(b).
[405] eComment from Rob Beranek on behalf of Cleveland Cliffs (Cleveland Cliffs eComment) at 16 (Nov. 22, 2017).
[406] Cleveland Cliffs eComment at 16.
[407] Cleveland Cliffs eComment at 17.
[408] Letter from Lawrence Sutherland on behalf of U.S. Steel (U.S. Steel letter) at 37-38 (Nov. 22, 2017).

278. The MPCA maintains that, for this rulemaking, it used a "weight-of-evidence approach as it reviewed the corroborating evidence from sources to determine if the wild rice beneficial use exists or has existed in a water." Further, the MPCA states:[409]

> Many of the supporting documents used in the MPCA's review do not contain complete information about the density or acreage of wild rice. Therefore, MPCA scientists used their best professional judgement to determine if the available information provided reasonable evidence that the water demonstrated the wild rice beneficial use (or had done so since November 28, 1975).
>
> For example, where a corroborating source qualitatively identified a water as having "lush" stands of wild rice, the MPCA considered that it met the beneficial use as a wild rice water. Because no single source provided comprehensive or consistent data about the presence of wild rice, the MPCA was not able to apply a strict criterion for what information did or did not reasonably characterize a wild rice water. The MPCA reasonably made the best use of the information from all sources as a basis for professional judgement.

279. In considering possible wild rice waters for inclusion in the list at 7050.0442, subp. 2, the MPCA did not explicitly apply the evidentiary expectations it proposes in Minn. R. 7050.0471, subp. 2. Nor did the MPCA explain why it rejected each proposed specific water that the MPCA excluded from the list in the proposed rule.

280. The MPCA acknowledges that it may not have included all of the waters where the wild rice use has existed since November 28, 1975 in the list proposed at Minn. R. 7050.0471.[410]

281. In the SONAR, the MPCA addresses the questions of whether it has included all wild rice waters with an existing use, stating that the Agency

> acknowledges that the wild rice waters in this rulemaking may not include every water in Minnesota where the wild rice beneficial use has existed since November 28, 1975. Although the MPCA has made reasonable use of the information available to develop and justify the proposed list of Class 4D wild rice waters, there are additional waters that may be wild rice waters but for which there is not yet sufficient information to determine that the beneficial use is demonstrated.[411]

282. In response to the commenters who believe that the list of wild rice waters is under-inclusive, the MPCA responds that "it is likely that not all wild rice waters have

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[409] Ex. D at 47.
[410] Ex. D at 58.
[411] *Id.*

been identified and is proposing a specific process for future identification of wild rice waters" at proposed Minn. R. 7050.0471, subp. 2.[412]

283. In its December 1, 2017 Rebuttal memorandum, the MPCA states that it "does not agree that the presence (or evidence of past presence) of any amount of wild rice is indicative that the Class 4D wild rice beneficial use is an existing use in that water body."[413] In the same document, the MPCA states, with no affirmative presentation of facts to support the statement, that it "has identified those waters where wild rice is an existing use as wild rice waters. Some of those waters may not have wild rice today, but under the CWA must be protected if the use has existed since November 28, 1975."[414]

284. The 2011 legislature required the MPCA to engage in rulemaking only after completing significant research on "water quality and other environmental impacts on the growth of wild rice . . . ."[415] The amended rule was required to:

(1) address water quality standards for waters containing natural beds of wild rice, as well as for irrigation waters used for the production of wild rice;

(2) designate each body of water, or specific portion thereof, to which wild rice water quality standards apply; and

(3) designate the specific times of year during which the standard applies.[416]

285. The MPCA was not authorized to engage in separate preliminary rulemaking to establish criteria for designating wild rice water bodies.[417]

286. The Administrative Law Judge concludes that the plain language in 2011 Minn. Laws 1st Spec. Sess. ch. 2, art. 4, § 32(b), requires the MPCA to consider the criteria listed in the 2011 Session Law, but does not require that any one of the criteria be determinative. Therefore, the Administrative Law Judge concludes that there is no minimum wild rice acreage or density required for the MPCA to determine that a water body is included in the listing of wild rice water bodies.

287. The Administrative Law Judge concludes that the MPCA's proposed list of wild rice waters at Minn. R. 7050.0471, subps. 3 through 9 is defective because it fails to include all waters previously identified by the MDNR and federally recognized Indian tribes as waters where wild rice was an existing use since November 28, 1975. The MPCA's approach, in using a "weight-of-evidence" standard to identify waters such as those with "lush stands of wild rice" that would meet its criteria for "the beneficial use as a wild rice water" violates federal law, which prohibits removing an existing use for wildlife

[412] MPCA Response Memo at 13.
[413] MPCA Rebuttal Memo at 12.
[414] MPCA Rebuttal Memo at 13.
[415] 2011 Minn. Laws 1st Spec. Sess. ch. 2, art. 4(d).
[416] 2011 Minn. Laws 1st Spec. Sess. ch. 2, art. 4(a).
[417] 2011 Minn. Laws 1st Spec. Sess. ch. 2, art. 4.

unless more stringent criteria are applied.[418] Because Minn. R. 7050.0471 violates federal law, it fails to meet the requirements of Minn. R. 1400.2100.D and is defective.

288. The MPCA could cure the defect at Minn. R. 7050.0471 by amending the listed waters to include all waters previously identified by the MDNR and federally recognized Indian tribes as waters where wild rice was an existing use since November 28, 1975. The Administrative Law Judge concludes that adding the wild rice waters as described in this paragraph would not constitute modification that makes the rule substantially different than the rule as originally proposed based on the standards set forth at Minn. Stat. § 14.05, subd. 2.

D. Other Rule Parts Not Approved

287. In addition to the disapproved proposed rules and proposed changes to the proposed rules discussed above, there are several other rule parts which the Administrative Law Judge finds do not meet the legal requirements for rulemaking. Because of the significant underlying problems with these proposed rules overall, the following rules, and the standards they violate, are listed without additional discussion for the purpose of putting the Agency on notice should it reconsider this rulemaking in the future:

a. Minn. R. 7050.0224, 5, C. Site-specific sulfate standard. The proposed rule is disapproved based on a violation of Minn. R. 1400.2100.D. No process is provided for the commissioner to determine that "the beneficial use is not harmed." The criteria included in the rule, "reliable and representative data characterizing the health and viability of the wild rice . . . ," are vague and grant the commissioner discretion in excess of statutory authority to determine whether to substitute the existing standard.

b. Minn. R. 7050.0224, subp. 6. This proposed rule concerns the existing narrative standard for Class 4D [WR] waters currently at Minn. R. 7050.0224, subp. 1. The narrative standard applied to the only other wild rice waters previously identified in rule. The proposed rule moves the narrative standard to Minn. R. 7050.0224, subp. 6, and explicitly restricts application of the narrative standard to the wild rice waters originally identified in the rule, at Minn. R. 7050.0470, excluding the wild rice waters listed at 7050.0471 from the scope of its protections.[419] The Administrative Law Judge disapproves Minn. R. 7050.0224, subp. 6, to the extent that it does not apply to all wild rice waters. The MPCA provided no basis to distinguish between protections needed for the waters listed at Minn. R. 7050.0470 and those listed at Minn. R. 7050.0471. Therefore, to apply the narrative standard only to those listed at 7050.0470 violates Minn.

[418] 40 C.F.R. § 131.11(h)(1).
[419] Test. of Nancy Schuldt, Oct. 26, 2017 Tr. at 95-96.

R. 1400.2100.B because the record does not demonstrate the reasonableness of the rule.

E. Technical Errors

288. The language included in the following proposed rules appears to amend version of subparts which are no longer in effect. These are technical errors rather than legal defects. The Agency may cure the errors by amending the proposed language to propose changes to the current versions of the rule:

a. Minn. R. 7050.0220, subp. 5a

b. Minn. R. 7050.0470, subps. 1 through 9

F. Changes to the Proposed Rule

289. Following the public hearings, in its Response and Rebuttal Comments, the MPCA makes a number of proposed changes to the proposed rule. Because the Agency suggested changes to the proposed rule language after the date it was originally published in the *State Register*, it is necessary for the Administrative Law Judge to determine if this new language is substantially different from that which was originally proposed.

290. The standards to determine whether any changes to proposed rules create a substantially different rule are found in Minn. Stat. § 14.05, subd. 2(b). The statute specifies that a modification does not make a proposed rule substantially different if:

> (1) the differences are within the scope of the matter announced . . . in the notice of hearing and are in character with the issues raised in that notice;
>
> (2) the differences are a logical outgrowth of the contents of the . . . notice of hearing, and the comments submitted in response to the notice; and
>
> (3) the notice of hearing provided fair warning that the outcome of that rulemaking proceeding could be the rule in question.

291. In reaching a determination regarding whether modifications result in a rule that is substantially different, the Administrative Law Judge is to consider whether:

> (1) persons who will be affected by the rule should have understood that the rulemaking proceeding . . . could affect their interests;
>
> (2) the subject matter of the rule or issues determined by the rule are different from the subject matter or issues contained in the . . . notice of hearing; and

(3) the effects of the rule differ from the effects of the proposed rule contained in the . . . notice of hearing.[420]

292. To the extent that they are not approved, the MPCA's suggested language changes are described in the following paragraphs.

1. Changes That Are Not Approved

(1) Minn. R. 7050.0224, subp. 5, B (1)

293. The EPA comments that "it is not possible to say with certainty," regarding the equation-based sulfate standard set forth at Minn. R. 7050.0224, subp. 5, B (1), "that the relationships between sediment pore water sulfide and total organic carbon and total extractable iron used to calculate protective water column sulfate concentrations remain valid outside the range of the data used to develop the criterion."[421]

294. Commenter Nathan Johnson similarly observes:

> It is possible that a limitation on the model predictions could be imposed . . . which would not allow high sulfate concentrations to be calculated by the model if the statistical strength of the model's predictive abilities towards the edge of the domains is limited. Using the proposed equation to extrapolate to very high surface water sulfate concentrations (higher than those observed commonly in the observational dataset) represents a potential instance of applying the model beyond an appropriate domain of applicability. The same could be said for sediment carbon and iron.[422]

295. In response to these concerns, the Agency proposes to amend the equation for the numeric sulfate standard, "by setting constraints on the implementation of the equation that would ensure that the equation is protective."[423] The MPCA proposes to set these constraints so "that input values of carbon cannot be lower than the minimum value in the range of data used to develop the equation, because carbon enhances sulfide production." Similarly, under the MPCA's proposal the "input values of iron cannot be higher than the maximum value in the range of data used to develop the equation because iron removes sulfide from porewater."[424] The MPCA provides no specific values for its minimum carbon or maximum iron values.

296. As part of its response to the concerns raised by Mr. Johnson and the EPA about setting constraints consistent with the models, the MPCA proposes "that output

[420] *See* Minn. Stat. § 14.05, subd. 2.
[421] EPA Comments at 6.
[422] Nathan Johnson Comment at 1-2 (eComment Nov. 22, 2017).
[423] MPCA Rebuttal Memo at 3.
[424] *Id.*

values of sulfate cannot be higher than the maximum value in the range of data used to develop the equation, 838 mg/L."[425]

297. The MPCA asserts that the constraint on sulfate is appropriate "because observed sulfate levels were an input to the development of the equation, and the equation is of unknown validity outside the range used to develop it."[426] The Agency believes that this approach "will help assuage commenter concerns about exceedingly high sulfate levels that may result from the equation." However, the Agency realizes that imposing these limits may also raise concerns for other commenters.[427]

298. The Administrative Law Judge finds that, to the extent the equation-based standard remains a viable part of this rule, the sulfate cap is needed and reasonable and would not constitute a modification that makes the rule substantially different than the rule as originally proposed based on the standards set forth at Minn. Stat. § 14.05, subd. 2.

299. The Administrative Law Judge finds that, to the extent the equation-based standard remains a viable part of this rule, unspecified minimum carbon or maximum iron input values for the equation-based standard are not reasonable. They are unconstitutionally vague and violate the standards of Minn. R. 1400.2100.E.

(2) Minn. R. 7050.0224, subps. 5.E and F

300. In Minn. R. 7050.0224, subp. 5, E, the MPCA proposes to incorporate Sampling and Analytical Methods for Wild Rice Methods. As the name indicates, this document sets out methods for collecting and analyzing wild rice water sediment samples.

301. The MPCA explains that a "primary goal of incorporating the sampling methodology into the rule was to provide clarity so that others can conduct sampling and to ensure that the sampling, which is foundational to the developing of a numeric sulfate standard, is completed consistently and accurately." Because this goal is important to the MPCA, it plans to incorporate any changes to the methods incorporated by reference through rulemaking.[428]

302. Commenter Norman Miranda notes:

> The dilemma I see for utility managers regardless of whatever protective limit is adopted is to convince their respective City Council and rate payers that a very limited number of samples and sample locations yielded adequate and conclusive data to justify a significant capital investment. … I believe MPCA is on the right track offering a consistent sampling regime of a fixed number of samples at a prescribed location array. … I believe at least two sampling events conducted in appropriate but separate locations

[425] MPCA Rebuttal Memo at 4.
[426] *Id.*
[427] *Id.*
[428] MPCA Rebuttal at 5.

> need to be conducted by the MPCA. I realize the MPCA has limited financial resources to conduct extensive sampling and analysis in multiple locations for every discharger. However, to offer some flexibility, I think the Rule should include a provision that municipalities/permitted facilities be given the opportunity to conduct additional sampling/testing beyond two events that would be required under the Rule. The ground rules for this additional sampling could include:
>
> - Regulated party must submit a plan for MPCA approval showing proposed alternative sample locations.
> - Sampling must follow MPCA "Sampling and Analytical Methods" and be conducted by approved lab/consultant.
> - Sampling/testing to be done before or concurrent with MPCA sampling as not to delay MPCA's schedule.
> - Cost of additional sampling events to be the responsibility of the Regulated Party.
>
> In return I believe there should be language where the MPCA will give the Regulated Party's data set the same weight if all conditions are followed.[429]

303. The MPCA agrees that some flexibility may be needed as more sampling occurs, and appreciates that many permittees want to do more sampling, and perhaps sooner, than the MPCA plans to undertake. While the MPCA plans to do most sampling with its own resources, it plans to allow the use of data submitted by other parties (whether regulated parties or others) if the data was collected in accordance with the MPCA's requirements.[430]

304. The MPCA is proposing to amend Minn. R. 7050.0224, subp. 5, B (1) (a) - (c) at lines 8.6, 8.11, and 8.13, to require that analysis and sampling happen consistent with the methods that are incorporated by reference, rather than requiring exact adherence to the methods. This will allow some flexibility if, for example, an analytical method is slightly updated. The MPCA is also proposing to add language that the sediment samples are collected in areas where wild rice is growing or may grow within the wild rice water. The proposed rule language would read:[431]

> Where:
>
> (a) organic carbon is the amount of organic matter in dry sediment. The concentration is expressed as percentage of carbon, as determined ~~using~~ consistent with the method for organic carbon analysis in Sampling and Analytical Methods for Wild Rice Waters, which is incorporated by reference in item E;

[429] eComment of Norman Miranda (Nov. 15, 2017).
[430] MPCA Rebuttal at 4-5.
[431] MPCA Rebuttal at 5.

> (b) iron is the amount of extractable iron in dry sediment. The 8.10 concentration is expressed as micrograms of iron per gram of dry sediment, as determined ~~using~~ consistent with the method for extractable iron in Sampling and Analytical Methods for Wild Rice Waters;
>
> (c) sediment samples are collected ~~using~~ consistent with the procedures established in 8.14 Sampling and Analytical Methods for Wild Rice Waters;

305. The MPCA is proposing additional related changes, likely to be codified as rule part 7050.0224, subp. 5, E, which would read as follows:[432]

> For each wild rice water identified in 7050.0471, the methods for selecting sediment sampling sites and for collecting, processing and analyzing sediment samples must be documented, including all QA/QC. Where methods are used that are consistent with but different from those specified in Sampling and Analytical Methods for Wild Rice Waters, the intended methods and how they will be used to calculate the numeric sulfate standard must be submitted to and approved by the Commissioner prior to sample collection.

306. The MPCA believes these changes will allow parties wishing to undertake sampling of wild rice waters needed to calculate a protective sulfate value the flexibility to do so, while ensuring necessary consistency. The MPCA intends that sampling by non-Agency personnel could occur at any time, even if MPCA sampling has already occurred. In those cases, the MPCA states, "the intended methods should describe how both the MPCA gathered data and any additional data will be used in concert." The MPCA intends that, in all cases, all sampling be documented.[433]

307. The Administrative Law Judge disapproves the MPCA's proposed language requiring prior approval of data collection methods to plan for allowing non-Agency personnel to engage in sampling and data collection of wild rice waters because the MPCA provides no criteria for approving alternate sampling plans. This delegates discretion to the Agency beyond what is allowed by law, in violation of Minn. R. 1400.2100.D.[434]

308. The MPCA states in its Rebuttal memorandum, but nowhere in the rule, that the MPCA will make the final determination about the numeric sulfate standard for any given water body.[435]

309. The MPCA includes no process and no criteria in the proposed rule language for the Agency to determine which of possible competing numeric sulfate

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[432] MPCA Rebuttal at 5. The incorporation by reference would then be renumbered as Subp. 5, F. MPCA Rebuttal at 5.
[433] MPCA Rebuttal at 5.
[434] *See Lee v. Delmont*, 228 Minn. 101, 113, 36 N.W.2d 530, 538 (1949); *accord Anderson v. Commissioner of Highways*, 126 N.W.2d 778, 780 (Minn. 1964).
[435] MPCA Rebuttal at 5.

standards will apply in a given wild rice water. While the Administrative Law Judge does not disapprove incorporating by reference into the rule the Sampling and Analytical Methods for Wild Rice Waters, the Agency's larger scheme of permitting multiple players to propose standards with no written, transparent process or criteria for choosing among those standards exceeds the Agency's authority.

310. The Administrative Law Judge disapproves the MPCA's proposed language because, by granting the Agency authority to choose which standard to apply with no criteria in rule, the rule grants the Agency discretion beyond what is allowed by law in violation of Minn. R. 1400.2100.D.[436]

(3) Minn. R. 7050.0224, subp. 5, B (2)

311. The MPCA received several comments about the Alternate Standard set forth at Minn. R. 7050.0224, subp. 5, B (2). This alternate standard procedure develops a replicable approach to developing an alternate standard for areas where the equation does not fit – where there is high sulfate but low porewater sulfide. A number of commenters objected to the standard for a variety of reasons. [437]

312. In its Rebuttal, the MPCA proposes to revise Minn. R. 7050.0224, subp. 5, B (2), as follows:[438]

> The commissioner may establish an alternate sulfate standard for a wild rice water when the ~~ambient~~ <u>surface water</u> sulfate concentration is above the calculated sulfate standard and data demonstrates that sulfide concentrations in pore water are 120 micrograms per liter or less. Data must be gathered ~~using~~ <u>consistent with</u> the procedures specified in Sampling and Analytical Methods for Wild Rice Waters, which is incorporated by reference in item E. The alternate sulfate standard ~~established must be either the annual average sulfate concentration in the ambient water or a level of sulfate the commissioner has determined will maintain the sulfide concentrations in pore water at or below 120 micrograms per liter.~~ <u>is determined by calculating the ratio of measured sulfide, in micrograms per liter, to 120 micrograms per liter and applying that ratio to the surface water sulfate as follows</u> $\frac{120}{porewater\ sulfate} * surface\ water\ sulfate$.

313. The Administrative Law Judge disapproves of Minn. R. 7050.0224, subp. 5, B (2), because, as with the repeal of the 10 mg/L sulfate standard, the MPCA has failed to make an affirmative presentation of facts demonstrating that, in establishing an Alternative Standard which would allow increased levels of sulfate in wild rice waters, it

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[436] *See Lee v. Delmont*, 228 Minn. 101, 113, 36 N.W.2d 530, 538 (1949); *accord Anderson v. Commissioner of Highways*, 126 N.W.2d 778, 780 (Minn. 1964).
[437] Test. of P. Maccabee, Oct. 23, 2017 Tr. at 104; eComment of Kurt Anderson on behalf of Minnesota Power (Minnesota Power eComment) at 18-19 (Nov. 21, 2017); eComment of Chrissy Bartovich and Lawrence Sutherland on behalf of U.S. Steel (U.S. Steel eComment) at 34 (Nov. 22, 2017).
[438] MPCA Rebuttal at 7.

is protecting the public health or welfare, enhancing the quality of water, and ensuring the proposed water quality standards provide for the attainment and maintenance of the water quality standards of downstream waters, as required by federal and state law. Therefore, the Administrative Law Judge concludes that the proposed Alternative Standard violates Minn. R. 1400.2100.D, because it conflicts with other applicable law.

(4) Part 7050.0130, subp. 6a

314. **Part 7050.0130, subp. 6a** defines a "water identification number" or "WID" as a unique identifier used by the agency to identify a surface water.[439] Mining Minnesota objects to the MPCA's use of WIDs to describe the identified wild rice waters at proposed Minn. R. 7050.0471.[440] The basis for Mining Minnesota's objection is that the WIDs fail to describe the areas where wild rice beds are located with sufficient specificity, resulting in a list that designates waters with no wild rice, or no history of wild rice presence, as wild rice waters.[441] The result of the MPCA's use of what is essentially an administrative convenience, according to Mining Minnesota, is an overbroad regulation that "will inflict significant hardship on industry, companies, and private citizens across the state in a manner that is contrary to legislative intent."[442]

315. The MPCA disagrees with this criticism, stating that "WIDs are an important component of the MPCA's water programs."[443] The MPCA notes that the EPA agrees with the MPCA's assessment that rulemaking is required to make changes to a WID number that would entirely remove the WID from a particular water, or from a subpart of the water already identified as a wild rice water.[444] The MPCA contends that it is logical to apply the standard to the entire WID for lakes, wetlands, and reservoirs, because in these situations, the water generally "moves and mixes throughout the waterbody."[445] The MPCA notes that, in those cases where part of a lake or reservoir, such as a bay, is hydrologically isolated, the MPCA has a mechanism for assigning a separate WID to the hydrologically separate part of the waterbody.[446]

316. While the MPCA recognizes "that there may [be] cases where the presence of wild rice within a large or very diverse WID does not justify the application of the standard to the entire WID" the MPCA suggests that, in those cases, it "can split the WID and conduct a use and value determination . . . to remove the wild rice beneficial use from the WID that does not support the beneficial use."

317. The Administrative Law Judge concludes that the MPCA's proposal to "split the WID and conduct a use and value determination . . . to remove the wild rice beneficial

[439] Ex. C at lines 1.16-1.22.
[440] Letter from Frank Ongaro on behalf of Mining Minnesota (Mining Minnesota letter) at 3 (Nov. 22, 2017).
[441] Mining Minnesota letter at 3-4.
[442] Mining Minnesota letter at 7.
[443] MPCA Rebuttal at 14.
[444] *Id.*
[445] *Id.*
[446] *Id.*

use from the WID that does not support the beneficial use" at some time in the future would violate the federal prohibition on removing an existing use.[447] This proposal is not currently in the proposed rule and the Administrative Law Judge does not approve including it.

2. Changes That Are Approved

318. The MPCA proposes changes to a number of proposed rules in its Response and Rebuttal memoranda. Should the MPCA proceed with revisions to the overall rule, the Administrative Law Judge concludes that the MPCA's proposed changes to the rule parts listed below would be needed and reasonable and would not constitute modifications that make the rule substantially different than the rule as originally proposed based on the standards set forth at Minn. Stat. § 14.05, subd. 2:

a. Minn. R. 7050.0130, subp. 2b[448]

b. Minn. R. 7050.0130, subp. 6c[449]

c. Minn. R. 7050.0220, subps. 1, B (1-4), 3a, 4a, 5a and 6a[450]

d. Minn. R. 7050.0220, subp. 3a[451]

e. Minn. R. 7050.0224, subp. 5, B[452]

f. Minn. R. 7050.0471, subp. 3[453]

g. Minn. R. 7050.0471, subps. 6 and 8[454]

h. Minn. R. 7050.0471, subp. 8[455]

i. Minn. R. 7053.0406, subp. 1[456]

j. Minn. R. 7053.0406, subp. 2[457]

k. Minn. R. 7053.0406, subp. 2, B[458]

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[447] 40 C.F.R. § 131.3 (e).
[448] MPCA Rebuttal at 2.
[449] MPCA Rebuttal at 3. The MPCA Rebuttal mistakenly refers to the rule part in question as part 7050.0220, subp. 6c.
[450] MPCA Rebuttal at 2.
[451] MPCA Rebuttal at 2-3.
[452] Rebuttal at 7. EPA Comments at 5.
[453] MPCA Response to Comments at 13.
[454] MPCA Response to Comments at 14.
[455] This WID location tool is intended to be supplementary to the Tableau interactive mapping tool presently available on the MPCA wild rice web page http://www.pca.state.mn.us/water/protectingwild-rice-waters. MPCA Response to Comments at 14.
[456] MPCA Response to Comments at 14-15.
[457] MPCA Response at 15. Minn. R. 7050.0190 contains provides that a variances from a water quality standard includes a variances for its related WQBEL. Environmental Protection Agency Comments (EPA Comments) at 15 (Nov. 22, 2017).
[458] MPCA Response at 15.

G. Additional Findings

319. The Administrative Law Judge finds that the Agency has demonstrated by an affirmative presentation of facts the need for and reasonableness of all rule provisions that are not specifically addressed in this Report.

320. Further, the Administrative Law Judge finds that all provisions that are not specifically addressed in this Report are authorized by statute, and that, to the extent they are severable from the defective rules, there are no other defects that would bar the adoption of those rules.

321. Because some of the defects in the rule are defects in foundational portions of the proposed rules, the Administrative Law Judge advises the Agency against resubmitting the rule for approval of changes unless it addresses the defects in the wild rice water sulfate standard and the list of wild rice waters. However, the list of wild rice waters proposed at Minn. R. 7050.0471 is severable from the wild rice water sulfate standard. Therefore, the Administrative Law Judge finds that the Agency could choose to resubmit the proposed list of wild rice waters separately from the wild rice water sulfate standard.

Based upon the Findings of Fact and the contents of the rulemaking record, the Administrative Law Judge makes the following:

CONCLUSIONS OF LAW

1. The Agency gave proper notice of the hearing in this matter, pursuant to Minn. Stat. §14.14, subd. 1(a).

2. The Agency has failed to fulfill the procedural requirements of Minn. Stat. §§ 14.127 and 14.131, paragraphs 1, 5, 7, and 8. All other procedural requirements of rule and law have been satisfied for both the proposed repeal of the 10 mg/L sulfate standard and the adoption of the proposed rules.

3. The following proposed rules are **DISAPPROVED:**

   a. Proposed **Minn. R. 7050.0220, subps. 3a, 4a, 5a, 6a**: deleting reference to 10mg/L sulfate wild rice water standard violates Minn. R. 1400.2100 B and D.

   b. Proposed **Minn. R. 7050.0224, subp. 2**: repealing 10mg/L sulfate wild rice water standard violates Minn. R. 1400.2100.B and D.

   c. Proposed **Minn. R. 7050.0224, subp. 5, A**: to the extent the language incorporates the standard in items B (1) and (2) the language violates Minn. Stat. § 14.38 and Minn. R. 1400.2100.B and G.

d. Proposed **Minn. R. 7050.0224, subp. 5, A**: to the extent the language incorporates the standard in item C, the language violates Minn. R. 1400.2100.D.

e. Proposed **Minn. R. 7050.0224, subp. 5, B (1)**: violates Minn. R. 14.38 and Minn. R. 1400.2100.B, G, and E.

f. Proposed **Minn. R. 7050.0224, subp. 5, C**: violates Minn. R. 1400.2100.D.

g. Proposed **Minn. R. 7050.0224, subp. 6**: need or reasonableness for rule not established. Failure to distinguish between [WR], which are provided the additional protection of the narrative standard, and other wild rice waters listed at Minn. R. 7050.0471 violates 1400.2100.B.

h. Proposed **Minn. R. 7050.0471, subps. 3 through 9**: violates Minn. R. 1400.2100.D and E.

4. The following changes to rules as originally proposed are **DISAPPROVED:**

a. Proposed changes to **Minn. R. 7050.0224, subp. 5, B (1):** violates Minn. R. 1400.2100.E.

b. Proposed changed to **Minn. R. 7050.0224, subps. 5, E and F:** violate Minn. R. 1400.2100.D.

c. Proposed changes to **Minn. R. 7050.0224, subp. 5, B (2):** violates Minn. R. 1400.2100.D.

5. The Administrative Law Judge has suggested actions to correct some of the defects cited herein and to improve the clarity of the proposed rules should they be resubmitted for approval in the future.

6. Due to the disapproval of the proposed rules and the repeal of the existing rules, this Report has been submitted to the Chief Administrative Law Judge for her approval pursuant to Minn. Stat. § 14.15, subd. 3.

7. Any Findings that might properly be termed Conclusions, and any Conclusions that might properly be termed Findings, are hereby adopted as such.

8. A Finding or Conclusion of need and reasonableness with regard to any particular rule subsection does not preclude and should not discourage the Agency from further modification of the proposed rules based upon this Report and an examination of the public comments, provided that the rule finally adopted is based on facts appearing in this rule hearing record and is not substantially different from the proposed rule.

Based upon the foregoing Conclusions, the Administrative Law Judge makes the following:

RECOMMENDATION

IT IS HEREBY RECOMMENDED that the proposed rules be **DISAPPROVED.**

Dated: January 9, 2018

LAURASUE SCHLATTER
Administrative Law Judge

Reported:

Marcia L. Menth, Kirby Kennedy & Associates, St. Paul – 10/23
Calvin J. Everson, Danielson Court Reporting, Virginia – 10/24
Lorna D. Jacobson, Jacobson Reporting & Video Services, Bemidji – 10/25
Nathan D. Engen, Cloquet – 10/26
Nathan D. Engen, Brainerd – 10/30
Kelly L. Brede, Kirby Kennedy & Associates, St. Paul – 11/2

U. S. STEEL MINNTAC
TWIN LAKES WILD RICE RESTORATION OPPORTUNITIES PLAN
FINAL REPORT

FEBRUARY 28, 2019

PREPARED FOR

U. S. STEEL MINNTAC

P.O. BOX 417

MT. IRON, MN 55768

PREPARED BY

NORTHEAST TECHNICAL SERVICES, INC.

526 CHESTNUT STREET

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EXECUTIVE SUMMARY

Department of the Army Wetland Permit Number 2011-00832-JCB (Permit) was issued to U. S. Steel on December 10, 2012 for proposed impacts to wetlands within the U. S. Steel Minntac "Progression", which allowed continued mining to the existing Permit to Mine boundary in the Minntac West Mine Pit. Special Conditions 9 and 10 of the Permit required the development and implementation of a Twin Lakes Wild Rice Restoration Opportunities Plan that included "the development of a five-year wild rice restoration and monitoring program for those areas of the Twin Lakes that show the greatest potential for restoration based on best information available in the time frame allowed…".

The Twin Lakes Wild Rice Restoration Opportunities Plan (Plan) was developed by U. S. Steel and Northeast Technical Services (NTS) to satisfy Special Condition 9 of the Permit and submitted to the U.S. Army Corps of Engineers (Corps) on April 11, 2013. The Plan was subsequently revised to address comments from the Corps and other interested parties, and resubmitted to the Corps on August 16, 2013. The Corps approved of the Plan on November 22, 2013. In anticipation of Corps approval, and to satisfy Special Condition 10 of the Permit, work on the Plan was initiated on October 9, 2013 with the deployment of a pressure transducer at the steel bridge separating Little Sandy and Sandy lakes to record fluctuations in lake levels. Additional activities were completed in 2013, although the overall scope was limited due to the lateness of the open water season. Monitoring activities continued each subsequent year, 2014 – 2018, from ice-out to mid- to late-Autumn. Descriptions of the activities and accomplishments from each Plan year, including 2013, are detailed in annual reports that have been submitted to the Corps by the end of each respective calendar year.

This final report represents the culmination of the Plan and that five-year effort, and provides a comprehensive evaluation of the monitoring efforts that have been conducted, a presentation of the various factors that influence wild rice growth in this setting, and analyses of the primary opportunities for restoration of wild rice in the Twin Lakes.

1.0 INTRODUCTION/BACKGROUND

During the summer of 2013, U. S. Steel and NTS developed the Twin Lakes Wild Rice Restoration Opportunities Plan (Plan) to evaluate the opportunities for wild rice restoration within Little Sandy Lake and Sandy Lake, commonly referred to as the Twin Lakes. Little Sandy and Sandy lakes are connected by a narrow channel approximately 20 meters in width. Historically, a north-south trending county road was routed through this area and crossed the narrow channel between the Twin Lakes via a steel truss bridge. The county road is no longer used for typical vehicle travel, but instead is used as a regional snowmobile trail. According to 1966 documentation (Sternberg and Hope 1966a, b), the distribution of wild rice in Sandy Lake was described as being extensive at that time. Site maps created following field work associated with Sternberg and Hope (1966a, b) indicate that wild rice was present "throughout" Sandy Lake. Although the actual acreage was not reported, the stand was reported to be in good condition with "…several boats ricing on the lake." Wild rice was also reported throughout Little Sandy Lake, with a denser wild rice stand observed in the NE corner. Measured water depths ranged from 2.0 – 3.0 feet throughout these lakes (Sternberg and Hope 1966a, b), which are typically associated with wild rice areas, and is documented to be appropriate for wild rice growth. According to published literature sources water depths of 0.5 – 3.0 feet are more conducive to wild rice growth and propagation (MN DNR 2008; Vogt 2012). Historical water depths in Little Sandy and Sandy lakes appear to have been more favorable for wild rice growth than in more recent times. Vogt (2012) observed wild rice plants in Sandy Lake during 2006, 2007, 2010, 2011, and 2012 surveys. No surveys were completed in 2008 or 2009. The density of wild rice plants observed during each of these surveys was fewer than approximately 100 total plants. Wild rice in Little Sandy Lake was observed only during the 2006 and 2012 surveys. Subsequent wild rice surveys completed by the 1854 Treaty Authority identified areas of sparse wild rice plant density in variable locations within the Twin Lakes system. During 2015, three specific areas within each lake were used as wild rice test seeding areas for the Plan. During the 2016, 2017, and 2018 wild rice surveys, wild rice plants were observed in all six seeded areas and was reported to be present at variable densities.

For the purposes of the Plan, the entire area/volume of the Twin Lakes system was considered as the potential area within which wild rice restoration opportunities would be considered. Throughout the 5+ field seasons (approximately April – October) of the Plan, observations and datasets from the Twin Lakes were obtained and accumulated, as follows: specific physical characteristics of interest to successful wild rice restoration opportunities such as water depth, the presence of competing aquatic vegetation, and sediment type (e.g., sandy, more organic rich), were evaluated; surface water, sediment, and sediment pore water quality sampling events were completed each year of the study, many of which were above-and-beyond the scope of the Plan as approved, to define the chemical characteristics of the system; and hydrologic/hydraulic modeling of the Twin Lakes system was undertaken to determine the reasons behind the apparently high lake levels relative to what was historically observed.

As discussed above, historically when wild rice was reported as present throughout the Twin Lakes water depths were reported as 2.0-3.0 feet. This is within the appropriate water depth range for wild rice germination, growth, and development into mature seed producing plants. As this system has aged, competing perennial aquatic vegetation has become more dense within portions of both of the Twin Lakes, and in particular Sandy Lake, as well as in the Sand River downstream of Sandy Lake. Additionally, beavers have constructed and maintained several dams within the Sand River below Twin Lakes that have increased the water depths of the lakes. As a critical component of the Plan, beaver trapping and (beaver) dam removal efforts were completed in an effort to mitigate their influences on increasing water depth in the lakes. Although water depths around the internal periphery of the Twin Lakes can be more appropriate for wild rice growth and development, few if any wild rice plants have been observed in these areas. Based on historical wild rice density reports, the absence of wild rice in areas of more appropriate water depth was puzzling. If viable wild rice seeds were present in the sediment of these areas, wild rice plants would most likely be observed. Instead, based on yearly wild rice surveys completed by 1854 Treaty Authority personnel, wild rice plants were infrequently observed in areas of appropriate water depth, almost exclusively in Sandy Lake, and areas of sparse wild rice plants varied between years. Although this indicates wild rice seed can survive in Twin Lakes sediment over time, the spatial variability of wild rice plant observations has been confounding.

Records indicate that not only were historical water depths more favorable to wild rice growth and propagation, but that there were fewer perennial aquatic plants competing with wild rice for needed resources. Yearly aquatic plant surveys were completed as a required component of the Plan, during which several taxa of aquatic plants were observed and identified in areas conducive and non-conducive to wild rice growth. Perennial aquatic plants such as cattails have reproductive advantages, not available to wild rice as an annual, allowing them to tolerate water depth fluctuations. Additional perennial aquatic vegetation such as Coontail and pondweed can survive in water under ice and snow; and therefore, have a unique advantage to outcompete wild rice for resources such as light during and following spring melt. Historical and current non-managed growth, development, and increased distribution of perennial aquatic plants competing with wild rice has likely resulted in decreased availability of areas conducive to wild rice growth, development, and distribution.

Finally, historical distribution of wild rice within the Twin Lakes system would suggest that the sediment characteristics throughout this system would be conducive to wild rice growth and development. However, it appears that some areas within the Twin Lakes contain sediment with a greater proportion of sand and/or gravel rather than the organic-rich sediment type preferred by wild rice. This suggests that some areas within each of these lakes may not be conducive to wild rice growth and development, completely unrelated to any influence from water depth, competing aquatic vegetation, or characteristics of surface water or sediment pore water quality.

The objective of the Plan was to identify opportunities for wild rice restoration in the Twin Lakes. This final report details the specific factors influencing wild rice growth in the Twin Lakes and provides suggestions on opportunities for successful long-term restoration of wild rice in Sandy and Little Sandy lakes.

2.0 SURFACE WATER QUALITY

2.1 INFLOW/OUTFLOW MONITORING DESCRIPTIONS

U. S. Steel began sampling and testing surface water quality of the Twin Lakes starting in May 2014 as prescribed by the Plan. Surface water samples were collected during each month of open water through 2018. The location and parameters sampled varied over time depending on several factors, which is explained below for each designated location (see Figure 1). Prior to 2014, Twin Lakes surface water quality was monitored through a separate agreement between the Bois Forte Band of Chippewa (Bois Forte) and U. S. Steel. This work is discussed further in Section 2.2 below.

Water quality sampling sources included the inflows to Little Sandy Lake (Inflow 1, Inflow 2 and Inflow 3), a tributary to Sandy Lake from the north into its northeast arm (Culvert Inflow), another small tributary to Sandy Lake from the south (Sandy Lake South Inflow), and the Twin Lakes system outflow (Twin Lakes Outflow, previously referred to as Outflow 2 Sand River). It should be noted that the inflow samples referred to above were collected either from active, measurable inflow (Inflow 1, the Culvert Inflow and the Sandy Lake South Inflow) or from areas at the periphery of the lake in close proximity to what appears to be inflow channels from aerial photos (e.g., Inflow 2 and Inflow 3). Areas of discrete, measureable flow at the Inflow 2 and Inflow 3 locations were not accessible by canoe at any time during the course of the Plan primarily due to the density of vegetation present at the wetland channel/lake interface. Flow from the wetland channels corresponding to the Inflow 2 and Inflow 3 locations enters the lake in a diffuse manner, preventing the quantification of inflow to Little Sandy Lake from these sources. Therefore, samples were collected at the mouth of the inflow channels. Water was also sampled periodically from the approximate centers of Little Sandy and Sandy lakes to evaluate the general water quality within each lake. It should be noted that sampling from the Inflow 3 site was discontinued for the 2017 and 2018 monitoring seasons, since previous water quality characterization results indicated no significant difference between the water sampled at this location and samples collected from the middle of Little Sandy Lake. A description of each of the sampling sources, with the exception of the mid-lake samples, is provided here:

Inflow 1 – corresponds to the discharge of the Sand River into the southeast quadrant of Little Sandy Lake. Water quality samples are collected from the inflow channel approximately 20 meters downstream of a wooden suspension snowmobile bridge crossing the Sand River at the inlet.

Inflow 2 – is situated on the very west edge of Little Sandy Lake and represents flow entering the system from a wetland complex to the southwest that originates near the northeast corner of the Minntac tailings basin perimeter dike.

Inflow 3 – represents discharge to the system from general wetlands present north of Little Sandy Lake. The Inflow 3 sampling location is situated on the northwest side of Little Sandy Lake at the mouth of a north/south trending wetland complex. As noted above, water quality sampling from this location was discontinued after the 2016 monitoring season because no statistical difference was observed in the water quality results between Inflow 3 samples and samples collected from the middle of Little Sandy Lake (LSL Mid).

Culvert Inflow – represents tributary flow from the north entering the east end of Sandy Lake near the discharge into the Sand River. A culvert through the access road to the canoe landing was identified in 2014 on a stream that appeared to be the main source of flow to this tributary (previously referred to as "Outflow Trib 1"). The culvert is located roughly 1080 meters upstream from where the tributary discharges into Sandy Lake. Water quality sampling results from 2014 showed that there were no significant differences between the Outflow Trib 1 and Culvert Inflow samples, and therefore all subsequent sampling for this source was conducted at the culvert.

Sandy Lake South Inflow – represents tributary inflow from the south entering the southeast arm of Sandy Lake. This sampling point was identified during the aquatic plant survey in August 2016, after which water quality sampling and flow monitoring was implemented.

Twin Lakes Outflow – is located in the Sand River channel approximately 450 meters downstream from the mouth of the north tributary (characterized by Culvert Inflow / Outflow Trib 1). Water sampled at this location is representative of the total outflow from the Twin Lakes system.

With the minor exceptions described above, water samples were collected on a monthly basis during each open-water monitoring season of the Plan from the inflow sources to Little Sandy Lake (Inflow 1, Inflow 2 and Inflow 3), the identified inflow sources to Sandy Lake (Culvert Inflow and Sandy Lake South Inflow), the outflow from the system (Twin Lakes Outflow) and from the approximate center of each lake (see Figure 1 below). Analytical results from these monthly sampling events were tabulated by event date and are presented in Appendix A. In addition, summaries of the sampling results for each of the five years of Plan implementation are presented in Tables 1 – 5 below.

It should be noted that the list of analytical parameters changed over the five-year Plan. After each Plan year, the results were reviewed and parameters that were below detection limits or relatively unchanged were removed from the profile.

- Aluminum: Most results for aluminum were under 50 µg/L. Therefore, measurement of this parameter was discontinued prior to the fourth year (2017).
- Arsenic: During the first year, all water samples tested for arsenic were well below the applicable water quality standard. After the second sampling event of 2015 this parameter was discontinued.
- Barium: Concentrations of barium were typically between 20 and 30 ug/L and did not vary over the first seven sampling events conducted for the Plan. Analysis of this parameter was discontinued after the first sampling event of 2015.
- Gallium, Molybdenum, Silver: The first two sample events showed results below the detection limit for these three parameters at all locations. Therefore, analysis of gallium, molybdenum and silver were discontinued after the second sampling event of 2014.
- Cadmium, Lead, Zinc: The first two sample events of 2014 did not show results for cadmium, lead and zinc above the detection limit at any of the sampling locations except Culvert Inflow. After the second sampling event of 2014 these analyses were discontinued at all of the sampling locations with the exception of the Culvert Inflow source, which continued through the end of the 2014 sample season. Aside from that one result, no other samples resulted in values above the detection limit at the Culvert Inflow. Therefore, analyses of these three parameters was totally discontinued prior to 2015.
- Copper: The analytical results for copper followed the same trend as described above for Cd, Pb, and Zn. Aside from an elevated concentration of copper above detection at the Culvert Inflow, no other samples resulted in values above the detection limit. Therefore, analysis of these three parameters was totally discontinued prior to 2015.
- Nickel: The first two sample events showed results below the detection limit for nickel at all locations. Measurement of this parameter was discontinued after the second sampling event of 2014.
- Phosphorus: This parameter was sampled during the entire first year and showed results at or near the detection limit at all locations. Therefore, prior to 2015, analysis of this parameter was discontinued. Note that the low-level method of phosphorus analysis was not used and therefore, the detection limit reported by the lab was 0.10 mg/L.
- Strontium, Rubidium: These parameters were sampled the entire first year of the Plan (2014) and the first two sample events of the second year (2015). Results for strontium and rubidium were fairly consistent during this time, so this measurement was discontinued after the second sample event of 2015.
- Nitrogen: Since most of the nitrogen analysis showed results at or near detection limits at all locations, with the exception of Total Kjeldahl Nitrogen, all nitrogen analyses were discontinued after the second sample event of 2014. However, analysis of Ammonia Nitrogen was reestablished for the first sample event of 2015 and continued for the remainder of the Plan.
- Specific Ultraviolet Absorbance, Ultraviolet Absorbance (SUVA, UVA): SUVA is another way to measure Dissolved Organic Carbon in surface water. Since there was a Total Organic Carbon

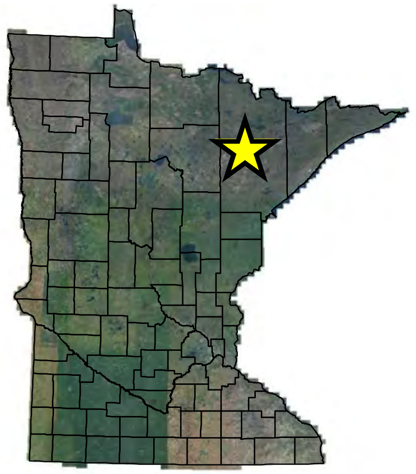
measurement included in the sampling plan, running this test was viewed as redundant. Therefore, analysis of this parameter was discontinued after the second sample event of 2015.

N

0 1,150 2,300 4,600

Feet

1 Inch = 2,340 Feet



Legend

- Inflow Gauging
- Outflow Gauging
- Inflow Water Sample
- Outflow Water Sample
- Lake Middle Water Sample

Figure 1
2014-2018 Twin Lakes
Inflow/Outflow Water Sampling
and Flow Gauging Locations

Twin Lakes
US Steel Corporation -
Minnesota Ore Operations
Mt. Iron, Minnesota (St. Louis County)

NTS Environmental Science & Engineering
www.netechnical.com

Date Drawn : February 12, 2019	
Drawn By : T. Muck	**1**
NTS Project #: 10170E	

TABLE 1
TWIN LAKES WATER QUALITY 2014

	Reporting	Little Sandy Inflow 1			Little Sandy Inflow 2			Little Sandy Inflow 3			Little Sandy Middle			Sandy Middle			Culvert Inflow			Twin Lakes Outflow		
Analytes - Cations	Units	Average	Min	Max	Average	Min	Max	Average	Min	Max	Average	Min	Max	Average	Min	Max	Average	Min	Max	Average	Min	Max
Aluminum	µg / L	27.0	<20.0	52.0	15.8	<20.0	41.7	<20.0	<20.0	<20.0	30.6	30.6	30.6	37.7	37.7	37.7	NM	NM	NM	20.2	22.8	35.1
Arsenic	µg / L	0.75	<0.50	0.75	0.4	<0.50	1.1	0.60	<0.50	0.69	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	0.72	<0.50	1.10	0.60	0.51	0.92
Barium	µg / L	37.9	23.1	58.9	26.6	19.4	35.4	29.2	22.3	35.5	23.3	23.3	23.3	21.4	21.4	21.4	31.2	23.9	38.2	25.5	18.9	31.2
Calcium	mg / L	66.9	37.5	95.0	32.5	25.4	40.5	33.4	24.6	44.4	29.5	29.5	29.5	25.3	25.3	25.3	13.1	11.0	15.5	24.1	19.1	34.8
Iron	µg / L	860	229	1980	543	169	1100	258	173	459	717	717	717	800	800	800	4646	1870	7520	975	409	1470
Magnesium	mg / L	92.5	44.3	140	42.8	34.4	52.8	44.7	36.1	62.3	36.5	36.5	36.5	30.5	30.5	30.5	4.4	3.9	5.2	27.4	19.7	44.9
Manganese	µg / L	142	54.4	347	56.5	23.9	92.2	75.4	25.5	127	42.7	42.7	42.7	42.5	42.5	42.5	183	82.3	300	64.8	27.6	138
Phosphorus	mg / L	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Potassium	mg / L	6.1	2.5	11.4	3.3	1.7	4.0	3.2	2.2	3.7	3.7	3.7	3.7	3.5	3.5	3.5	1.4	0.93	1.9	2.9	2.2	3.4
Rubidium	µg / L	2.9	2.0	4.0	2.3	1.5	2.6	2.6	2.3	3.0	2.6	2.6	2.6	2.5	2.5	2.5	0.90	1.1	1.4	2.1	1.6	2.5
Sodium	mg / L	38.3	18.4	58.2	15.5	12.0	19.5	14.3	9.3	23.1	12.9	12.9	12.9	11.8	11.8	11.8	4.0	3.2	4.5	10.9	8.3	17.8
Strontium	µg / L	238	133	327	112	85.5	142	114	78.2	154	98.5	98.5	98.5	86.3	86.3	86.3	54.6	44.2	63.4	85.8	66.5	123
Analytes - Anions																						
Chloride	mg / L	57.3	9.5	103	21.3	15.8	28.5	21.3	8.0	30.1	17.1	17.1	17.1	15.7	15.7	15.7	10.3	6.4	13.1	16.6	13.3	25.8
Nitrogen, Kjeldahl, Total	mg / L	0.4	<0.50	0.75	0.92	0.66	1.2	1.0	0.59	1.8	0.72	0.72	0.72	0.74	0.74	0.74	1.1	0.9	1.2	0.70	<0.50	1.2
Ammonia as Nitrogen	mg / L	<0.50	<0.50	<0.50	<0.050	<0.050	<0.050	<0.050	<0.050	<0.50	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
Unionized Ammonia, as Nitrogen	ug/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sulfate	mg / L	328	107	540	125	89.3	162	104	9.9	156	121	121	121	98.6	98.6	98.6	0.60	<2.0	<2.0	80.3	44.6	124.0
Analytes - Other																						
Total Dissolved Solids	mg / L	829	431	1170	403	333	465	407	318	489	366	366	366	315	315	315	151	114	192	299	221	375
Alkalinity, Total as CaCO3	mg / L	191	95.7	259	142	69.0	253	132	90.2	188	95.3	95.3	95.3	74.1	74.1	74.1	38.2	32.1	45.9	85.9	53.4	129
Dissolved Organic Carbon	mg / L	16.6	10.3	20.5	22.7	15.6	26.5	24.3	20.2	28.6	22.0	22.0	22.0	22.0	22.0	22.0	20.5	8.5	30.4	21.8	16.7	26.2
Total Hardness by 2340B	mg / L	548	276	814	257	207	317	267	210	368	224	224	224	189	189	189	50.8	43.7	60.0	173	132	272
UV Absorbance @ 254 nm	mg / L	0.672	0.320	0.930	0.896	0.561	1.20	1.01	0.781	1.40	0.958	0.958	0.958	0.938	0.938	0.938	1.02	0.360	1.90	0.890	0.570	1.10
SUVA	cm^{-1}	3.9	3.1	4.5	3.9	3.6	4.6	3.8	2.3	4.7	4.4	4.4	4.4	4.3	4.3	4.3	3.9	1.3	5.2	4.2	3.6	5.0
YSI Probe Plus Data																						
pH	Units	7.4	7.0	8.6	7.5	6.6	8.4	7.8	6.9	8.5	7.6	7.6	7.6	7.7	7.7	7.7	6.6	6.6	6.8	7.6	7.0	8.6
Temperature	°C	16.3	7.2	21.7	16.3	7.7	23.4	19.7	7.3	25.2	23.6	23.6	23.6	22.6	22.6	22.6	16.6	7.3	23.9	17.5	7.9	23.1
Specific Conductance	uS / cm	1098	569	1620	546	261	689	542	364	678	504	504	504	387	387	387	117	96.0	137	381	307	561

Note: To find each location's frequency of sampling, please review the 2014 Twin Lakes WRROP Annual Report under Twin Lakes Inflow/Outlfow Water Sampling Data.

Table 2

Twin Lakes Water Quality 2015

	Reporting	Little Sandy Inflow 1			Little Sandy Inflow 2			Little Sandy Inflow 3			Little Sandy Middle			Sandy Middle			Culvert Inflow			Twin Lakes Outflow		
Analytes - Cations	**Units**	**Average**	**Min**	**Max**	**Average**	**Min**	**Max**	**Average**	**Min**	**Max**	**Average**	**Min**	**Max**	**Average**	**Min**	**Max**	**Average**	**Min**	**Max**	**Average**	**Min**	**Max**
Aluminum	µg / L	69	29.7	124	15.4	10.1	54.3	<10.0	<10.0	16.4	<0.10	<0.10	<0.10	8.0	<50.0	18.1	25.4	<50.0	53.0	14.3	<50.0	35.8
Arsenic	µg / L	<0.05	<0.05	<0.05	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	NM	NM	NM	NM	NM	NM	0.38	<0.50	0.76	<0.50	<50.0	<0.50
Barium	µg / L	19.0	19.0	19.0	23.7	23.7	23.7	26.5	26.5	26.5	NM	NM	NM	NM	NM	NM	17.5	17.5	17.5	24.4	24.4	24.4
Calcium	mg / L	64	38.4	91.7	45.7	27.9	68.0	40.0	30.5	53.1	49.6	40.7	59.1	39.4	33.4	47.4	12.1	9.0	15.4	33.6	15.6	42.2
Iron	µg / L	963	407	2030	995	218	4170	235.7	80.0	448.0	121	121	121	268	171	315	2600	1180	3800	583	287	1200
Magnesium	mg / L	90	53	133	65.7	38.2	97	60.2	46.5	79.8	71.7	57.7	83.9	57.2	47.2	69.5	4.3	3.2	5.3	45.6	14.3	59.1
Manganese	µg / L	154	28.5	309	76.5	32.8	128	93.9	14.8	258	98.7	98.7	98.7	68.2	40.1	129	134	46.1	210	52.1	32.6	67.5
Phosphorus	mg / L	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	NM	NM	NM	NM	NM	NM	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Potassium	mg / L	7.6	5.6	11.6	4.1	1.78	5.73	3.2	1.6	4.4	5.1	5.1	5.1	4.4	4.1	4.8	1.5	1.2	1.9	4.2	1.8	6.0
Rubidium	µg / L	2.9	2.8	2.9	3.0	3.0	3.0	2.5	2.4	2.6	NM	NM	NM	NM	NM	NM	1.3	1.2	1.4	2.8	2.8	2.8
Sodium	mg / L	36.3	21.3	52.4	21.6	13.7	30.6	17.8	11.1	25.5	26.0	20.2	31.3	21.9	17.9	26.5	4.2	3.7	4.7	18.1	6.9	23.2
Strontium	µg / L	152	129	175	130.5	128	133	102	101	102	NM	NM	NM	NM	NM	NM	39.7	34.3	45.1	122	107	136
Analytes - Anions																						
Chloride	mg / L	54	31.4	85.4	30.7	23.6	43.5	23.2	13.2	33.9	37.8	31.4	47.6	32.2	28.5	39.1	10.5	8.2	13.4	27.0	12.1	35.4
Nitrogen, Kjeldahl, Total	mg / L	0.68	<0.50	0.98	1.1	0.73	1.6	0.90	0.59	1.2	0.85	0.72	1.1	0.85	0.65	1.1	0.40	<0.50	0.83	0.71	0.57	1.0
Ammonia as Nitrogen	mg / L	0.02	<0.10	0.10	0.03	<0.10	0.17	0.05	<0.10	0.12	<0.10	<0.10	<0.10	0.15	0.15	0.15	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Unionized Ammonia, as Nitrogen	ug/L	0.09	0.00	1.9	0.25	0.00	5.0	0.43	0.00	6.7	0.00	0.00	0.00	4.8	1.3	11.5	0.00	0.00	0.00	0.00	0.00	0.00
Sulfate	mg / L	326	191	498	227	157	340	179	52.5	250	240	219	279	187	162	223	2.5	<2.0	2.8	146	33.8	200
Analytes - Other																						
Total Dissolved Solids	mg / L	747	457	1040	549	399	737	473	309	623	572	475	649	467	399	546	121	95.0	166	388	174	473
Total Suspended Solids	mg / L	1.8	<1.0	3.6	1.7	<1.0	3.5	1.3	1.6	2.0	1.2	1.2	3.2	1.6	<1.0	4.0	3.3	1.2	5.2	1.9	<1.2	4.0
Alkalinity, Total as CaCO3	mg / L	162	93.1	233	143	105	221	148	92.6	201	145	110	178	117	93.7	153	36.7	24.6	46.2	97.5	47.4	134
Dissolved Organic Carbon	mg / L	14.3	9.4	18.4	19.4	12.9	28.5	20.5	14.7	30.7	18.3	17.0	20.1	18.8	17.0	20.3	12.8	7.5	16.3	16.2	10.8	19.3
Total Hardness by 2340B	mg / L	529	314	776	385	227	569	348	268	461	419	339	493	334	278	405	47.9	35.7	60.6	272	97.9	349
UV Absorbance @ 254 nm	cm^{-1}	0.466	0.429	0.502	0.476	0.408	0.544	0.574	0.468	0.679	NM	NM	NM	NM	NM	NM	0.525	0.478	0.572	0.422	0.360	0.484
SUVA	L / mg*m	3.5	3.4	3.5	3.3	3.3	3.3	3.4	3.3	3.4	NM	NM	NM	NM	NM	NM	4.5	4.4	4.6	3.4	3.3	3.5
YSI Probe Plus Data																						
pH	Units	7.3	6.9	7.7	7.5	7.0	7.8	7.5	6.9	8.1	8.1	7.9	8.4	8.0	7.8	8.2	6.9	6.7	7.1	7.7	7.0	8.1
Temperature	ºC	13.6	6.9	19.7	15.5	6.3	22.1	13.9	7.3	21.6	16.4	7.3	22.3	16.1	6.6	22.7	13.5	7.3	18.8	15.4	6.4	23.1
Specific Conductance	uS / cm	1038	632	1435	842	703	1150	698	476	943	831	730	949	670	610	746	112	85.0	130	554	219	698

Note: To find each location's frequency of sampling, please review the 2015 Twin Lakes WRROP Annual Report under Twin Lakes Inflow/Outlfow Water Sampling Data.

NM = Not Measured

TABLE 3
TWIN LAKES WATER QUALITY 2016

Analytes - Cations	Reporting Units	Little Sandy Inflow 1 Average	Min	Max	Little Sandy Inflow 2 Average	Min	Max	Little Sandy Inflow 3 Average	Min	Max	Little Sandy Middle Average	Min	Max	Sandy Middle Average	Min	Max	Culvert Inflow Average	Min	Max	Twin Lakes Outflow Average	Min	Max
Aluminum	µg / L	96	<50.0	284	28	<50.0	111	11.5	<50.0	69.1	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	16.4	<50.0	132	19.0	<50.0	57.3
Calcium	mg / L	55.9	39.4	69.6	39.0	30.7	47.4	34.4	30.1	40.0	35.0	28.2	46.0	36.3	31.5	38.7	12.0	10.0	14.2	27.8	24.3	33.4
Iron	µg / L	4842	1150	20700	1155	442	2320	1060	268	3270	388	388	388	650	650	650	5498	1560	10700	1553	502	3280
Magnesium	mg / L	75.1	45.6	99.3	54.4	41.9	69.1	50.9	47.5	56.0	32.0	38.3	67.2	49.7	42.9	55.6	4.2	3.7	4.9	36.0	31.2	46.5
Manganese	µg / L	177	81.3	429	121	51.9	214	127	77.2	220	63.3	63.3	63.3	38.4	38.4	38.4	233	62.9	419	85.6	46.8	138
Potassium	mg / L	6.0	2.6	9.5	3.4	2.3	4.6	2.7	1.5	4.3	3.5	2.9	4.1	3.3	3.0	3.6	1.4	0.94	1.8	2.9	2.2	3.5
Sodium	mg / L	29.6	17.1	39.0	17.3	14.3	23.0	13.5	9.2	16.8	16.6	13.5	23.0	17.1	15.2	20.1	3.8	3.1	4.2	13.1	11.5	17.1
Analytes - Anions																						
Chloride	mg / L	43.6	20.9	56.5	23.9	17.9	33.7	18.0	12.5	21.7	23.8	17.8	34.7	24.3	18.4	30.2	9.1	7.1	10.6	19.2	15.4	26.1
Nitrogen, Kjeldahl, Total	mg / L	0.93	<0.60	2.6	1.2	0.70	2.1	1.0	0.60	1.6	0.72	<0.50	1.4	0.70	0.79	1.3	0.49	<0.50	1.3	0.87	<0.50	1.5
Ammonia as Nitrogen	mg / L	0.06	<0.10	0.36	0.09	0.15	0.29	0.06	<0.10	0.16	0.05	<0.10	0.15	0.04	<0.10	0.11	0.02	<0.10	0.12	0.11	<0.10	0.32
Unionized Ammonia, as Nitrogen	ug/L	0.20	0.00	3.2	0.48	0.14	9.8	0.31	0.00	2.3	1.08	0.00	14.3	0.78	0.00	7.8	0.04	0.00	1.0	1.0	0.00	7.9
Sulfate	mg / L	251	120	338	155	96.7	216	112	39.6	163	145	104	176	148	125	183	0.4	<2.0	2.3	92.3	64.3	114
Analytes - Other																						
Total Dissolved Solids	mg / L	660	431	836	465	407	561	409	367	473	439	363	548	421	389	460	133	113	155	330	276	392
Total Suspended Solids	mg / L	4.7	1.5	14	7.5	<2.5	22.0	3.5	<2.5	6.5	2.5	2.0	3.2	0.9	<1.0	1.6	9.4	3.2	26	2.0	<1.0	3.6
Alkalinity, Total as HCO3-	mg / L	196	149	278	192	120	251	198	140	255	148	106	222	151	127	179	39.7	34.8	48.4	128	92.4	152
Alkalinity, Total as CaCO3	mg / L	161	122	228	157	98	206	162	115	209	121	87	182	124	104	147	33	29	40	105	76	125
Dissolved Organic Carbon	mg / L	25.7	10.5	63.7	27.8	15.6	38.9	28.2	16.2	38.2	21.6	21.6	21.6	25.1	25.1	25.1	21.8	11.7	35.4	24.9	14.8	39.1
Total Hardness	mg / L	449	286	582	322	249	402	295	280	330	287	228	392	295	255	326	47.1	40.4	55.5	230	189	349
YSI Probe Plus Data																						
pH	Units	7.1	6.7	7.3	7.2	6.9	7.8	7.2	7.2	7.4	7.8	7.3	8.2	7.8	7.3	8.1	6.8	6.5	7.3	7.5	7.3	7.6
Temperature	°C	15.2	5.8	21.4	16.9	6.0	24.2	16.0	5.4	23.6	18.4	7.6	25.1	18.0	7.3	24.8	15.4	5.8	20.0	16.7	6.5	25.0
Specific Conductance	uS / cm	915	547	1141	628	572	781	560	517	644	655	567	732	534	459	619	160	102	417	439	359	527

Note: Little Sandy Middle and Sandy Middle Locations were sampled only once for Aluminum, Iron, Manganese, Potassium and Dissolved Organic Carbon and there were three monthly events where Total Suspended Solids, Nitrogen-Kjeldahl and Ammonium as Nitrogen were analyzed. For the sampling frequency at each location, please review the Twin Lakes 2016 Inflow/Outflow Water Sampling Data in Appendix C.

TABLE 4
TWIN LAKES WATER QUALITY 2017

	Reporting	Little Sandy Inflow 1			Little Sandy Inflow 2			Sandy Lake So. Inflow			Little Sandy Middle			Sandy Middle			Culvert Inflow			Twin Lakes Outflow		
Analytes - Cations	**Units**	**Average**	**Min**	**Max**	**Average**	**Min**	**Max**	**Average**	**Min**	**Max**	**Average**	**Min**	**Max**	**Average**	**Min**	**Max**	**Average**	**Min**	**Max**	**Average**	**Min**	**Max**
Calcium	mg / L	55.8	47.0	74.6	40.6	30.0	49.5	9.1	4.8	14.7	42.8	37.3	47.1	34.5	27.3	37.3	12.3	10.8	15.9	29.5	25.8	32.1
Iron	µg / L	1422	831	1840	762	327	1160	4910	448	15000	414	233	722	580	208	1100	2932	1610	3550	797	450	1330
Magnesium	mg / L	78.3	63.1	109	60.7	44.1	69.9	10.3	5.8	14.6	63.7	53.1	71.1	50.2	38.3	56.0	4.2	3.6	5.2	40.3	34.7	45.2
Manganese	µg / L	65.2	18.5	106	73.2	32.7	141	163	59.6	313	64.3	24.7	121	61.4	22.7	111	132	87	158	67.2	38.5	125
Potassium	mg / L	5.3	3.7	7.2	3.0	2.2	3.4	1.4	0.7	2.3	3.7	3.0	4.8	3.4	2.9	4.0	1.4	1.0	1.7	3.0	2.5	3.4
Sodium	mg / L	30.0	24.4	42.0	17.3	12.5	21.2	8.0	5.6	9.3	19.8	17.3	22.6	16.8	12.6	18.8	4.3	4.0	4.7	14.1	11.7	15.6
Analytes - Anions																						
Chloride	mg / L	44.4	31.5	58.2	23.8	16.6	28.6	16.7	10.4	21.6	28.2	23.7	32.3	24.4	18.2	28.4	11.7	8.8	14.2	21.4	17.5	26.0
Nitrogen, Kjeldahl, Total	mg / L	0.74	<0.60	0.94	0.90	0.81	1.0	1.1	0.64	2.3	0.70	<0.60	0.79	0.91	0.70	1.3	0.57	<0.60	0.68	0.79	0.66	0.89
Ammonia as Nitrogen	mg / L	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	0.24	<0.10	0.62	<0.10	<0.10	0.10	<0.10	<0.10	0.18	<0.10	<0.10	0.16	<0.10	<0.10	<0.10
Unionized Ammonina, as Nitrogen	ug/L	0.00	0.0	0.00	0.00	0.00	0.00	0.33	0.00	4.3	0.00	0.00	9.6	0.00	0.00	10.4	0.00	0.00	4.4	0.00	0.00	0.00
Sulfate	mg / L	276	217	388	163	126	186	4.6	<2.0	<2.0	187	170	201	145	122	153	2.7	<2.0	3.0	114	99.5	128
Analytes - Other																						
Total Dissolved Solids	mg / L	613	360	863	451	314	511	141	74.0	218	457	367	507	386	281	437	94.2	61.0	116	331	269	390
Total Suspended Solids	mg / L	1.5	1.2	2.0	3.3	1.6	5.6	5.9	1.6	22.0	2.2	1.6	4.0	1.4	<1.0	1.6	4.0	2.0	6.0	1.9	1.2	3.0
Alkalinity, Total as HCO_3^-	mg / L	177	134	246	182	124	223	51.4	17.9	85.5	181	132	220	145	100	178	37.9	28.4	48.9	124	94.0	146
Alkalinity, Total as $CaCO_3$	mg / L	145	110	202	149	102	183	42.1	14.7	70.1	149	108	180	119	82	146	31.1	23.3	40.1	102	77.0	120
Dissolved Organic Carbon	mg / L	20.8	13.1	25.6	24.3	23.3	25.6	32.2	19.4	55.6	20.9	15.2	23.8	22.1	16.2	26.2	15.8	12.0	21.8	21.2	15.5	24.7
Total Hardness	mg / L	462	377	636	351	257	411	65.0	36.0	96.6	369	312	409	293	226	324	47.9	41.9	61.0	239	207	264
YSI Probe Plus Data																						
pH	Units	7.3	7.2	7.4	7.4	7.0	7.8	6.8	6.5	7.3	8.0	7.6	8.3	7.7	7.3	8.1	7.0	6.7	7.9	7.7	7.6	7.8
Temperature	ºC	14.1	5.8	22.5	15.7	6.1	20.7	12.2	6.1	17.1	16.2	6.9	24.0	15.8	6.8	23.0	13.0	6.2	18.2	14.8	6.9	21.7
Specific Conductance	uS / cm	929	748	1228	667	496	796	160	97.1	219	729	620	802	605	472	721	107	65.5	143	496	430	558

Note: Little Sandy Inflow 3 was not sampled in 2017 due to lack of a channel. The sampling site "Sandy Lake South Inflow" replaced it in the table above.

Also, the alkalinity was changed in 2016 to analyze as HCO_3^-. This table and 2016 below were changed to include both HCO_3^- and $CaCO_3$.

TABLE 5
TWIN LAKES WATER QUALITY 2018

	Reporting	Little Sandy Inflow 1			Little Sandy Inflow 2			Sandy Lake So. Inflow			Little Sandy Middle			Sandy Middle			Culvert Inflow			Twin Lakes Outflow		
Analytes - Cations	**Units**	**Average**	**Min**	**Max**	**Average**	**Min**	**Max**	**Average**	**Min**	**Max**	**Average**	**Min**	**Max**	**Average**	**Min**	**Max**	**Average**	**Min**	**Max**	**Average**	**Min**	**Max**
Calcium	mg / L	56.8	35.5	105.0	39.0	23.0	50.7	6.7	3.7	10.0	38.3	31.1	50.3	38.3	29.2	49.4	11.2	8.5	14.6	29.9	26.7	34.2
Iron	µg / L	1155	541	2100	1685	177	5760	4402	871	10900	657	144	2580	465	114	1120	2315	1010	3520	720	386	1320
Magnesium	mg / L	108.1	47.3	334.0	56.8	34.8	74.3	7.1	4.5	10.4	57.6	46.0	71.8	57.0	43.7	75.0	3.8	2.9	4.9	42.0	35.3	52.0
Manganese	µg / L	74.5	26.8	160.0	121.5	35.2	227.0	86.7	8.3	188.0	76.7	18.6	200.0	62.6	25.2	130.0	108.7	55.6	153.0	69.2	23.5	105.0
Potassium	mg / L	5.8	3.2	11.1	3.4	1.6	5.5	1.5	0.5	2.5	3.6	2.7	4.4	3.3	0.1	5.5	1.8	1.3	2.5	3.2	2.5	4.3
Sodium	mg / L	32.4	18.9	67.3	17.9	9.1	24.3	3.8	2.4	6.6	18.6	15.3	25.2	19.3	15.1	25.1	4.9	3.5	5.8	14.7	12.6	17.6
Analytes - Anions																						
Chloride	mg / L	50.7	27.1	111	28.0	20.7	38.2	6.6	2.8	16.1	28.4	24.1	41.1	30.2	21.3	37.3	13.3	8.0	17.9	19.7	1.0	27.4
Nitrogen, Kjeldahl, Total	mg / L	0.7	0.5	1.1	0.9	0.5	1.4	1.1	0.6	1.7	0.6	0.5	0.8	0.6	0.5	0.8	0.6	0.5	0.8	0.6	0.5	0.7
Ammonia, as Nitrogen	mg / L	0.13	0.10	0.18	0.15	0.10	0.23	0.42	0.13	1.10	0.13	0.11	0.18	0.13	0.11	0.18	0.1	0.1	0.2	0.2	0.1	0.2
Unionized Ammonia, as Nitrogen	ug/L	0.64	0.11	3.8	0.78	0.08	5.5	0.47	0.05	4.4	3.2	0.61	20.4	2.2	0.52	7.2	0.16	0.02	0.67	1.38	0.25	5.8
Sulfate	mg / L	293.5	164.0	652.0	171.2	131.0	220.0	2.3	2.0	3.8	165.2	121.0	241.0	177.2	113.0	223.0	2.6	2.0	4.1	96.5	6.0	165.0
Analytes - Other																						
Total Dissolved Solids	mg / L	725.2	459.0	1440.0	499.3	394.0	632.0	129.8	72.0	188.0	NM	NM	NM	NM	NM	NM	108.3	74.0	136.0	356.8	318.0	400.0
Total Suspended Solids	mg / L	1.4	1.0	2.0	3.2	1.0	7.0	6.8	1.0	15.0	NM	NM	NM	NM	NM	NM	3.3	1.0	7.3	2.2	1.0	4.7
Alkalinity, Total as HCO3-	mg / L	214.9	137.9	407.5	203.5	80.5	290.4	49.0	24.5	75.6	NM	NM	NM	NM	NM	NM	40.8	31.8	57.2	152.7	130.5	192.8
Alkalinity, Total as CaCO3	mg / L	176.2	113.0	334.0	166.8	66.0	238.0	40.2	20.1	62.0	NM	NM	NM	NM	NM	NM	33.5	26.1	46.9	125.2	107.0	158.0
Dissolved Organic Carbon	mg / L	18.6	10.7	28.8	26.9	15.5	37.2	32.5	21.9	52.1	NM	NM	NM	NM	NM	NM	13.9	6.8	22.0	20.0	14.2	28.4
Total Hardness	mg / L	478.3	283.0	986.0	331.0	201.0	429.0	46.2	27.6	67.7	NM	NM	NM	NM	NM	NM	43.8	33.3	55.6	247.5	214.0	297.0
YSI Probe Plus Data																						
pH	Units	7.3	7.1	7.8	7.3	6.8	7.8	6.6	6.3	7.1	7.9	7.7	8.4	7.8	7.6	7.9	6.7	6.3	7.1	7.5	7.3	7.8
Temperature	ºC	13.6	2.0	18.8	15.6	4.0	21.0	14.4	9.4	16.6	15.9	3.6	22.4	15.7	3.9	22.4	11.6	3.4	15.2	15.1	4.3	21.6
Specific Conductance	uS / cm	1004	625	1925	751	606	921	209	80	553	769	673	927	635	553	830	121.3	83.4	163.8	531	480	612

Note: Little Sandy Inflow 3 was not sampled in 2018.

NM = Not Measured

2.2 BOIS FORTE SAMPLING

As mentioned above, starting in 2010 and continuing through 2014, U. S. Steel funded a surface water monitoring program at Twin Lakes which was administered by Bois Forte. There were four open water monitoring locations sampled each month, which are described below:

Twin 1 – corresponds to Inflow 1 to Little Sandy Lake described in Section 2.1 above.

Twin 2 – corresponds to the center of Little Sandy Lake described in Section 2.1.

Twin 3 – corresponds to the center of Sandy Lake described in Section 2.1.

Twin 4 – corresponds to the Twin Lakes Outflow described in Section 2.1.

Please note that Bois Forte continued the monitoring program after 2014 and through 2018 using funding from the 1854 Treaty Authority.

This Report utilizes some of the Bois Forte sampling data to compare parameters from the above four locations over nine years of monitoring (2010 – 2018). The Bois Forte data that was used from the sources described above, will be referred to in this Report as Inflow 1, Little Sandy Lake Middle, Sandy Lake Middle and Twin Lakes Outflow.

2.3 MEASURED EXCEEDANCES OF MN WATER QUALITY STANDARDS (2014-2018)

During the five years of Plan work, nearly 200 samples were collected for analysis of various water quality parameters. Some of these parameters are associated with water quality standards contained in Minnesota Rule 7050. Table 6 below describes applicable water quality standards along with exceedances of those standards found at the Twin Lakes sampling locations during the five-year period. It should be mentioned that one exceedance each for copper, lead and zinc came from the non-mining influenced source, Culvert Inflow, during the June 2014 sample event. As described in Section 2.1 above, testing for copper, lead and zinc continued for the remainder of the year at Culvert Inflow with no additional results above the detection limit.

In summary, there were two exceedances of aluminum out of 104 samples; 12 exceedances of hardness out of 192 samples; 5 exceedances of pH out of 200 samples (pH between 6.0 and 9.0 SU); 15 exceedances of Total Dissolved Solids (TDS) out of 192 samples; 13 exceedances of specific conductance out of 200 samples; 8 exceedances of alkalinity out of 190 samples and 153 exceedances of sulfate (10 mg/L, which is currently being disputed but is under agency review and subject to change) out of 200 samples. Table 7 presents the specifics concerning each exceedance (parameter, reported value, location and sample event date).

Table 6
Exceedances of Surface Water Standards
Twin Lakes Monitoring (2014 - 2018)

Parameter	Number of Samples	Water Quality Standards and Number of Exceedances									
		2B		3C		4A		4B		5	
		Standard	#	Standard	#	Standard	#	Standard	#	Standard	#
Aluminum *	104	125 ug/L	2								
Arsenic *	48	53 ug/L	0								
Copper	22	6.4 ug/L**	1								
Lead	22	1.3 ug/L**	1								
Zinc	22	59 ug/L**	1								
Hardness as $CaCO_3$	192			500 mg/L	12						
pH	200	6.5-9.0 SU	3	6.0-9.0 SU	0	6.0-8.5 SU	2	6.0-9.0 SU	0	6.0-9.0 SU	0
Solids, Total Dissolved,	192					700 mg/L	10	1000 mg/L	5		
Specific Conductance	200					1000 umhos/cm	13				
Sulfate as $SO_4^=$	200					10 mg/L	153				
Unionized Ammonia as Nitrogen	168	40 ug/L	0								
Alkalinity as HCO_3^-	190					5 meq/L	8				
Chloride as Cl^-	200	230 mg/L	0	250 mg/L	0						
Sodium as Na^+	200					60% of Cation	0				

Note 1: This assessment includes the following monitoring locations: LSL Inflow 1, LSL Inflow 2, LSL Inflow 3, Twin Lakes Outflow, Sandy Lake Middle, Little Sandy Lake Middle, SL South Inflow and Culvert Inflow.

Note 2: SL South Inflow and the Culvert Inflow are non-mining impacted sources. The other locations mentioned are influenced by mining.

*** Aluminum and Arsenic were not analyzed over the entire five year period. Aluminum was included in the 2014, 2015 and 2016 season, while Arsenic was included only for the 2014 season.**

**** This WQS is based on Hardness, which 50 mg/L as $CaCO_3$ was used.**

TABLE 7

SPECIFICS OF TWIN LAKES WATER QUALITY EXCEEDANCES

Parameter	Location	Date	Value	WQS	Units
Aluminum	Culvert Outflow *	7/22/2016	284	125	ug/L
Aluminum	Inflow 1	8/25/2016	132	125	ug/L
Copper	Culvert Outflow *	6/23/2014	11.4	6.4	ug/L
Lead	Culvert Outflow *	6/23/2014	12.8	1.3	ug/L
Zinc	Culvert Outflow *	6/23/2014	172	59	ug/L
Hardness	Inflow 1	8/22/2014	712	500	mg/L
Hardness	LSL Inflow 1	9/11/2014	721	500	mg/L
Hardness	LSL Inflow 1	10/13/2014	814	500	mg/L
Hardness	LSL Inflow 1	8/21/2015	560	500	mg/L
Hardness	LSL Inflow 1	9/25/2015	615	500	mg/L
Hardness	LSL Inflow 1	10/19/2015	776	500	mg/L
Hardness	LSL Inflow 1	5/26/2016	517	500	mg/L
Hardness	LSL Inflow 1	8/28/2016	582	500	mg/L
Hardness	LSL Inflow 1	10/20/2016	540	500	mg/L
Hardness	LSL Inflow 1	7/27/2018	636	500	mg/L
Hardness	LSL Inflow 1	8/29/2018	986	500	mg/L
Hardness	LSL Inflow 2	10/19/2015	569	500	mg/L
Dissolved Solids	LSL Inflow 1	7/21/2014	776	700	mg/L
Dissolved Solids	LSL Inflow 1	9/25/2015	838	700	mg/L
Dissolved Solids	LSL Inflow 1	8/21/2015	799	700	mg/L
Dissolved Solids	LSL Inflow 1	7/10/2015	752	700	mg/L
Dissolved Solids	LSL Inflow 1	10/20/2016	739	700	mg/L
Dissolved Solids	LSL Inflow 1	8/25/2016	836	700	mg/L
Dissolved Solids	LSL Inflow 1	5/26/2016	761	700	mg/L
Dissolved Solids	LSL Inflow 1	7/27/2017	863	700	mg/L
Dissolved Solids	LSL Inflow 1	7/27/2018	716	700	mg/L
Dissolved Solids	LSL Inflow 2	10/19/2015	776	700	mg/L
Dissolved Solids	LSL Inflow 1	8/22/2014	1030	1000	mg/L
Dissolved Solids	LSL Inflow 1	9/11/2014	1080	1000	mg/L
Dissolved Solids	LSL Inflow 1	10/13/2014	1170	1000	mg/L
Dissolved Solids	LSL Inflow 1	10/19/2015	1040	1000	mg/L
Dissolved Solids	LSL Inflow 1	8/29/2018	1440	1000	mg/L

Parameter	Location	Date	Value	WQS	Units
Spec. Conductance	LSL Inflow 1	8/22/2014	1347	1000	umhos/cm
Spec. Conductance	LSL Inflow 1	9/11/2014	1479	1000	umhos/cm
Spec. Conductance	LSL Inflow 1	10/13/2014	1620	1000	umhos/cm
Spec. Conductance	LSL Inflow 1	8/21/2015	1074	1000	umhos/cm
Spec. Conductance	LSL Inflow 1	9/25/2015	1224	1000	umhos/cm
Spec. Conductance	LSL Inflow 1	10/19/2015	1435	1000	umhos/cm
Spec. Conductance	LSL Inflow 1	5/26/2016	1109	1000	umhos/cm
Spec. Conductance	LSL Inflow 1	8/25/2016	1141	1000	umhos/cm
Spec. Conductance	LSL Inflow 1	10/20/2016	1057	1000	umhos/cm
Spec. Conductance	LSL Inflow 1	7/27/2017	1228	1000	umhos/cm
Spec. Conductance	LSL Inflow 1	7/27/2018	1024	1000	umhos/cm
Spec. Conductance	LSL Inflow 1	8/29/2018	1925	1000	umhos/cm
Spec. Conductance	LSL Inflow 2	10/19/2015	1150	1000	umhos/cm
Alkalinity	LSL Inflow 1	9/11/2014	316	305	mg/L
Alkalinity	LSL Inflow 1	10/13/2014	309	305	mg/L
Alkalinity	LSL Inflow 1	8/25/2016	339	305	mg/L
Alkalinity	LSL Inflow 1	8/29/2018	407	305	mg/L
Alkalinity	LSL Inflow 1	8/22/2014	312	305	mg/L
Alkalinity	LSL Inflow 2	10/13/2014	309	305	mg/L
Alkalinity	LSL Inflow 2	9/28/2016	306	305	mg/L
Alkalinity	LSL Inflow 3	9/28/2016	311	305	mg/L
pH	LSL Inflow 1	5/28/2014	8.6	6.5 - 8.5	
pH	TL Outflow	5/28/2014	8.6	6.5 - 8.6	SU
pH	SL South Inflow *	6/29/2018	6.4	6.5 - 8.7	SU
pH	SL South Inflow *	8/29/2018	6.3	6.5 - 8.8	SU
pH	Culvert Inflow *	10/22/2018	6.3	6.5 - 8.9	SU
					SU

* Non-mining influenced sources

Sulfate — Mining influenced locations were almost always above the 10 mg/l wild rice standard while non SL South Inflows and the Culvert Inflow were below.

2.4 Twin Lakes Water Quality – Nine Year Graphs

As stated above, monthly water quality data has been collected on Twin Lakes during the past nine open water seasons, between 2010 and 2018, by Bois Forte and U. S. Steel under two separate programs. Figures 2 through 9 show data for chloride, sulfate, specific conductance, TDS, ammonia, alkalinity, turbidity and pH at the Twin 1/Inflow 1, Twin 2/Little Sandy Lake Middle, Twin 3/Sandy Lake Middle and Twin 4/Twin Lakes Outflow locations.

The figures show that installation of a Seepage Collection and Return System (SCRS) on the east side of Minntac's Tailings Basin in 2011 resulted in a significant reduction in constituent concentration levels at all four locations. The sampling results also indicate that Inflow 1 has the highest concentration of constituents, which is not surprising as it is the expected primary source of seepage input from the Minntac tailings basin.

Little Sandy Lake Middle had the highest pH value, but doesn't follow the usual influence from Inflow 1, which tends to be the lowest in pH. The pH at the Sandy Lake Middle location is just slightly lower than Little Sandy Lake Middle. This trend seems to indicate that there are other factors influencing the pH at the middle of each lake whether due to other inflows or biological/chemical interactions. All locations show relatively low turbidity values. Ammonia was not measured on a consistent basis, therefore conclusions were not drawn from these data.

FIGURE 2
TWIN LAKES SURFACE WATER CHLORIDE

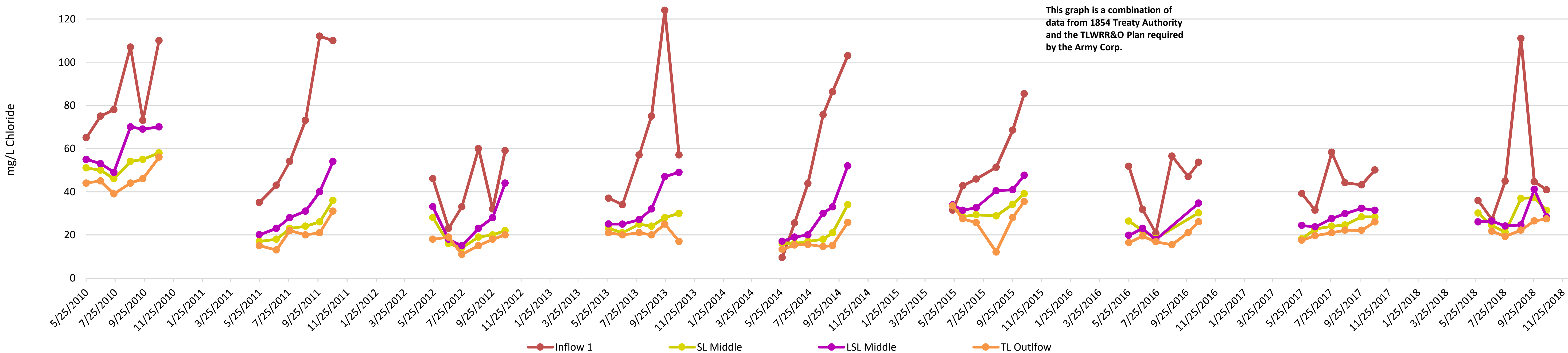


FIGURE 3
TWIN LAKES SURFACE WATER SULFATE

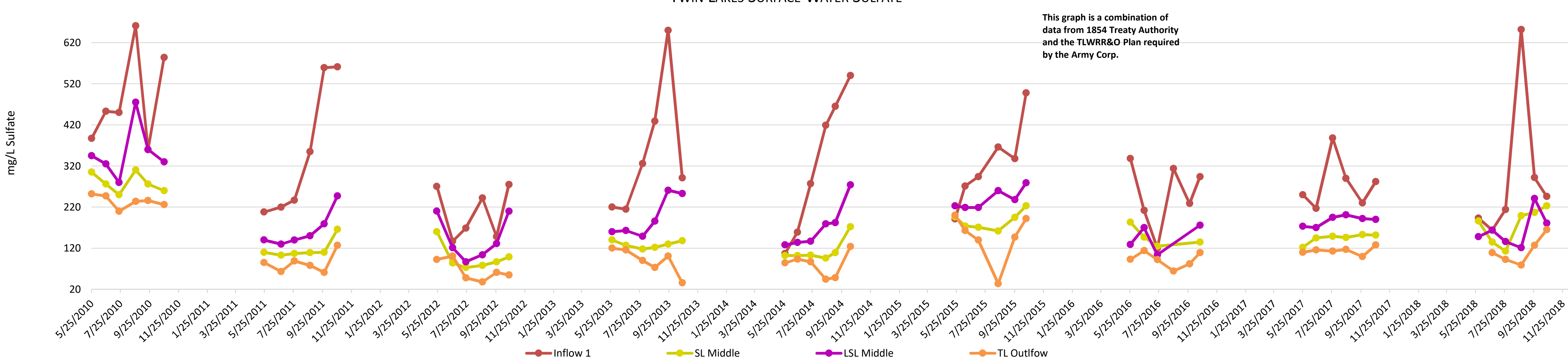


Figure 4
Twin Lakes Surface Water Specific Conductance

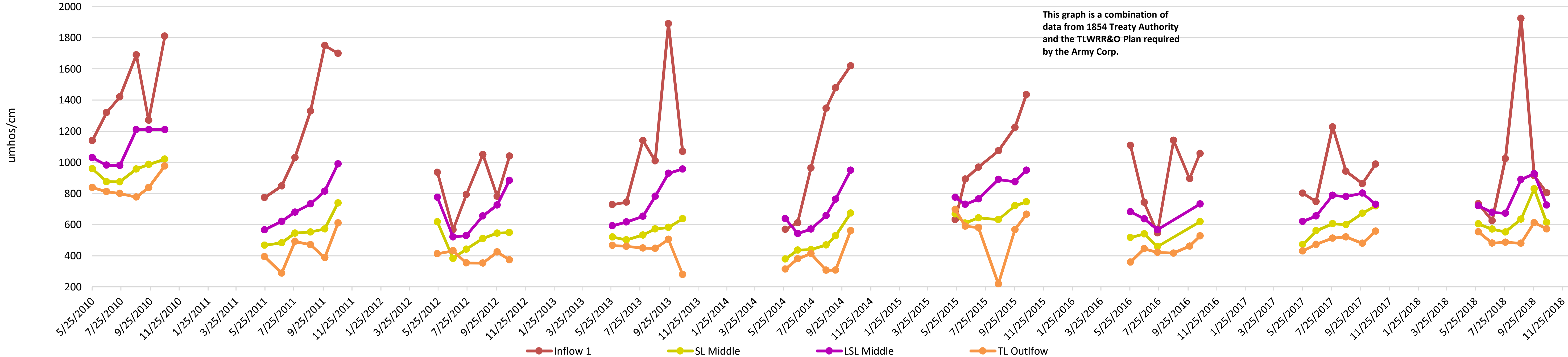


Figure 5
Twin Lakes Surface Water Total Dissolved Solids

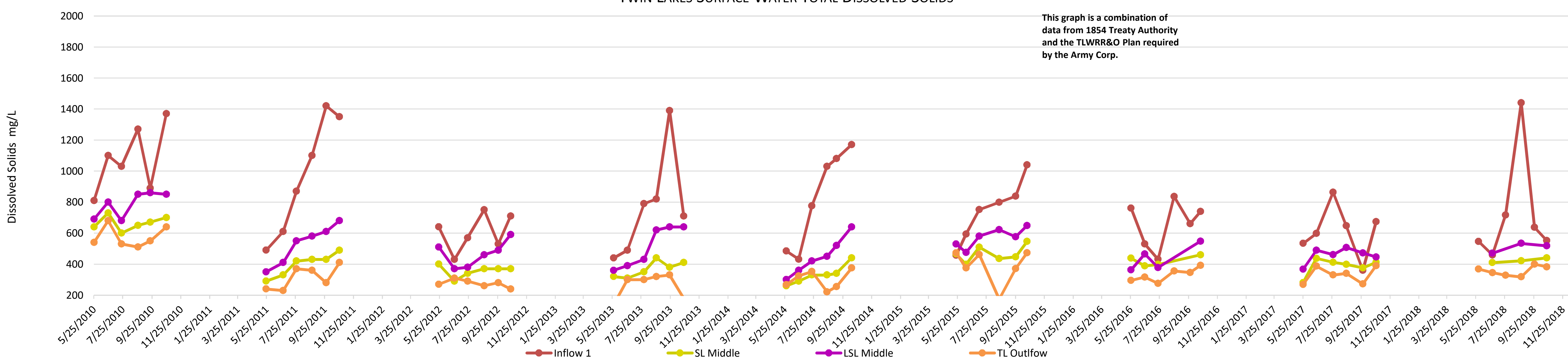


Figure 6

Twin Lakes Surface Water Ammonia as Nitrogen

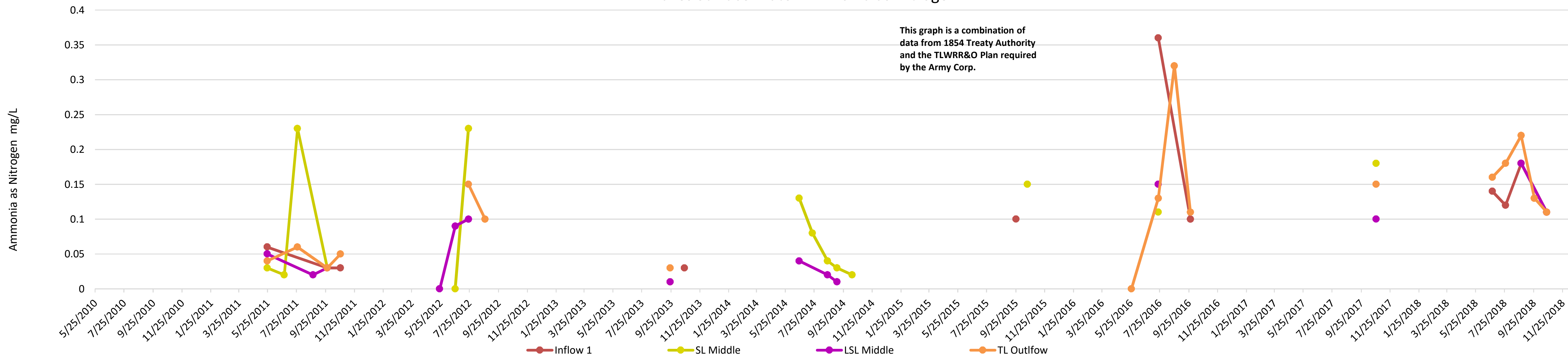


FIGURE 7

TWIN LAKES SURFACE WATER ALKALINITY HCO_3^-

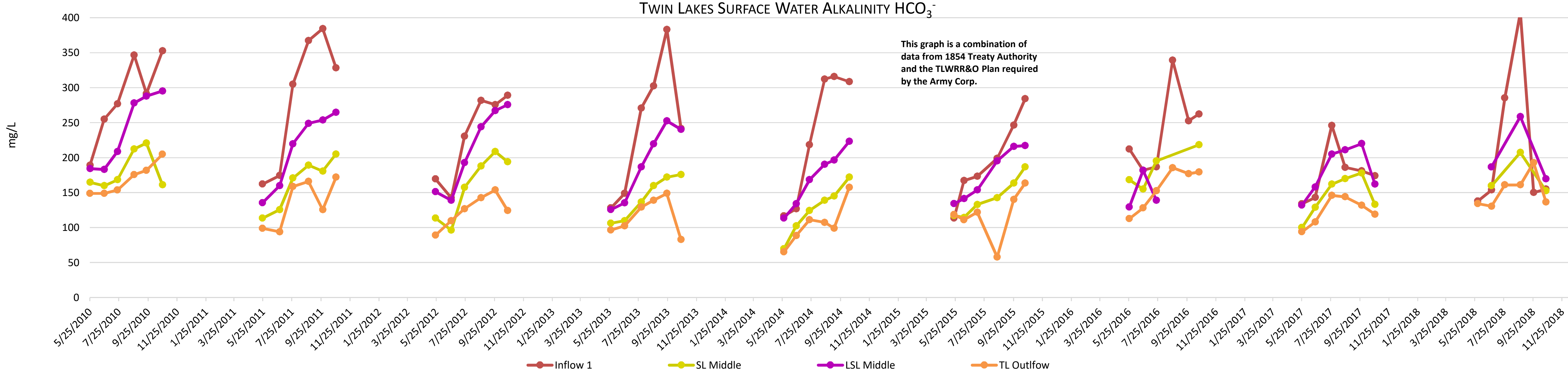


Figure 8
Twin Lakes Surface Water Turbidity

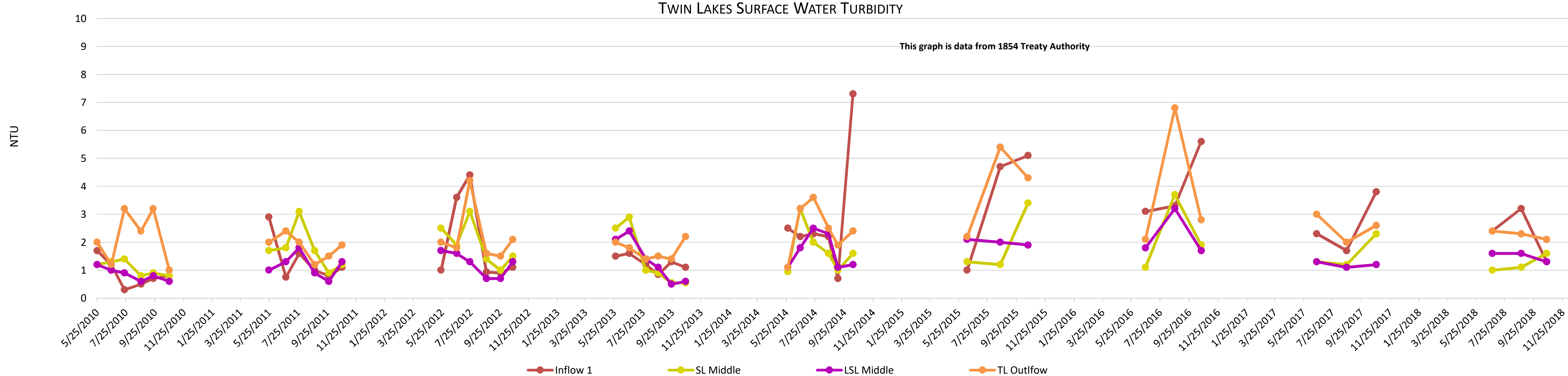
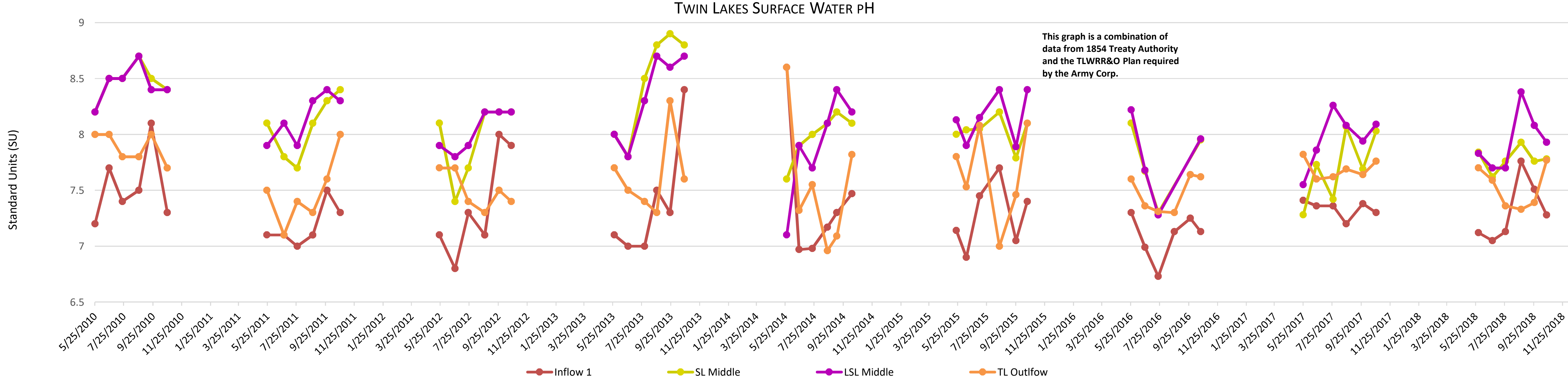


Figure 9
Twin Lakes Surface Water pH



2.5 TWIN LAKES WATER QUALITY – SEASONAL EFFECTS

A seasonal effect may be seen by comparing data from month to month and year to year. There were years when the concentrations of such parameters as chloride, sulfate and alkalinity continually increased from spring to fall. Other years show various up and down results without any correlation between years.

Mass loading of sulfate from Inflow 1 was developed from the five years of flow data that was consistently collected during each sample event (Figure 10). The sulfate mass loading analysis removes the dilution effect from precipitation. A review of the sulfate mass loading over each of the five years does seem to show a slight trend where the sulfate loading drops over the first few months of open water but spikes in August or September before it drops back down again. This was not as apparent in 2014 though with a small spike in October. There appears to be more variation in the amount of sulfate loading during the past two years (2017 and 2018) as compared with the first three years of monitoring.

The relationship that precipitation has on sulfate concentrations was also determined through data comparison at a number of locations in 2015 and 2018. Figures 11 and 12 show sulfate concentrations overlaid on daily precipitation data. Inflow 1 was seen in both years to have the highest sulfate concentration, as discussed in Section 2.4 above. It appears that there were larger rain events in 2018 than in 2015 and the overall concentration of sulfate was significantly lower during 2018. Dryer periods in both years did not seem to have a significant effect on increased sulfate concentrations nor did wet periods show significant reductions.

Figure 10
Little Sandy Lake Inflow 1 Surface Water Sulfate
(Kg/Day vs mg/L)

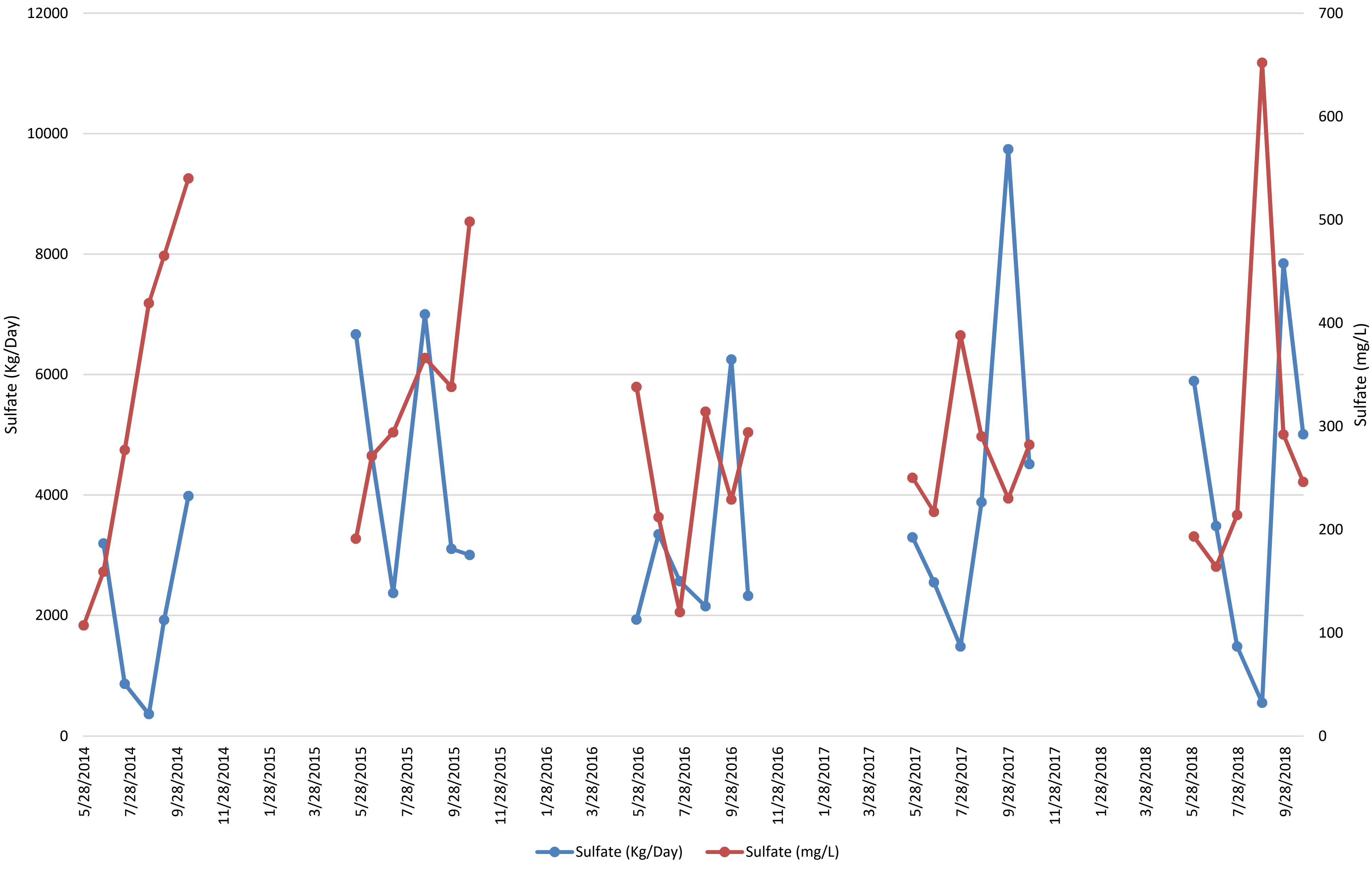
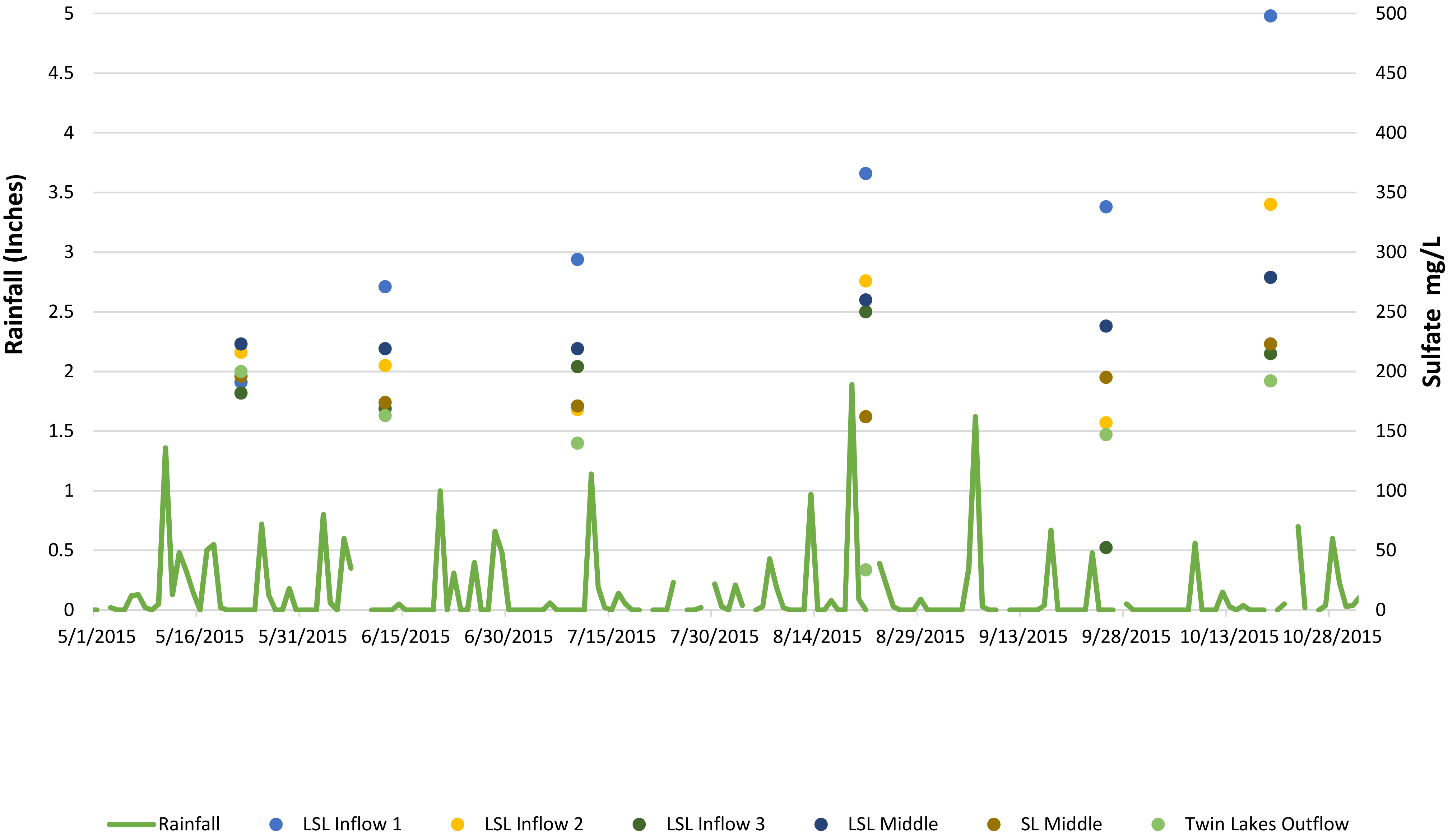


FIGURE 11
2015 TWIN LAKES
DAILY PRECIPITATION AND SULFATE



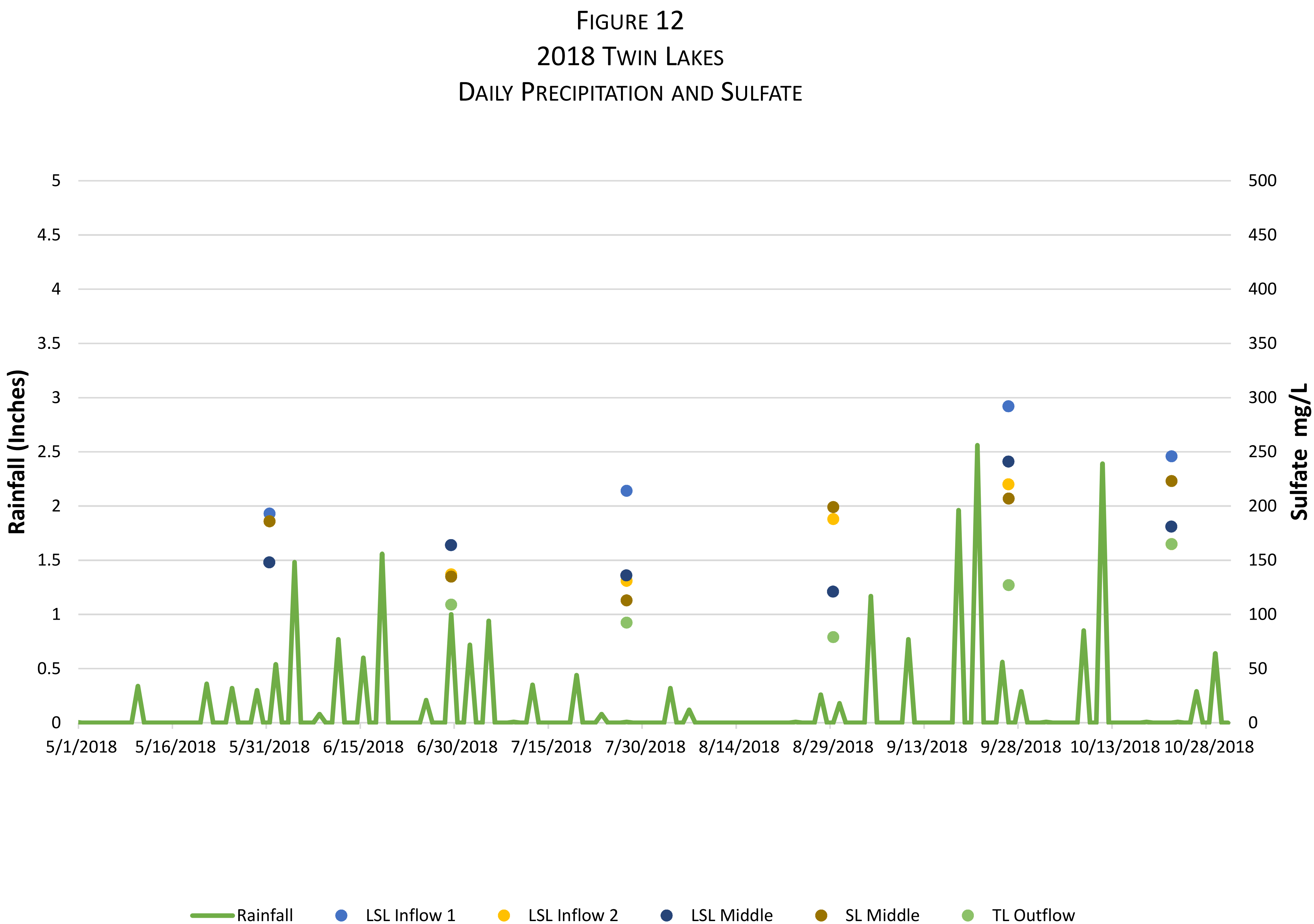


FIGURE 12
2018 TWIN LAKES
DAILY PRECIPITATION AND SULFATE
Rainfall (Inches)
Sulfate mg/L
0
0.5
1
1.5
2
2.5
3
3.5
4
4.5
5
0
50
100
150
200
250
300
350
400
450
500
5/1/2018
5/16/2018
5/31/2018
6/15/2018
6/30/2018
7/15/2018
7/30/2018
8/14/2018
8/29/2018
9/13/2018
9/28/2018
10/13/2018
10/28/2018
Rainfall
LSL Inflow 1
LSL Inflow 2
LSL Middle
SL Middle
TL Outflow

2.6 TWIN LAKES WATER QUALITY – WILD RICE PLOTS (2016)

The wild rice planted in the fall of 2015 was first observed growing in July of 2016 (see Figure 13). As defined by the Plan, water quality was to be evaluated at each wild rice location. The surface water at each wild rice plot was sampled on August 25, 2016 and on the September 28, 2016 (Tables 8 and 9). This included a site that was assumed to be natural growth and not intentionally planted (found on the South Side of Sandy Lake). The wild rice plots were given the following names: Sandy Lake Northwest, Sandy Lake East, Sandy Lake Southwest, Sandy Lake South (naturally seeded), Little Sandy Lake Northeast, and Little Sandy Lake South. No wild rice growth was found on what was called Little Sandy Lake Northwest in 2016.

U. S. Steel did not sample the middle of Little Sandy and Sandy Lakes during the August and September 2016 sampling events. However, Bois Forte did sample the surface water at the middle of both lakes approximately one day prior to the Plan August sampling event. The analytical results are included in Table 8. No samples from the middle of either lake were collected in September but Table 9 shows the September surface water chemistries from the wild rice plots. Figures 14 through 21 show the data from each wild rice plot in relation to each other.

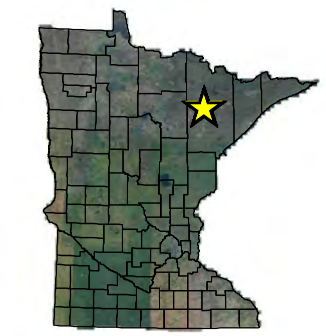
As stated above, the only data for comparison of Sandy Lake Middle and Little Sandy Lake Middle was from the August sampling event completed by Bois Forte. Although each location differs slightly, there appears to be no significant difference between the water quality within each plot and that of each lake middle sample. The sample results from the middle of each lake for chloride, sulfate, TDS, specific conductance and Total Kjeldahl Nitrogen appear to indicate an average of values found in each of the wild rice plots.

August and September data from all the wild rice plots did not seem to be significantly different from each other. However, the Little Sandy Lake wild rice plots tended to have slightly higher concentrations of chloride, sulfate, alkalinity and TDS, along with slightly higher specific conductance as compared to the Sandy Lake wild rice plots. The pH, Ammonia Nitrogen and Total Kjeldahl Nitrogen did not follow this trend and were lower in the Little Sandy Lake wild rice plots compared to those found in Sandy Lake. Although the Little Sandy Lake South wild rice plot had the highest concentrations of chloride, sulfate, alkalinity, and TDS, the pH, Ammonia Nitrogen and Total Kjeldahl Nitrogen did not follow this trend.

Sandy Lake South (natural growth) water chemistries were similar to the other wild rice plots for chloride, although this plot showed lower levels of sulfate, alkalinity, specific conductance and TDS. On the other hand, the Ammonia Nitrogen and Total Kjeldahl Nitrogen were somewhat higher. The pH for Sandy Lake Middle taken during the August sampling event was found to be lower than the samples indicated for the wild rice plots.

N

0 245 490 980
Feet
1 Inch = 490 Feet



Legend

- Natural Wild Rice Growth (2016-2018)
- Planted Wild Rice Growth (2016-2018)
- Planted Wild Rice Growth (2017-2018)

Figure 13
Twin Lakes 2016-2018
Wild Rice Growth Locations

Twin Lakes Survey
US Steel Corporation-
Minnesota Ore Operations
Mt. Iron, Minnesota (St. Louis County)

Environmental Science & Engineering
www.netechnical.com

Date Drawn : September 19, 2018
Drawn By : T. Muck
NTS Project #: 10170E

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TABLE 8
AUGUST 25, 2016 WILD RICE PLOT SURFACE WATER SAMPLE DATA

	Units	Detection Limit	Sandy Lake East	Sandy LakeNW	Sandy Lake SW	Sandy Lake South*	Little Sandy Lake South	Little Sandy Lake NE
Ammonia as Nitrogen	mg/L	0.10	**0.35**	**0.36**	**0.39**	**0.48**	<0.10	**0.13**
Total Kjeldahl Nitrogen	mg/L	0.60	**1.7**	**1.6**	**1.8**	**2.1**	**1.3**	**1.3**
Aluminum	mg/L	50.0	**64.0**	**58.7**	**99.5**	**196**	<50.0	<50.0
Calcium	mg/L	0.50	**30.8**	**33.4**	**27.6**	**22.5**	**44.5**	**39.7**
Iron	ug/L	50.0	**2850**	**2760**	**4720**	**10800**	**1580**	**1630**
Magnesium	mg/L	0.50	**39.6**	**43.7**	**35.7**	**27.3**	**62.8**	**55.4**
Manganese	ug/L	10.0	**88.9**	**126**	**178**	**243**	**97.8**	**132**
Potassium	mg/L	0.50	**2.5**	**2.7**	**2.4**	**2.1**	**3.1**	**2.7**
Sodium	mg/L	0.50	**13.5**	**14.6**	**12.7**	**11.4**	**21.1**	**17.4**
Total Hardness	mg/L	3.3	**240**	**263**	**216**	**168**	**370**	**327**
Total Alkalinity	mg/L	6.1	**168**	**178**	**156**	**118**	**229**	**223**
Total Dissolved Solids	mg/L	10.0	**380**	**393**	**389**	**339**	**472**	**535**
Total Suspended Solids	mg/L	1.0	**2.8**	**2.0**	**2.0**	**16.7**	**2.0**	**3.6**
Chloride	mg/L	1.0	**17.2**	**18.0**	**17.2**	**17.5**	**27.9**	**21.9**
Sulfate	mg/L	2.0	**77.0**	**87.2**	**70.2**	**43.5**	**152**	**121**
Dissolved Organic Carbon	mg/L	1.0	**42.0**	**40.7**	**47.2**	**51.2**	**33.9**	**36.1**
pH	SU	± 0.2	**7.6**	**7.7**	**7.3**	**6.5**	**7.7**	**7.8**
Specific Conductance	uS/cm	± 1%	**469**	**498**	**439**	**277**	**725**	**648**
Temperature	C	± 0.1	**20.6**	**21.0**	**20.6**	**18.1**	**20.4**	**21.2**

* This location was not planted rice but was found emerging "naturally".

Table 9
September 28, 2016 Wild Rice Plot Surface Water Sample Data

	Units	Detection Limit	Sandy Lake East	Sandy LakeNW	Sandy Lake SW	Sandy Lake South*	Little Sandy Lake South	Little Sandy Lake NE
Ammonia as Nitrogen	mg/L	0.10	**0.12**	**0.11**	**0.11**	**0.10**	<0.10	<0.10
Total Kjeldahl Nitrogen	mg/L	0.60	**1.2**	**1.0**	**1.0**	**0.87**	**0.81**	**0.80**
Aluminum	mg/L	50.0	**53.3**	**59.9**	**56.5**	NM	<50.0	<50.0
Calcium	mg/L	0.50	**34.3**	**38.0**	**35.3**	NM	**48.0**	**45.9**
Iron	ug/L	50.0	**1240**	**1110**	**1350**	NM	**565**	**569**
Magnesium	mg/L	0.50	**45.9**	**51.6**	**48.1**	NM	**65.9**	**63.8**
Manganese	ug/L	10.0	**42.3**	**56.8**	**55.9**	NM	**74.6**	**93.0**
Potassium	mg/L	0.50	**2.9**	**3.2**	**3.0**	NM	**4.2**	**3.7**
Sodium	mg/L	0.50	**16.4**	**18.2**	**17.1**	NM	**23.4**	**21.7**
Total Hardness	mg/L	3.3	**275**	**307**	**286**	NM	**391**	**377**
Total Alkalinity	mg/L	6.1	**188**	**189**	**172**	**52.7**	**221**	**221**
Total Dissolved Solids	mg/L	10.0	**393**	**461**	**403**	**198**	**541**	**516**
Total Suspended Solids	mg/L	1.0	**2.0**	**3.6**	**3.6**	NM	**1.6**	<1.0
Chloride	mg/L	1.0	**24.8**	**26.9**	**25.5**	**29.6**	**35.6**	**32.0**
Sulfate	mg/L	2.0	**100**	**123**	**108**	**12.9**	**176**	**159**
Dissolved Organic Carbon	mg/L	1.0	**31.5**	**30.0**	**31.2**	NM	**24.8**	**25.7**
pH	SU	± 0.2	**8.0**	**8.0**	**7.9**	**7.1**	**8.0**	**8.1**
Specific Conductance	uS/cm	± 1%	**559**	**619**	**572**	**295**	**786**	**741**
Temperature	C	± 0.1	**11.2**	**11.7**	**11.2**	**11.1**	**11.6**	**12.1**

* This location was not planted rice but was found emerging "naturally".

Figure 14
Wild Rice Plot Chloride

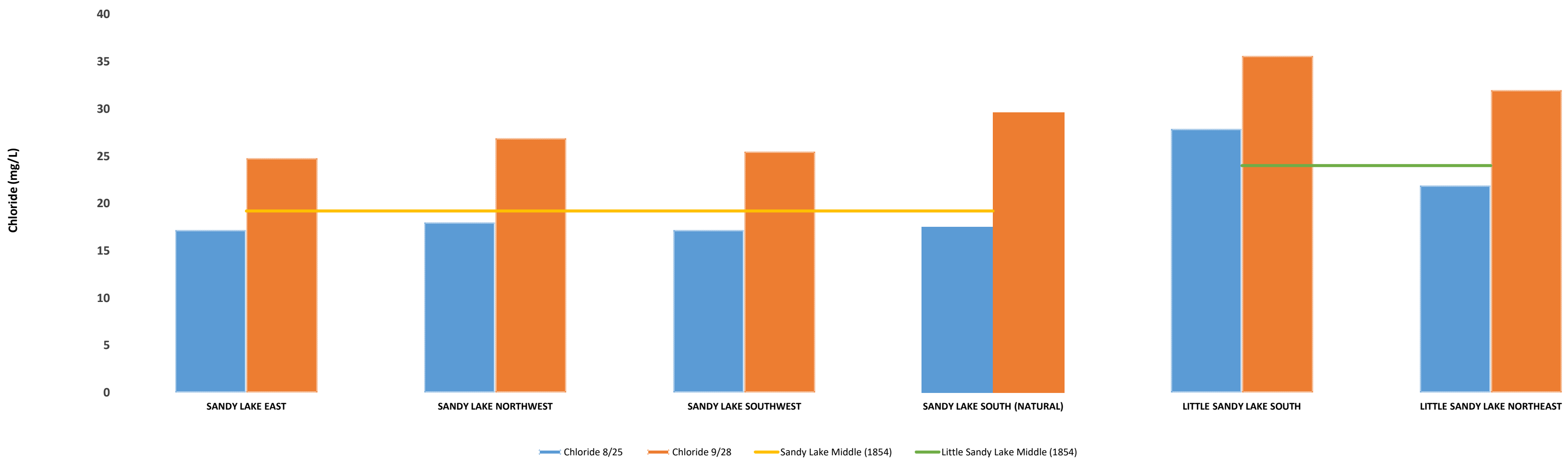


Figure 15
Wild Rice Plot Sulfate

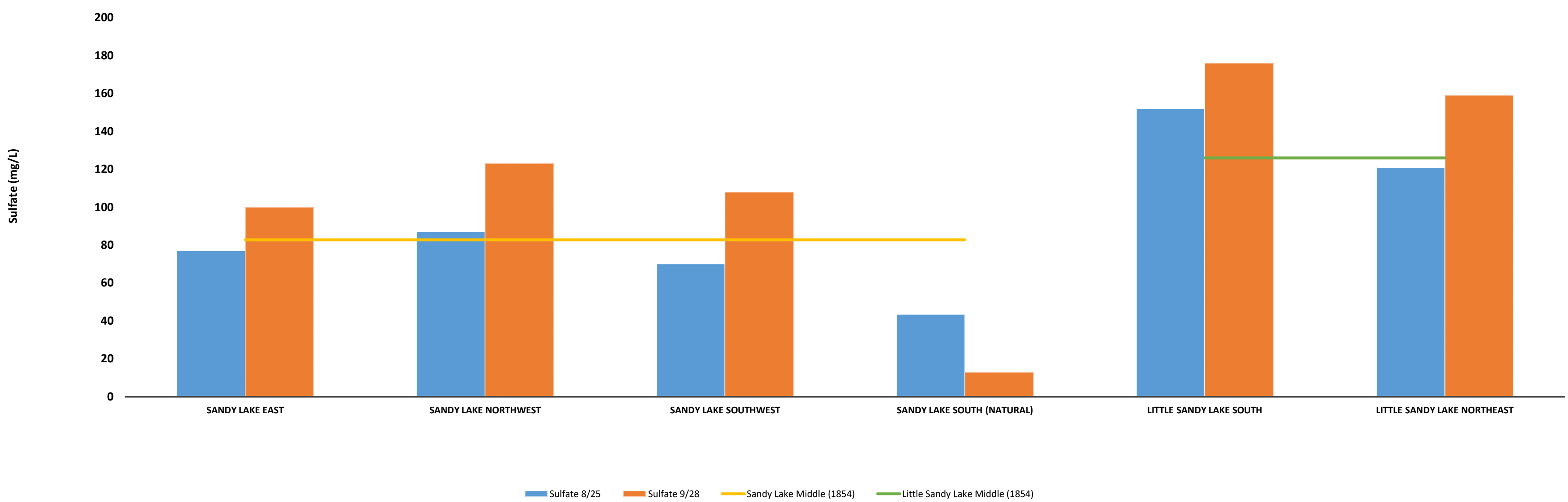


FIGURE 16
WILD RICE PLOT ALKALINITY

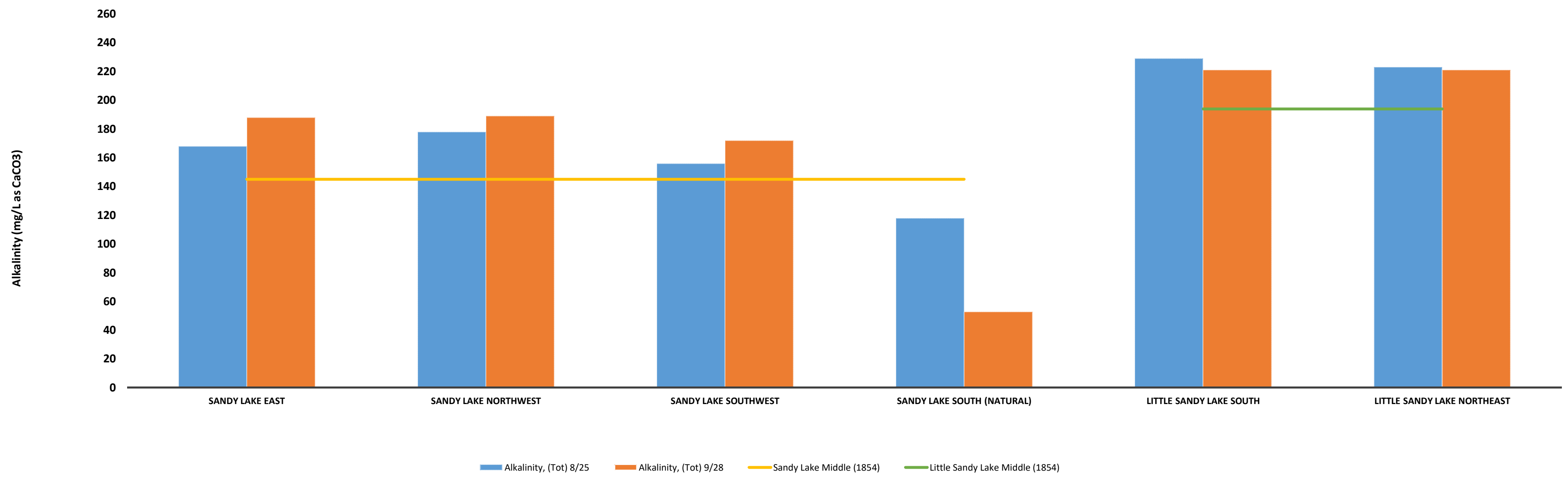


FIGURE 17
WILD RICE PLOT TOTAL DISSOLVED SOLIDS

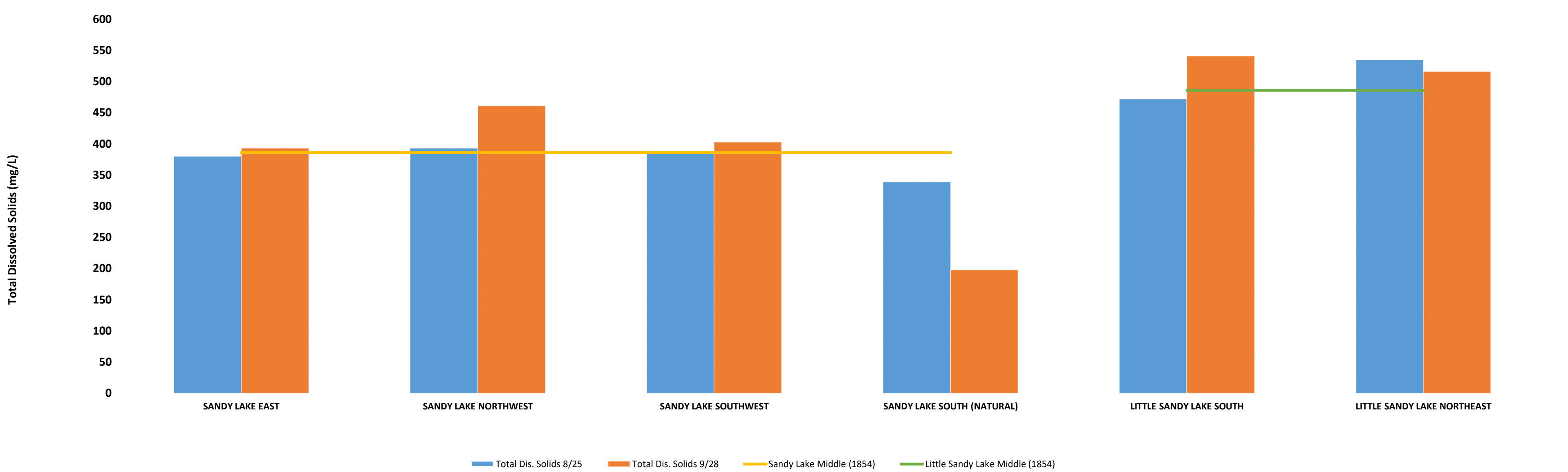


Figure 18
Wild Rice Plot Specific Conductance

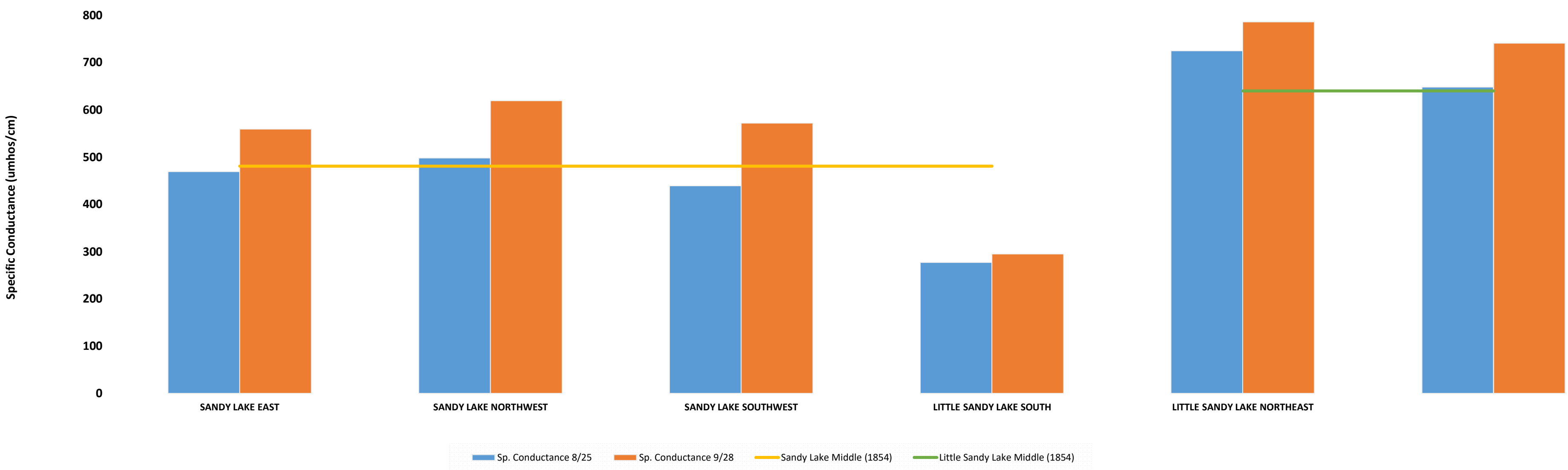


Figure 19
Wild Rice Plot pH

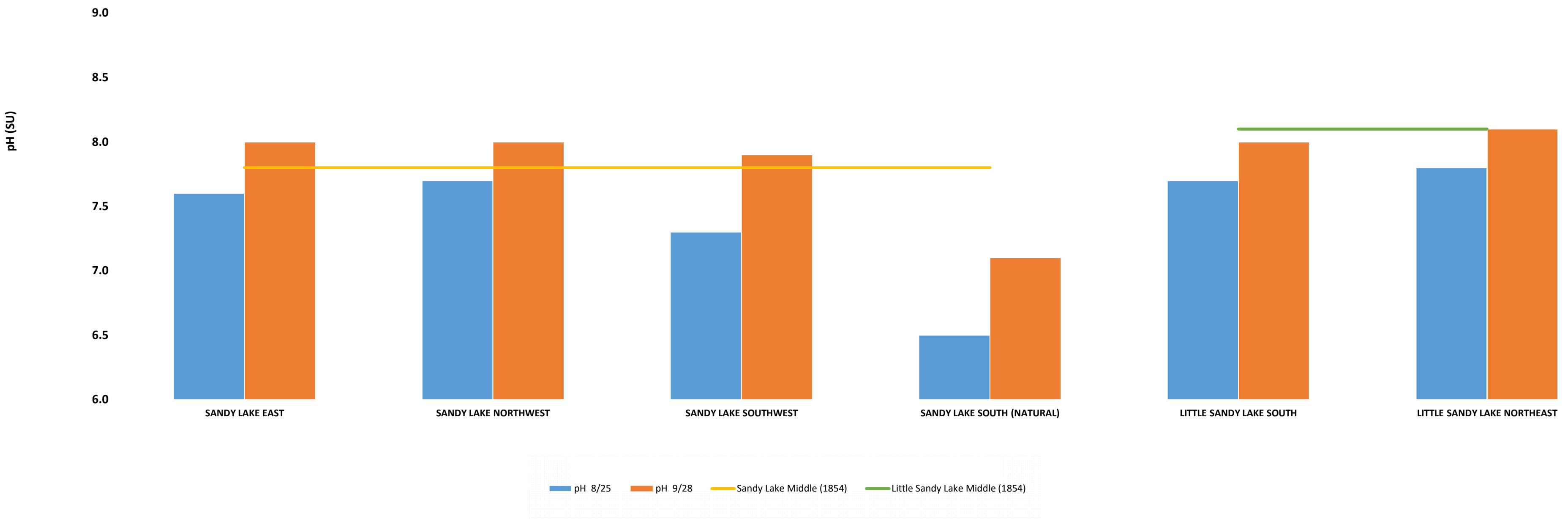


Figure 20
Wild Rice Plot Ammonia as Nitrogen

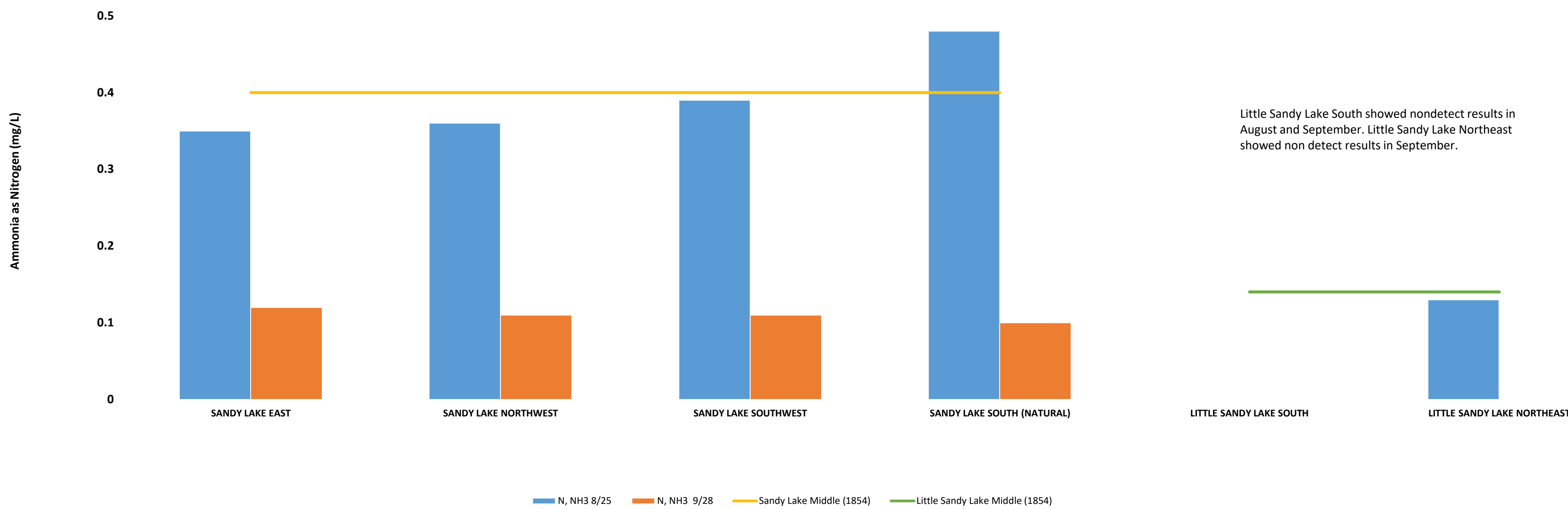
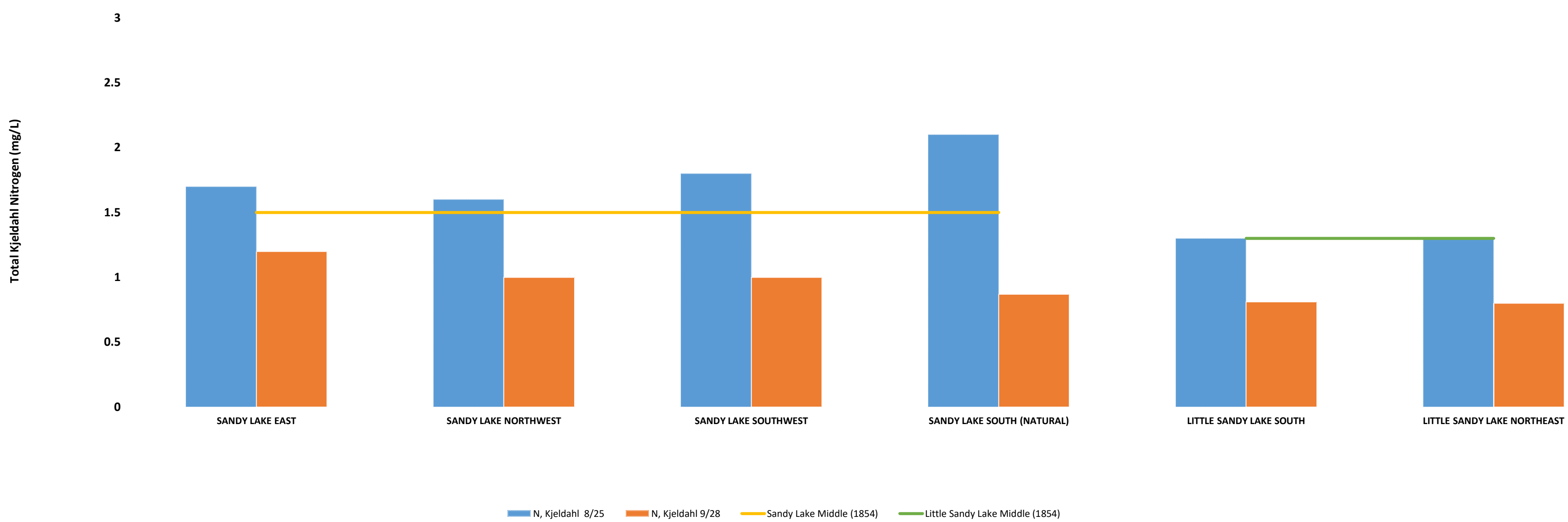


Figure 21
Wild Rice Plot Total Kjeldahl Nitrogen



2.7 Twin Lakes Water Quality – Quality Assurance

It is well understood that all State of Minnesota certified laboratories are required to perform various tests to verify that their results are as reported. This is accomplished by running duplicates, method blanks, matrix spikes, etc. For this report, three additional checks were performed in order to verify the data as it has been compiled in this final report.

The first evaluation was to complete an ion balance of major cations and anions to ensure that no significant constituents were being missed. This ion balance, showing cations and anions in terms of milliequivalents per liter (meq/L), is included in the sample results found in Appendix A. Ideally, the cations and anions should balance when expressed as meq/L. As can be seen, this was not always the case for samples collected at Twin Lakes. To evaluate specific water quality results, correlation coefficients were calculated for each of the cation/anion balances (see Table 10 below). With the exception of Culvert Inflow, most of the locations showed a very good correlation between the cation and anion concentrations. The reason for the low correlation coefficient for the Culvert Inflow results is not completely clear, but is likely caused by the relatively low concentrations of dissolved ions and the possibility that certain constituents were not analyzed that could have had a relatively large contribution to the overall balance.

Table 10. Correlation Coefficients

	Cation vs Anion Totals	Calculated TDS vs Actual TDS	TDS vs Specific Conductance
Inflow 1	0.99	0.97	0.97
Inflow 2	0.90	0.92	0.86
Inflow 3	0.92	0.83	0.76
South Inflow	0.97	0.88	0.78
Twin Lakes Outflow	0.87	0.82	0.89
Culvert Inflow	0.57	0.36	0.27
LSL Middle	0.96	0.73	0.83
SL Middle	0.86	0.78	0.59

The second evaluations was to compare the relationship between the calculated TDS vs the actual laboratory TDS values. The calculated TDS was determined by summing the laboratory results for each individual analysis. This "Calculated Total Dissolved Solids" data is presented in Appendix A. The calculated TDS can be individually compared with the actual laboratory TDS and, ideally, these values would be the same. As was done with the cation vs. anion comparison above, the correlation coefficient between the two TDS results was tabulated for each location (see Table 10). The TDS correlation coefficients were not as high as the cation vs. anion relationship and as with the ion balance evaluation the Culvert Inflow had a poor result of 0.36.

The third evaluation was the comparison of Specific Conductance to the laboratory TDS. The purpose of this comparison was to determine the relationship during the five years between the laboratory procedure and field measurements. These data are also found in Appendix A. The correlation coefficient results comparing TDS to the field specific conductance values for each location can be found in Table 10.   As seen in this table, not only did the Culvert Inflow produce a low correlation coefficient (0.43), but the SL Middle was also fairly low (0.59).

Overall, the checks on precision of the analytical data indicate that the primary constituents that make up the ions in solution at the various sampling sources were being measured.

3.0 SEDIMENT QUALITY

During October 2013, sediment cores were obtained from ten locations within each lake (Sandy Lake and Little Sandy Lake). Each sediment core was frozen and cut into 5-centimeter sections for measurement of physical and chemical characteristics. Due to the differing lengths of sediment in each core, a variable number of sections were obtained between cores. Using specific sections from these sediment cores, Dr. Peter Lee compared and contrasted the characteristics of Sandy and Little Sandy Lakes, Whitefish Lake (a wild rice producing lake near Thunder Bay, Ontario), sediment characteristics observed by Jorgenson (2013), and sediment characteristics observed by Myrbo et al. (2012) (Table 11). Sediment characteristics from two additional wild rice producing aquatic systems in Ontario (Rat River Bay and Wild Potato Lake) are provided for comparison to Sandy and Little Sandy Lakes' sediment characteristics (Table 11).

Contrasting total values in the top 5-centimeter (cm) sediment layer for Sandy Lake versus Little Sandy Lake (Table 11), Little Sandy Lake sediment had noticeably higher values for Acid Volatile Sulfide (AVS), B, Fe, Mn, and S and lower values for SEM (Cd, Cu, Ni, Pb, Zn). Other characteristics were similar in concentrations. Measured concentrations of Fe, S, AVS, Mn, and Pb in both sediments decrease considerably from the top 5-cm layer to the 6-10 cm layer. This trend continued to the 21-25 cm layer with S levels lower by approximately 10x, and Fe by approximately 5x at these sediment depths. Concentrations of these elements deeper within the sediment column may be representative of background concentrations prior to industry influences.

The suggestion of concentrations of specific elements at the 20-25 cm sediment depths as representative of pre-industry influence may also be supported by measured concentrations of these elements in sediment sampled from Rat River Bay and Wild Potato Lake. Each of these two systems support yearly harvestable densities of wild rice, and are non-industry influenced systems.

A concern about the ability of wild rice seeds to germinate and grow into seedlings in sediment sampled from Sandy and Little Sandy lakes existed at the initiation of this study. Therefore, during 2013 and 2014, wild rice bioassays were completed using bulk sediment sampled from Sandy Lake. The 2013 bioassay used single-bubble ambient air to aerate the water column of exposure chambers. Bioassay treatments in 2014 included both ambient air- and nitrogen- bubbled replicates. Due to space and time constraints, sediment from Little Sandy Lake was not used for initial wild rice bioassay experiments. Wild rice seeds were obtained from Whitefish Lake near Thunder Bay, Ontario. Whitefish Lake routinely contains a harvestable density of wild rice, and has been used as a field site and wild rice seed source for previous wild rice experiments. The overall purpose of this bioassay was to expose wild rice seeds obtained from Whitefish Lake to Sandy Lake sediment under laboratory conditions, and measure final dry weight following a seven-day exposure duration.

TABLE 11. TOTAL MEASURED CONCENTRATIONS OF CHARACTERISTICS FROM SEDIMENT SAMPLES OBTAINED FROM SANDY LAKE AND LITTLE SANDY LAKE (TWIN LAKES SYSTEM; 2013 DATA); JORGENSON 2013; MYRBO 2012; AND THREE WILD RICE PRODUCING SYSTEMS IN ONTARIO, CANADA – WHITEFISH LAKE, RAT RIVER BAY, AND WILD POTATO LAKE (LAKEHEAD UNIVERSITY ENVIRONMENTAL LABORATORY – LUEL – NON-PUBLISHED DATA).

			Sandy Lake			Little Sandy Lake									
	Detection Limit	Units	0-5 cm	6-10 cm	21-25 cm	0-5 cm	6-10 cm	21-25 cm	Jorgenson (2013)	Myrbo (mean)	Myrbo (min)	Myrbo (max)	Whitefish Lake	Rat River Bay	Wild Potato Lake
% Moisture Content	n/a	%	86.87	82.26	85.41	86.7	85.34	83.26	-	76.5	20.1	96	-	-	-
Acid Volatile Sulfides	0.0001	%	0.034	0.024	0.005	0.192	0.083	0.0051	-	-	-	-	-	-	-
Acid Volatile Sulfides	0.003	umole/g	10.71	7.53	1.64	60	25.93	1.6	-	0.72	0	6.25	1.9	-	-
SEM [Cd,Cu,Ni,Pb,Zn]	0.002	umole/g	0.991	0.733	0.916	0.125	0.112	0.084	-	1.39	-	-	-	-	-
Bulk Density	0.05	g/cm^3	0.12	0.19	0.12	0.16	0.18	0.21	-		-	-	-	-	-
Total As	2	ug/g	9.63	6.99	5.01	9.6	8.79	4.02	-	2.64	0.44	11.92	1	0.1	0.18
Total B	2	ug/g	28.7	17.71	20.37	61.58	45.12	44.63	-		-	-	-	-	-
Total Cd	0.25	ug/g	0.8	1.014	0.93	0.35	0.83	0.53	-	0.37	0.02	0.88	1.66	0.0336	509
Total Co	0.2	ug/g	8.04	6.1	5.14	5.83	6.09	5.75	-	2.11	0.19	10.26	0.71	0.227	0.524
Total Cr	0.03	ug/g	19.62	19.76	21.07	17.76	21.76	24.3	-	7.07	-	-	-	0.058	0.15
Total C	0.05	ug/g	11.47	11.67	12.2	9.69	11.94	11.62	-	7.19	0.68	22.65	25.84	0.2129	0.3862
Total Fe	0.1	ug/g	59414.6	35683.6	15315.47	68833.9	39081.4	13125.7	1210	8328.4	1298.4	50389	7852.65	287.808	777.455
Total Mn	0.05	ug/g	436.62	298.25	259.38	624.39	267.45	181.91	134.25	608.6	45.52	3814.96	135.41	11.59	36.829
Total Mo	2	ug/g	< DL	< DL	< DL	< DL	< DL	< DL	-	-	-	-	-	<DL	<DL
Total Ni	0.2	ug/g	12.55	13.04	14.86	8.44	11.4	14.3	-	8.43	-	-	-	1.1032	1.3898
Total Pb	1	ug/g	30.18	22.2	6.3	33.36	23.36	4.95	-	11.11	0.6	76.64	13.42	0.2475	0.4016
Total S	1	ug/g	47,172.4	28,590.4	6,374.58	64,517.3	32,975.5	4,071.13	4,519	3116	55	12,515	247.19	1.36	1.91
Total Se	2	ug/g	< DL	< DL	< DL	< DL	< DL	< DL	-	-	-	-	-	<DL	<DL
Total Zn	0.03	ug/g	98.36	92.2	75.23	68.16	82.9	61.61	75.14	38.05	4.92	103.98	49.7	1.6394	2.9717
Total Carbon	0.01	%	20.63	18.71	24.5	17.31	16.76	18.23	-	-	-	-	-	-	-
N in Sediment	0.01	%	1.72	1.47	1.69	1.7	1.43	1.32	-	-	-	-	-	-	-

Results of the 2013 bioassay indicated that wild rice seedlings grown in Sandy Lake sediment had a significantly higher final dry weight than those grown in Whitefish lake sediment (Figure 22). However, results of the 2014 bioassay indicated that wild rice seedlings germinated and grown in Sandy Lake sediment with air as the single-bubble aeration source had a significantly lower dry weight biomass than those germinated and grown in Whitefish Lake sediment with either air or nitrogen gas (N2) as the bubble source (Figure 23). Regardless of the statistical conclusions regarding final dry weight (g), wild rice seeds germinated and grew into healthy seedlings in Sandy Lake sediment in all replicates of both years' bioassay trials.

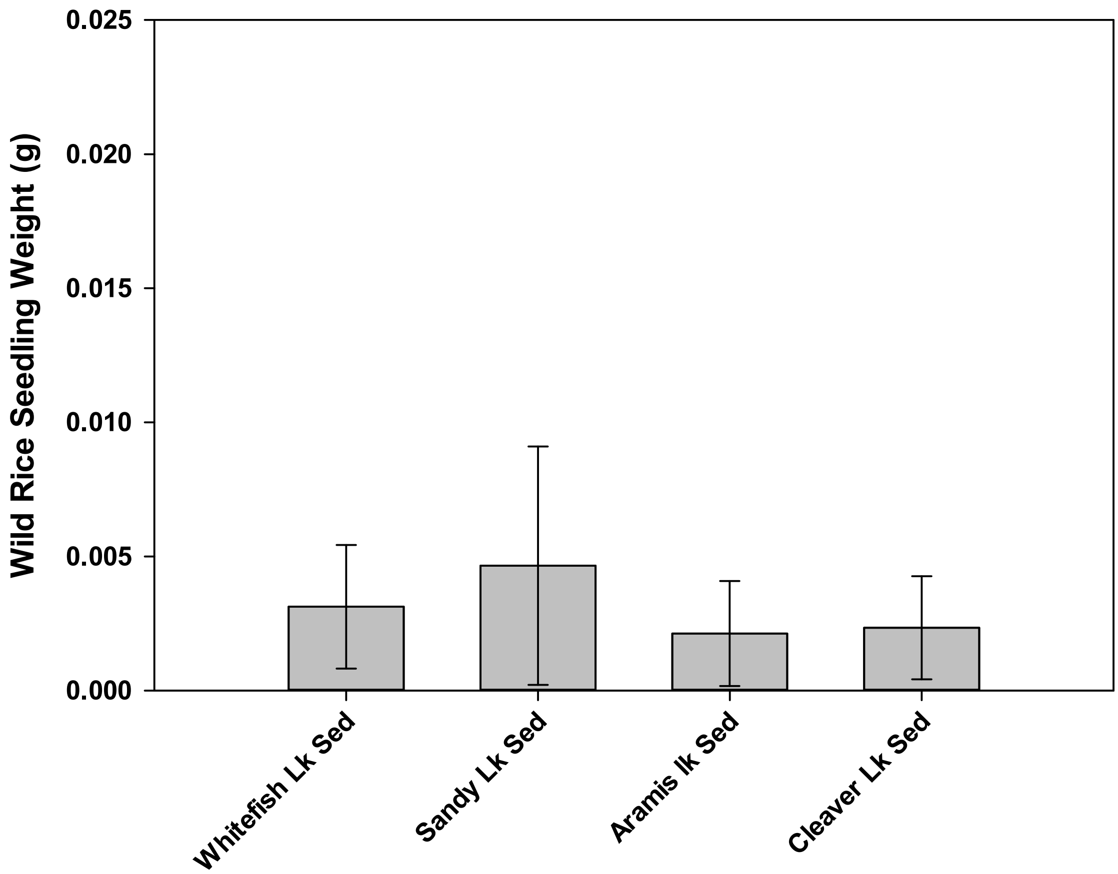


FIGURE 22. 2013 WILD RICE SEEDLING AVERAGE FINAL DRY WEIGHT RESULTS FOLLOWING THE SEVEN-DAY BIOASSAY EXPOSURE DURATION. Error bars represent one standard deviation.

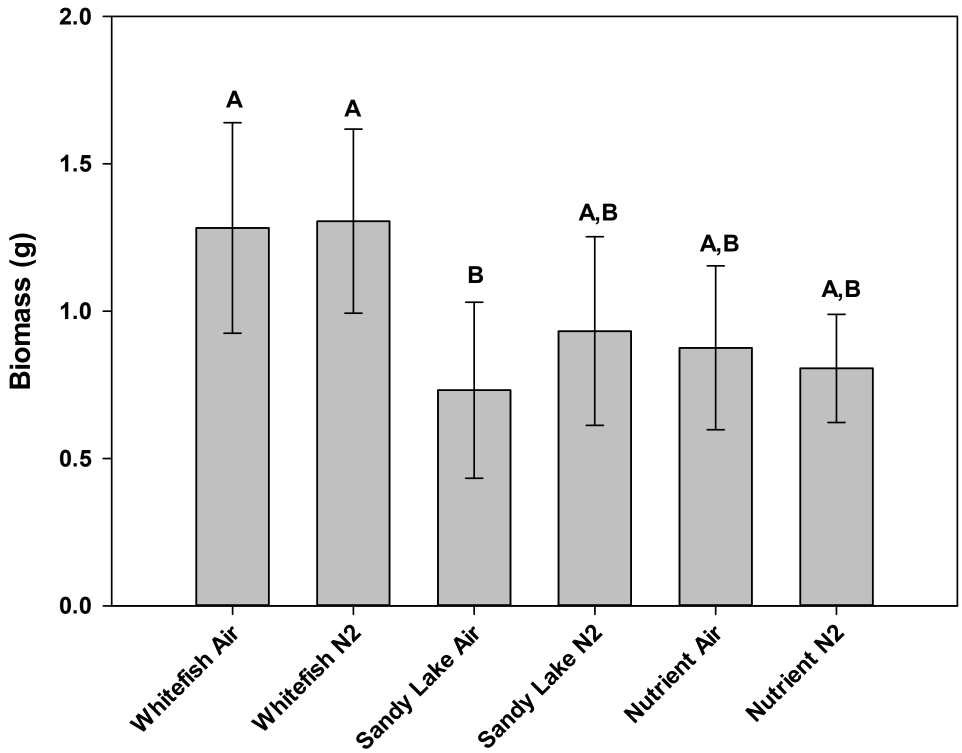


FIGURE 23. 2014 WILD RICE SEEDLING AVERAGE FINAL DRY WEIGHT RESULTS FOLLOWING THE SEVEN-DAY BIOASSAY EXPOSURE DURATION. Treatments labelled 'Nutrient' were used as controls during this initial wild rice bioassay. Error bars represent one standard deviation. Letters indicate statistical differences; columns sharing the same letter are not significantly different.

Separate studies related to wild rice restoration have been completed on two mining-influenced lakes in Ontario, Canada (see Appendix B). The subject Canadian lakes are significantly different from the Twin Lakes in that they are both meromictic (i.e., chemically stratified), with diverse and complex chemical characteristics below the chemocline, and receive significantly greater inputs of dissolved constituents. Similar to the studies described above, sediment from the two subject Canadian lakes were used to evaluate the growth potential of wild rice in contrast to sediment from a non-industry influenced aquatic system. Results of the evaluation indicated that there were no significant differences in wild rice seed germination between the three sediment sources. Subsequent mesocosm growth studies using sediment from the subject mining-influenced, as well as non-industry influenced, Canadian lakes resulted in the successful growth of wild rice seedlings into reproductively mature plants from all three sediment sources.

These observations, and observations of wild rice seedlings grown in Sandy Lake sediment in 2013 and 2014 bioassay tests, indicate that sediments from Sandy Lake, and likely Little Sandy Lake, will support germination, growth, and development of wild rice into mature seed producing plants under field conditions.

Based on the data collected and observations obtained during the Plan between 2013 and 2015, wild rice seeding events of select areas within each lake were developed and completed. Specifics of these wild rice seeding efforts are detailed in Section 8.0 of this report. However, in summary, over the course of two years of observations of wild rice seeded areas, wild rice plants in the aerial developmental stage were observed in all areas seeded within the Twin Lakes system. Therefore, in general, in areas of appropriate water depth and lack of competing vegetation, the sediment in both Little Sandy and Sandy lakes will support germination, growth, and development of wild rice into mature, seed producing plants. Overall, the quality of the sediment in both Little Sandy and Sandy lakes is more than sufficient to support germination, growth, and development of wild rice into reproductively mature, seed producing plants.

4.0 Pore Water Quality

4.1 Sediment Pore Water Quality

In 2013, the general process for obtaining pore water from sediment cores was as follows: 1) obtain and freeze sediment core; 2) cut sediment core into multiple sections (typically 10 cm of sediment or more to obtain sufficient volume of pore water for analyses); 3) thaw sediment and centrifuge thawed sample to 'fractionate' sediment particulates and pore water; 4) decant pore water; 5) analyze pore water. More than one of these steps may allow for the potential of atmospheric exposure.

The ten sediment cores collected from each lake in October 2013 were considered representative of central and peripheral locations throughout each lake. Dr. Peter Lee from Lakehead University Environmental Laboratory provided an evaluation of the sediment pore water characteristics including a comparison between Little Sandy Lake and Sandy Lake, previous MPCA pore water data, and a Canadian wild rice producing lake (Whitefish Lake) (see Appendix C).

The measured physical and chemical characteristics of sediment pore water samples from these cores are detailed in Appendix D. The results of analysis showed that concentrations of pore water sulfide were below detection (< 10 µg/L) in all samples from Sandy Lake. Although there was no measureable sulfide in the Sandy Lake pore water samples, it may have been mitigated by dissolved iron in the pore water which ranged from 0.326 – 7.988 mg/L in Sandy Lake. Of the fourteen pore water samples from sediment cores obtained from Little Sandy Lake, nine showed sulfide concentrations at or below detection, while the remaining five contained sulfide at concentrations ranging from 0.13 – 0.57 mg/L. However, this sulfide may also be mitigated by dissolved iron measured in the pore water, which ranged from 0.18 – 3.65 mg/L.

Although this has been the preferred method for collecting sediment samples and obtaining measurements of physical and chemical sediment characteristics, this method is lacking with respect to sediment pore water collection and characterization. This was evidenced by the inability to retrieve sufficient volumes of pore water from some of the sediment cores sampled during 2013 and 2014. Loss of sulfide may have also occurred during transport, which was evidenced by a "rotten egg" smell permeating from the sample bottles during and after transport.

4.2 PEEPER PORE WATER QUALITY

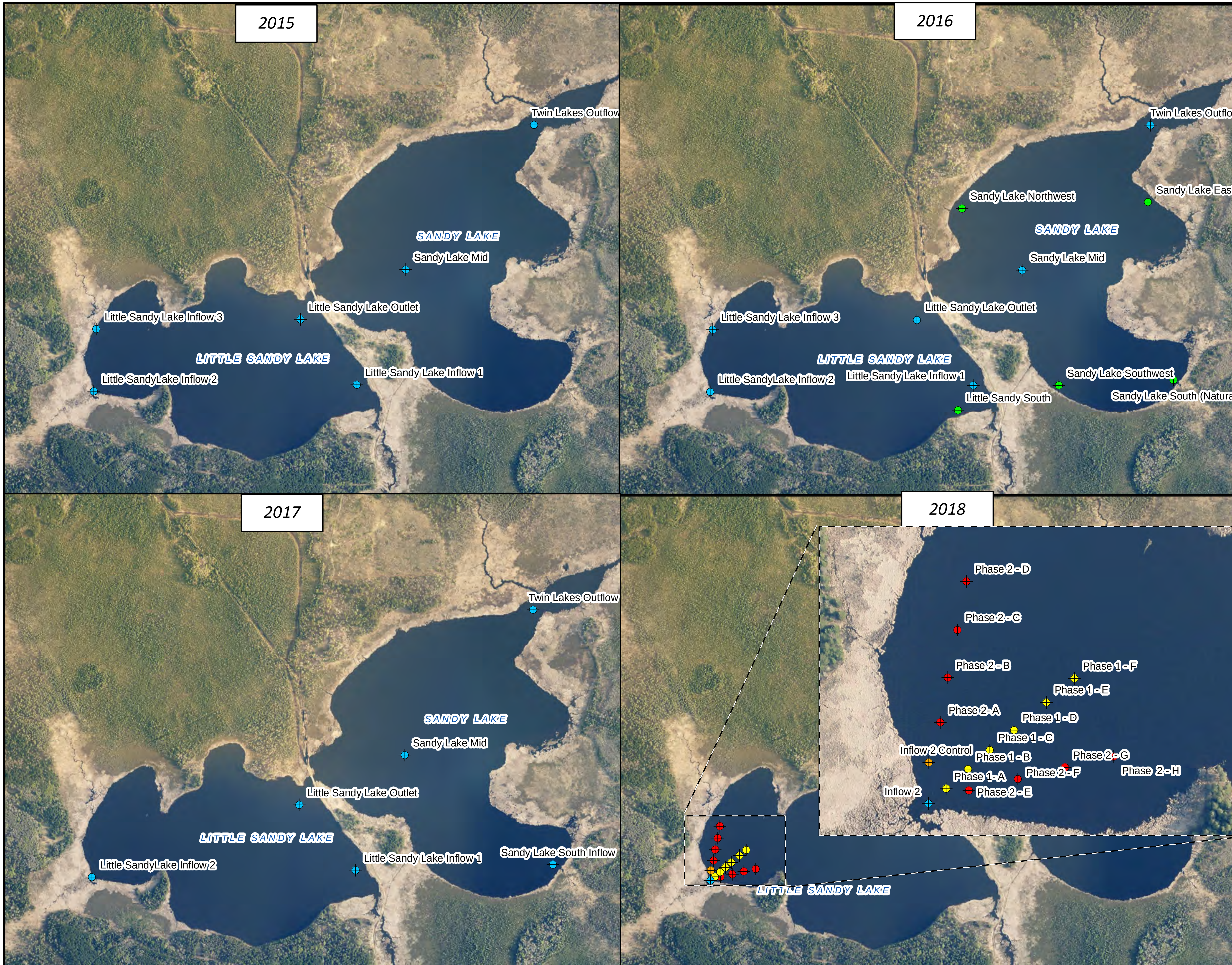
A more effective and defensible method of sediment pore water sampling and characterization is through the use of Rhizon type samplers and/or peepers. Generally, the use of peepers consists of a peeper assembly designed to hold four, 50-mL centrifuge tubes (see Figure 24) at the 0°, 120°, 240° and 360° locations around the peeper tube and within the top 10 cm of the sediment column when deployed. Each 50-mL centrifuge tube (see Figure 24) was completely filled (no headspace) with analytical standards-grade deionized water obtained from Pace Analytical Laboratories (Pace Analytical; Virginia, MN). Each tube contained a 0.45 µM pore size filter covering the tube surface, along with a polyethylene screen to protect the filter from damage. The screen and 0.45 µM filter covering the tube outlet were held in place by a plastic cap with the majority of the surface removed to allow for exchange of sediment pore water constituents into the deionized water to equilibrium via diffusion. Just prior to each deployment, four tubes were installed in the peeper assembly and then the peeper assembly was pushed into the lake bed sediment until the fixed 5-gallon bucket lid affixed just above the top centrifuge tube was in contact with the sediment surface. Following this procedure ensured that the inserted centrifuge tubes were located in the top 10 cm of sediment. Figure 25 shows an entire peeper assembly ready for deployment. Peepers were pulled from the sediment and samples collected from the sample vials for pore water analysis at roughly one-month intervals. Following sample collection, the sample vials pulled for analysis were replaced with freshly prepared vials and the peepers were placed back in the lake sediment.

Figure 24. Peeper sediment pore water sampling device

Figure 25. Example of a 50-mL centrifuge tube used for peeper sediment pore water quality measurements

During the 2015 sampling season, monthly peeper samples were obtained from Twin Lakes Outflow, Sandy Lake Middle, Little Sandy Lake Outlet (i.e., a location approximately 100 meters from the channel separating the Twin Lakes toward the center of Little Sandy Lake), Little Sandy Lake Inflow 2 and Little Sandy Lake Inflow 3. During 2016, sampling at these locations was repeated until August, when peepers were moved to wild rice growth locations. In 2017, the same locations as 2015 were again sampled, except that sampling at the Little Sandy Lake Inflow 3 location was discontinued, and sampling at the Sandy Lake South Inflow was established. In 2018, a two-phase delineation was established at the Inflow 2 location (see Figure 26 for all peeper locations from 2015-2018). Twin Lakes peeper data from 2015 through 2018 is shown in Appendix E.

The 2015 through 2017 measured concentrations of pore water sulfide and dissolved iron concentrations were inversely correlated (Figure 27) for all locations except Little Sandy Lake Inflow 2, i.e., pore water sulfide concentrations tended to decrease as pore water dissolved iron concentrations increased. The higher pore water sulfide concentrations seen at Little Sandy Lake Inflow 2 may have affected the available iron in the pore water in that location. Also, in general, it appears that the pore water sulfide concentrations increased throughout each season (Figure 28). This suggests that a seasonal influence may exist.

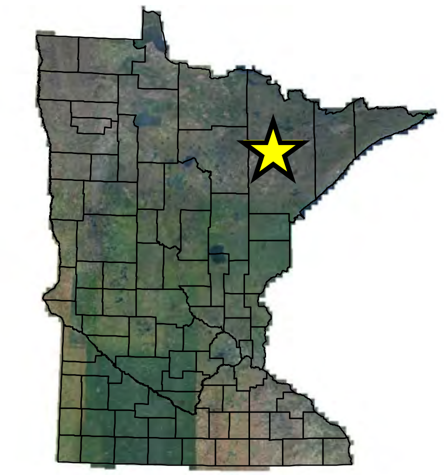


N

0 425,000 850,000 1,700,000

Feet

1 Inch = 906,440 Feet



Legend

- Wild Rice Peeper Deployment
- Peeper Deployment
- Inflow 2 Control
- Phase 1 Peeper Deployment
- Phase 2 Peeper Deployment

Figure 26
2015-2018 Twin Lakes
Peeper Locations

Twin Lakes
US Steel Corporation -
Minnesota Ore Operations
Mt. Iron, Minnesota (St. Louis County)

NTS Environmental Science & Engineering
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Date Drawn : February 13, 2019	
Drawn By : T. Muck	26
NTS Project #: 10170E	

Figure 27
Sulfide Iron Relationship in Twin Lakes
Peeper Pore Water (2015-2017)

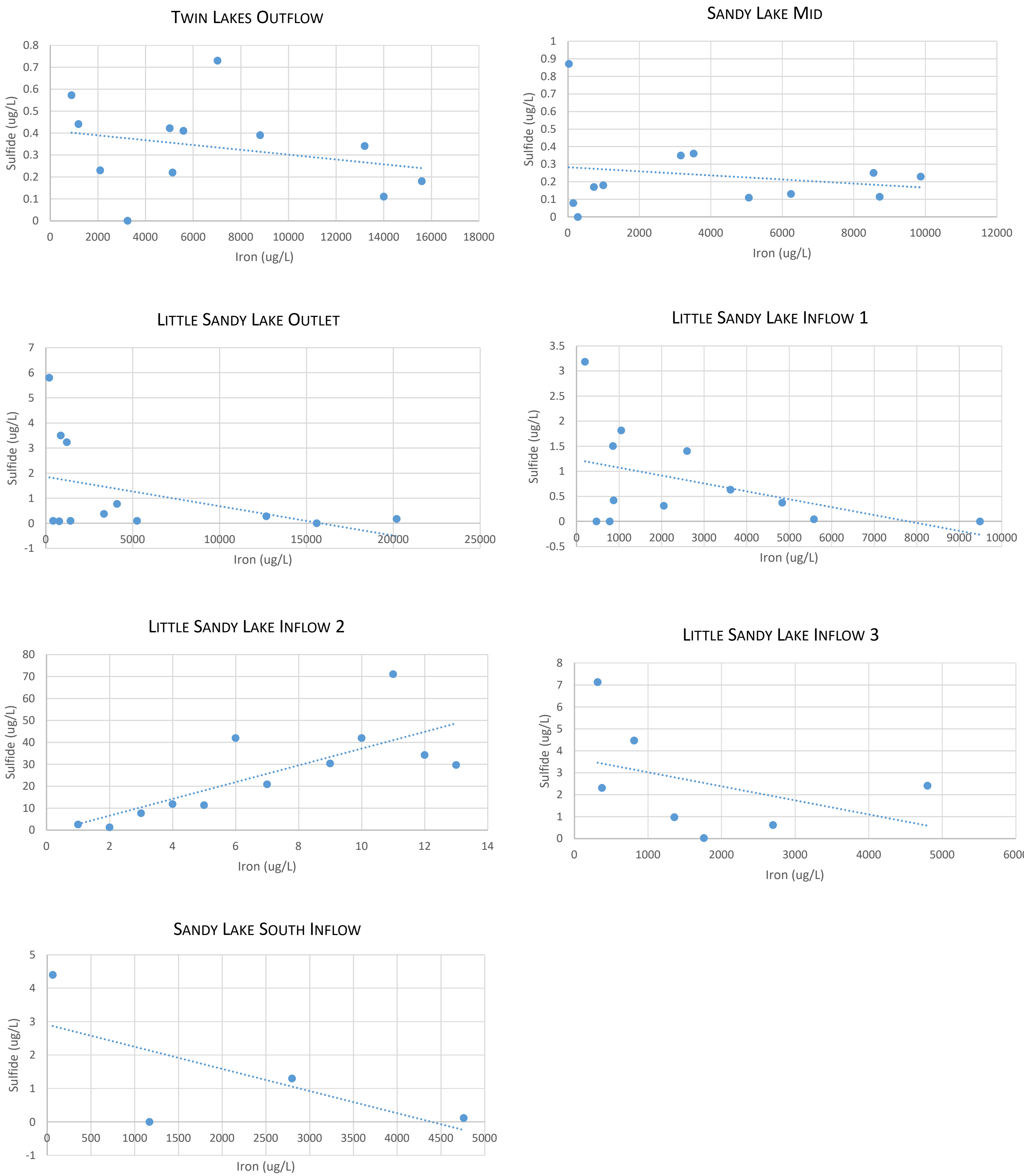
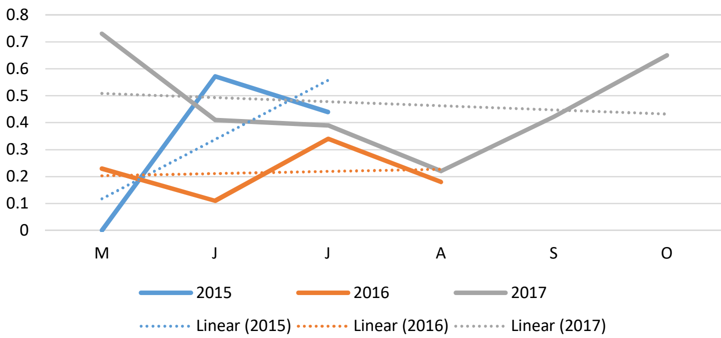
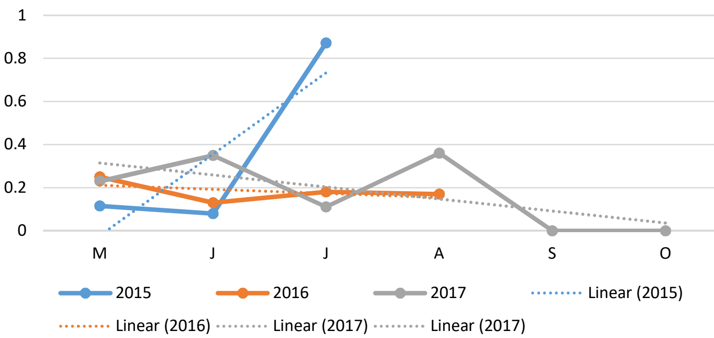


Figure 28
Sulfide Seasonal Influence in Twin Lakes
Peeper Pore Water (2015-2017)

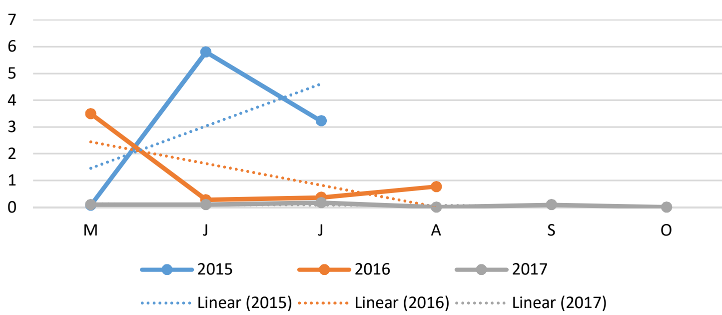
Twin Lake Outlet



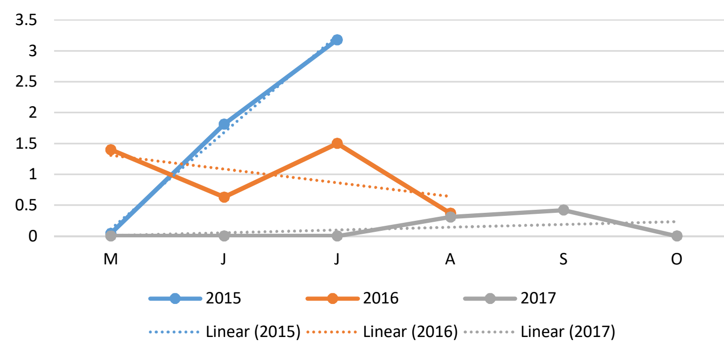
Sandy Lake Middle



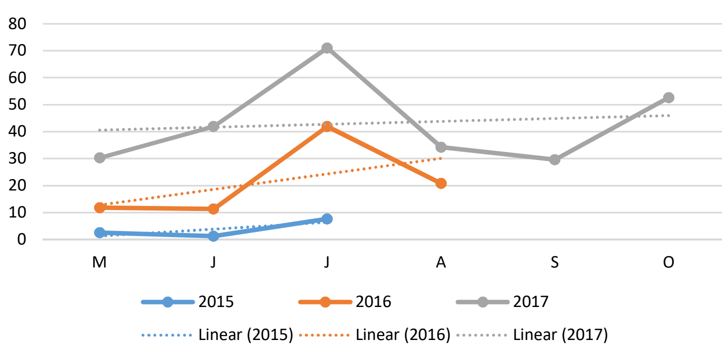
Little Sandy Lake Outlet



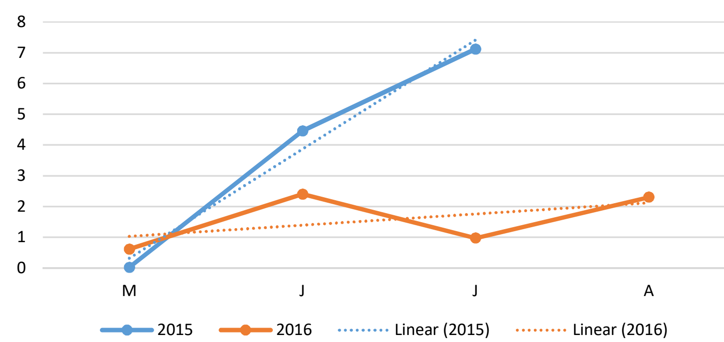
Little Sandy Lake Inflow 1



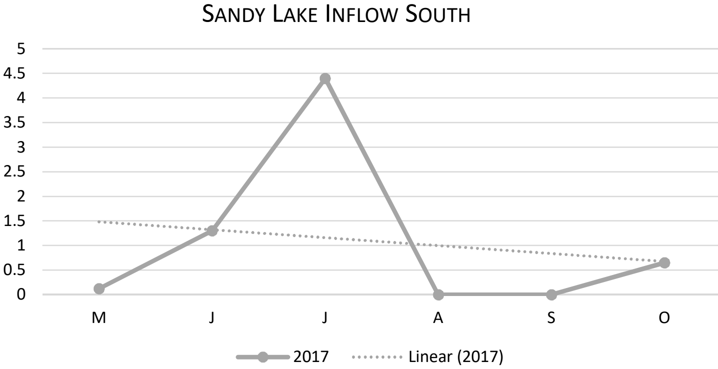
Little Sandy Lake Inflow 2



Little Sandy Lake Inflow 3



Sandy Lake Inflow South

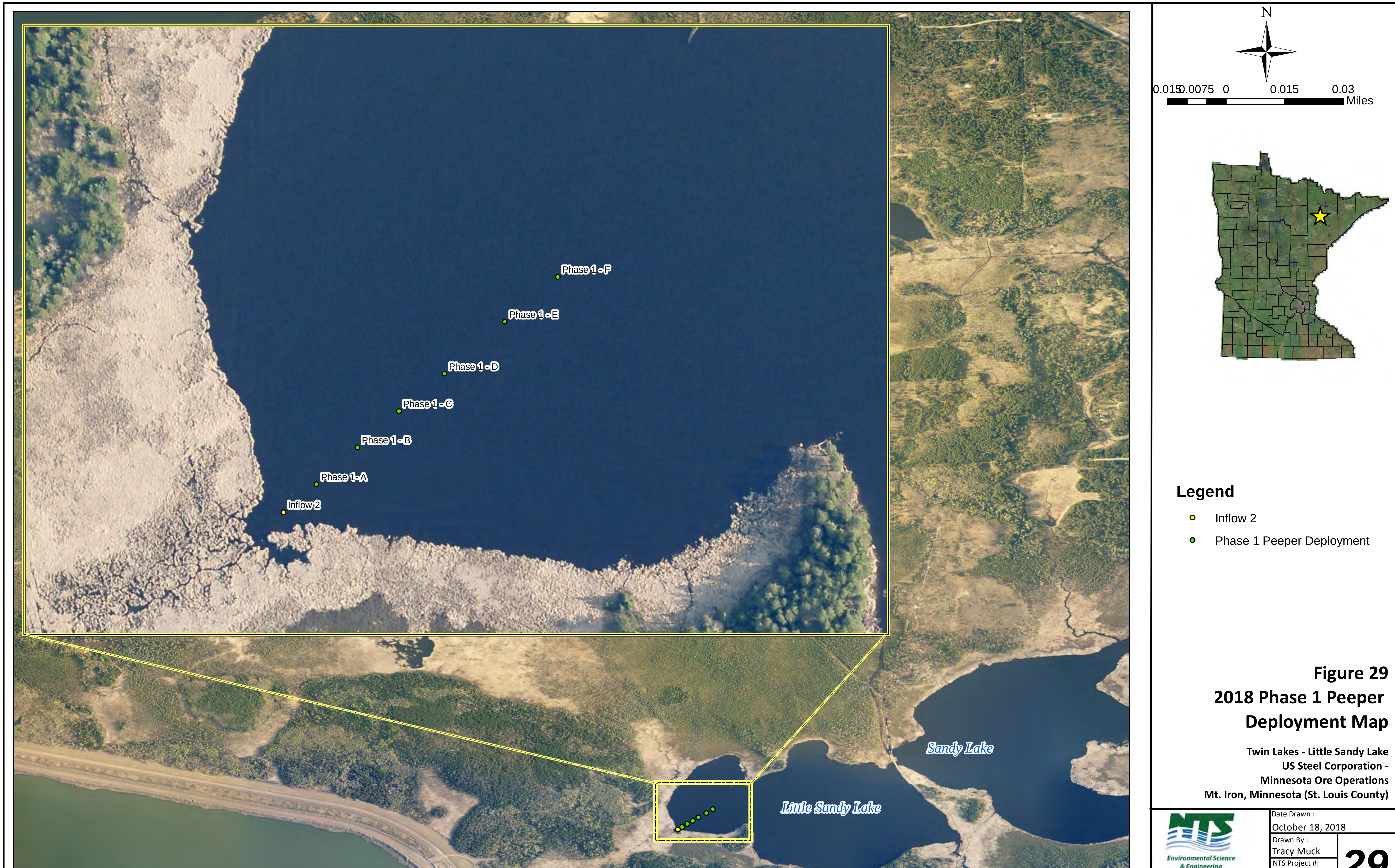


To address comments received after the 2015 monitoring season regarding use of peepers for sediment pore water characterization, a procedure was implemented to deoxygenate the sampling materials used in peepers. Peeper materials deoxygenated prior to use were the DI water, 50-mL centrifuge tubes, caps, filter, and screen. Deoxygenation was completed under nitrogen atmosphere in an air-tight glovebox, and followed the method described by Teasdale et al. (1995). Deoxygenated and prepared vials were sealed with parafilm and kept in a nitrogen atmosphere in a sealed plastic bag prior to field deployment. This procedure was undertaken in 2017 and, although there didn't appear to be any significant difference in sample results, continued throughout the remainder of the Plan.

In 2017, an updated method of obtaining and preserving peeper samples for sulfide was developed. At the time of retrieval, water in the upper-most and lower-most 50-mL tubes from the 0°and 360° locations on each peeper assembly were immediately combined in the sample bottle containing sodium hydroxide/zinc acetate preservative for subsequent analysis of sulfide. This was done to 1) minimize the potential atmospheric exposure of the sample prior to preservation, and 2) obtain a more representative sample of pore water characteristics specifically for sulfide. The remaining two intermediate 50-mL peeper tubes (at the 120° and 240° locations) were placed in separate sample bottles for measurement of sulfate, iron and manganese.

During the 2015 through 2017 sampling seasons, the highest sediment pore water sulfide concentrations were measured from samples obtained at the Inflow 2 monitoring location. Concurrently, the lowest total iron concentrations were measured in samples also obtained at this monitoring location. These data tend to indicate that as sulfide is produced in the pore water, available iron is bound as iron sulfide, thus decreasing the pore water total iron available for reaction with sulfide.

To better understand this trend, two phases of peeper deployment were planned for Little Sandy Lake near Inflow 2 in 2018. The primary objective of the 2018 peeper deployment was to delineate the aerial extent of the elevated pore water sulfide that has consistently been observed in the Inflow 2 area. During Phase 1, seven peepers were deployed in May 2018. The first peeper was located at the spot where Inflow 2 peepers had previously been deployed. The remaining six peepers were installed in one transect perpendicular to the shoreline at 50-100 feet spacing increments towards the center of the lake (see Figure 29). The peepers were sampled and redeployed in the same locations in June. In July, all of the peepers were sampled and removed with the exception of the Inflow 2 peeper, which was redeployed for Phase 2 in the same location. The Phase 2 peepers were initially planned to be placed in a transect perpendicular to the Phase 1 locations, spanning the southwest bay of Little Sandy Lake. However, data analysis from the first round of sampling in June, showed that the sulfide concentrations in each peeper trended lower toward the middle of the lake, while the iron concentrations trended higher. It was theorized that the Inflow 2 location is a localized area of high sulfide/low iron and these concentrations decreased and increased, respectively, farther away from Inflow 2. To test this theory, eight Phase 2 peepers were deployed in July in two transects on either side of the previous location of the Phase 1 transect (see Figure 30). As with the Phase 1 peepers, the Phase 2 peepers were sampled and redeployed in the same location in August. In September, the Phase 2 peepers were sampled again and removed for the season. Data collected from the peepers showed high sulfide concentrations at the Inflow 2 location and trended lower toward the center of the lake (see Figure 31). Peeper data also showed lower iron concentrations at the Inflow 2 peeper location trending higher toward the center of the lake (see Figure 32).



Legend

- Inflow 2
- Phase 1 Peeper Deployment

Figure 29
2018 Phase 1 Peeper Deployment Map

Twin Lakes - Little Sandy Lake
US Steel Corporation - Minnesota Ore Operations
Mt. Iron, Minnesota (St. Louis County)

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Background Imagery provided by Saint Louis County Web Services. Date of Imagery: May, 2016

Figure 30
2018 Phase 2 Peeper Deployment Map

Twin Lakes - Little Sandy Lake
US Steel Corporation - Minnesota Ore Operations
Mt. Iron, Minnesota (St. Louis County)

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N

0.02 0.01 0 0.02 0.04 Miles

Legend

- Inflow 2
- Phase 1 Peeper Deployment
- Phase 2 Peeper Deployment

Peeper Sulfide Concentrations

- 0.800047875 - 5
- 5.000000001 - 10
- 10.00000001 - 15
- 15.00000001 - 20
- 20.00000001 - 25
- 25.00000001 - 30
- 30.00000001 - 35
- 35.00000001 - 40
- 40.00000001 - 45
- 45.00000001 - 50
- 50.00000001 - 55
- 55.00000001 - 60

Figure 31
2018 Pore Water Sulfide Delineation Map

Twin Lakes - Little Sandy Lake
US Steel Corporation - Minnesota Ore Operations
Mt. Iron, Minnesota (St. Louis County)

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Drawn By : Tracy Muck	31
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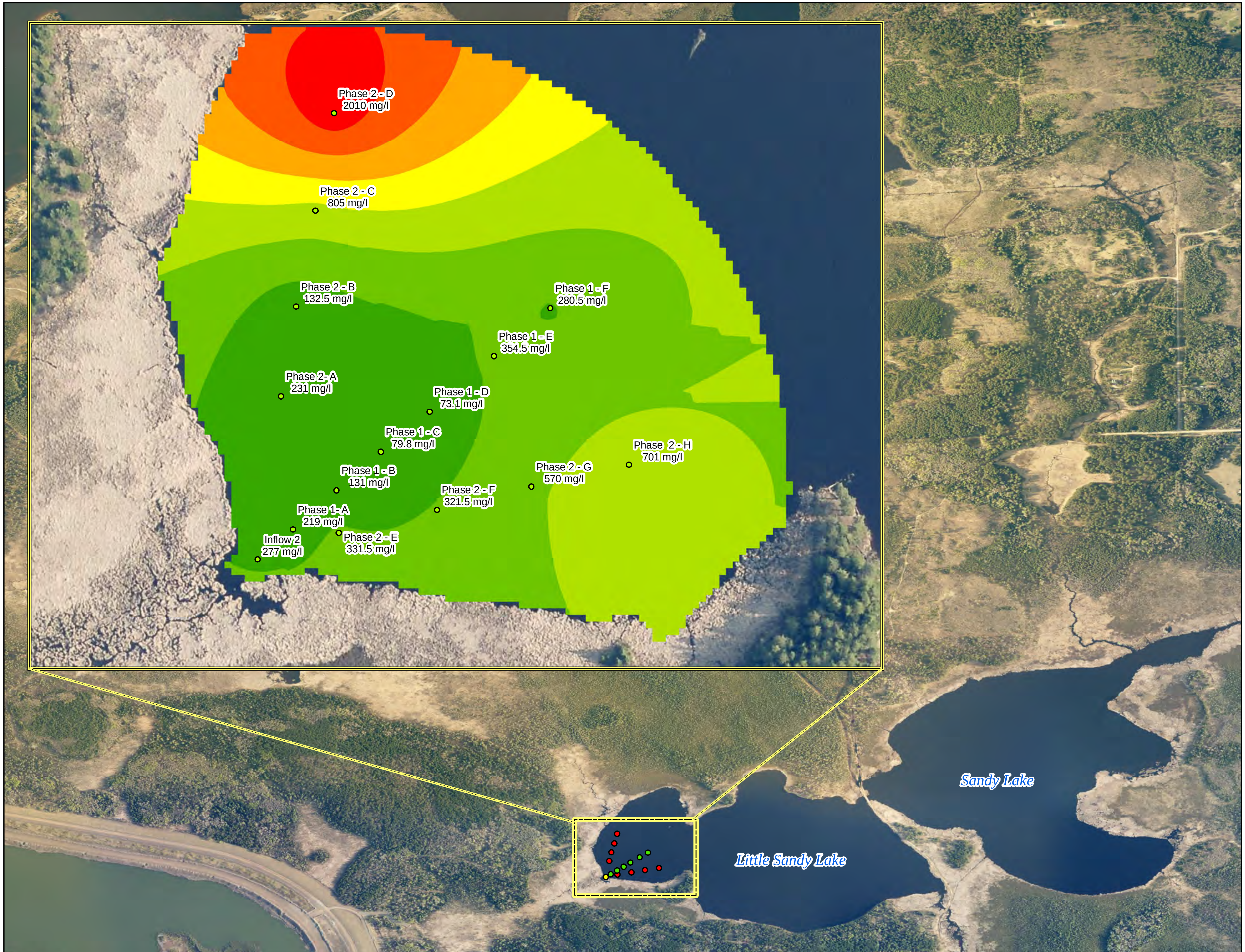

Figure 32
2018 Pore Water Dissolved Iron Delineation Map

Twin Lakes - Little Sandy Lake
US Steel Corporation - Minnesota Ore Operations
Mt. Iron, Minnesota (St. Louis County)

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Background Imagery provided by Saint Louis County Web Services. Date of Imagery: May, 2016

4.3 RHIZON PORE WATER QUALITY

In July 2017, the Minnesota Pollution Control Agency (MPCA) released procedures for sampling pore water from sediment (MPCA July 2017), which involved the use of Rhizon filters to directly sample sediment pore water from cores. During 2017 this alternate method of pore water sampling was used in a 'side by side' comparison with specific peepers in September. In 2018, this side-by-side method of sediment pore water sampling was again used in June and August. This was accomplished by inserting the Rhizon filter with attached tubing (see Figure 33) approximately 10 cm into a sediment core, applying a vacuum supplied by an evacuated 125-mL serum bottle containing sodium hydroxide/zinc acetate preservative, into which a minimum volume of 50 mL of pore water is aspirated (Figure 34). Concurrent peeper samples were obtained and preserved in the field using the method described in Section 4.2. In the same manner as described above for peeper materials, Rhizon materials were also deoxygenated prior to use for sediment pore water sampling. In addition, the 125-mL sample container was purged with nitrogen prior to evacuation. The sodium hydroxide/zinc acetate preservative was added under nitrogen atmosphere in an air-tight glovebox.

Although the method for using Rhizons for sediment pore water sampling was completed following the established MPCA guidelines, substantial differences were found to exist between concentrations of sulfide from peeper samples and Rhizon samples (see Figure 35). Specifically, in 2017, pore water sulfide concentrations measured by the peeper sampling technique were approximately double those measured when using Rhizons. Further, in 2017, a nearly identical peeper:Rhizon sulfide concentration ratio was observed between all side-by-side samples obtained using peepers and Rhizons. Although this trend was not seen during the 2018 Rhizon versus peeper side-by-side comparisons the Rhizon sulfide concentrations were almost always consistently lower than the peeper sulfide concentrations for the same location.

FIGURE 33. RHIZON FILTER APPARATUS USED FOR SEDIMENT PORE WATER SAMPLING. NOT PICTURED – 125-ML EVACUATED GLASS SAMPLE CONTAINER

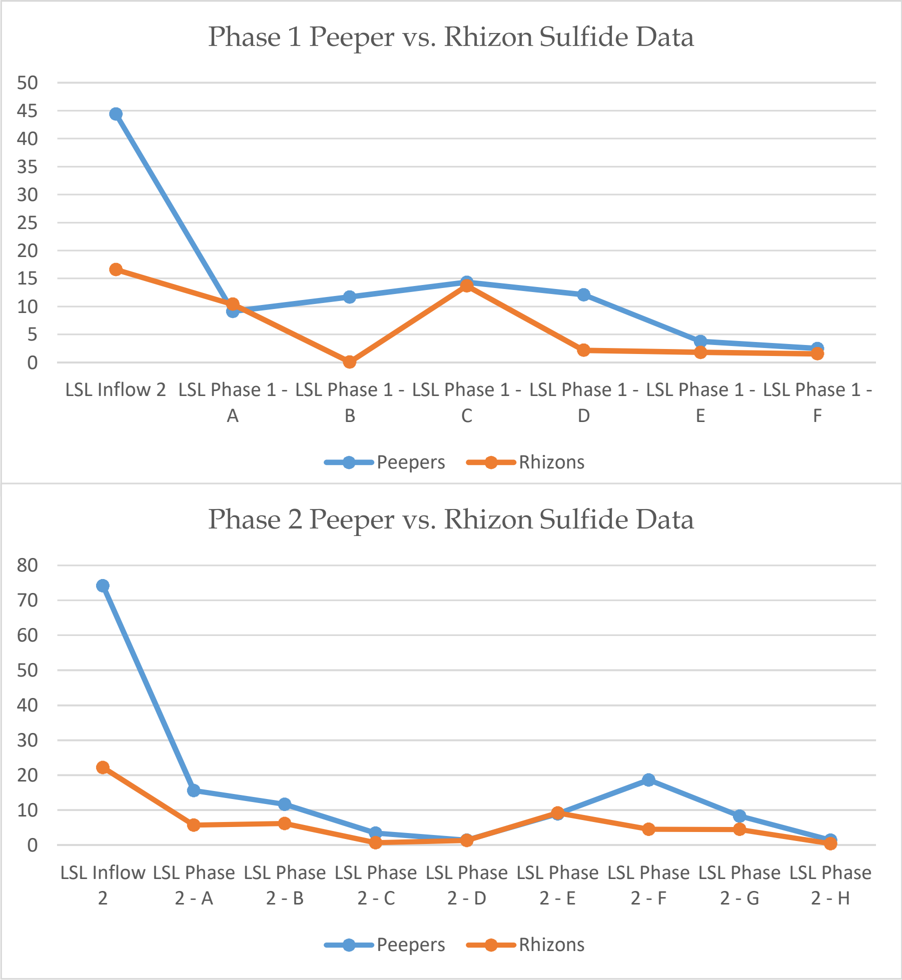
FIGURE 34. RHIZON FILTER APPARATUS IN USE FOR SAMPLING SEDIMENT PORE WATER

FIGURE 35

TWIN LAKES SULFIDE SAMPLE COLLECTION COMPARISON

	Peeper Sulfide mg/L	Rhizon Sulfide mg/L
	6/18/2018	6/15/2018
LSL Inflow 2	44.4	16.6
LSL Phase 1 - A	9.13	10.4
LSL Phase 1 - B	11.7	0.0786
LSL Phase 1 - C	14.3	13.7
LSL Phase 1 - D	12.1	2.16
LSL Phase 1 - E	3.75	1.78
LSL Phase 1 - F	2.49	1.53
	8/20/2018	8/20 & 8/21/2018
LSL Inflow 2	74.2	22.2
LSL Phase 2 - A	15.6	5.72
LSL Phase 2 - B	11.7	6.15
LSL Phase 2 - C	3.43	0.675
LSL Phase 2 - D	1.38	1.28
LSL Phase 2 - E	8.91	9.18
LSL Phase 2 - F	18.6	4.54
LSL Phase 2 - G	8.3	4.48
LSL Phase 2 - H	1.42	0.411

Note: The detection limit is <0.0779



In order to better understand what may be causing this divergence, a peeper assembly was planned for installation at a location near Inflow 2 (Inflow 2 Control) approximately 100 feet north of the Inflow 2 peeper. This peeper assembly was fitted with a Rhizon filter at 10 centimeters below the top of the sediment, with approximately 10 feet of attached tubing stored above the surface of the water at the top of the peeper assembly (see Figure 36). This peeper assembly was also fitted with peeper tubes and was deployed in July 2018. In August, this Rhizon was used to extract a sample "in-situ" for analysis of pore water sulfide. A sediment core was also collected and sampled "ex-situ" with a Rhizon, as was done at the other Phase 2 peeper locations. The peeper tubes from the peeper assembly were also sampled. All three samples were analyzed for sediment pore water sulfide. The results are shown in Table 12 below. It can be seen that the "ex-situ" Rhizon method produced the lowest results, while the "in-situ" method produced somewhat higher results. The peeper method shows pore water sulfide results higher than both of the Rhizon methods.

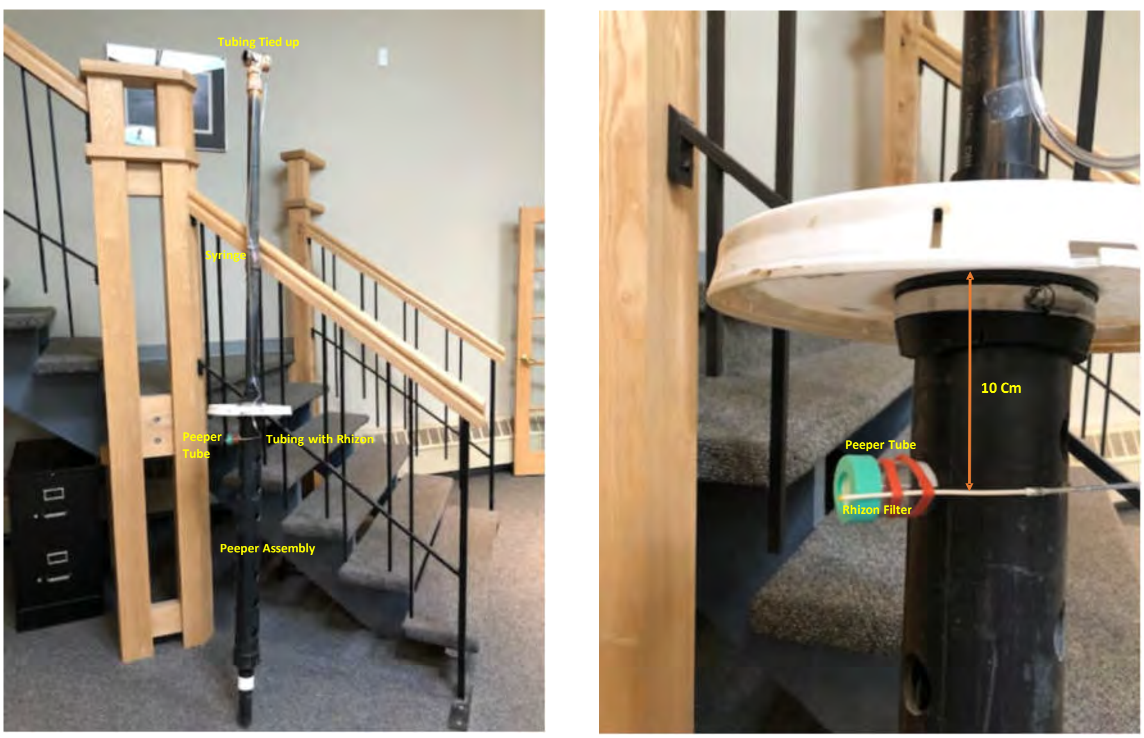


FIGURE 36. IN-SITU RHIZON ASSEMBLY ATTACHED TO PEEPER

TABLE 12: AUGUST 2018 SEDIMENT PORE WATER METHOD COMPARISON

Inflow 2 Control Location		
Ex-Situ Rhizon Method Sulfide (mg/L)	In-Situ Rhizon Method Sulfide (mg/L)	Peeper Method Sulfide (mg/L)
0.463	3.96	27.7

There are a number of possible explanations for these differences, including: disturbance caused by placement of the Rhizon filter into the sediment could have resulted in sulfide loss or transformation; the length of tubing required to satisfy the sampling protocol could be a source of oxygen for oxidation of sulfide to sulfate; and slightly different sampling techniques used by multiple personnel conducting sediment pore water sampling using Rhizons.

Additional side-by-side sediment pore water samples using peepers and Rhizons would be necessary to further elucidate and verify the differences in measured sulfide concentrations currently observed between these methods. Because consistent results were not obtained via the Rhizon method, it appears that this method is not representative of actual pore water sulfide concentrations. Therefore, it is recommended that future sediment pore water sampling techniques should utilize the peeper method.

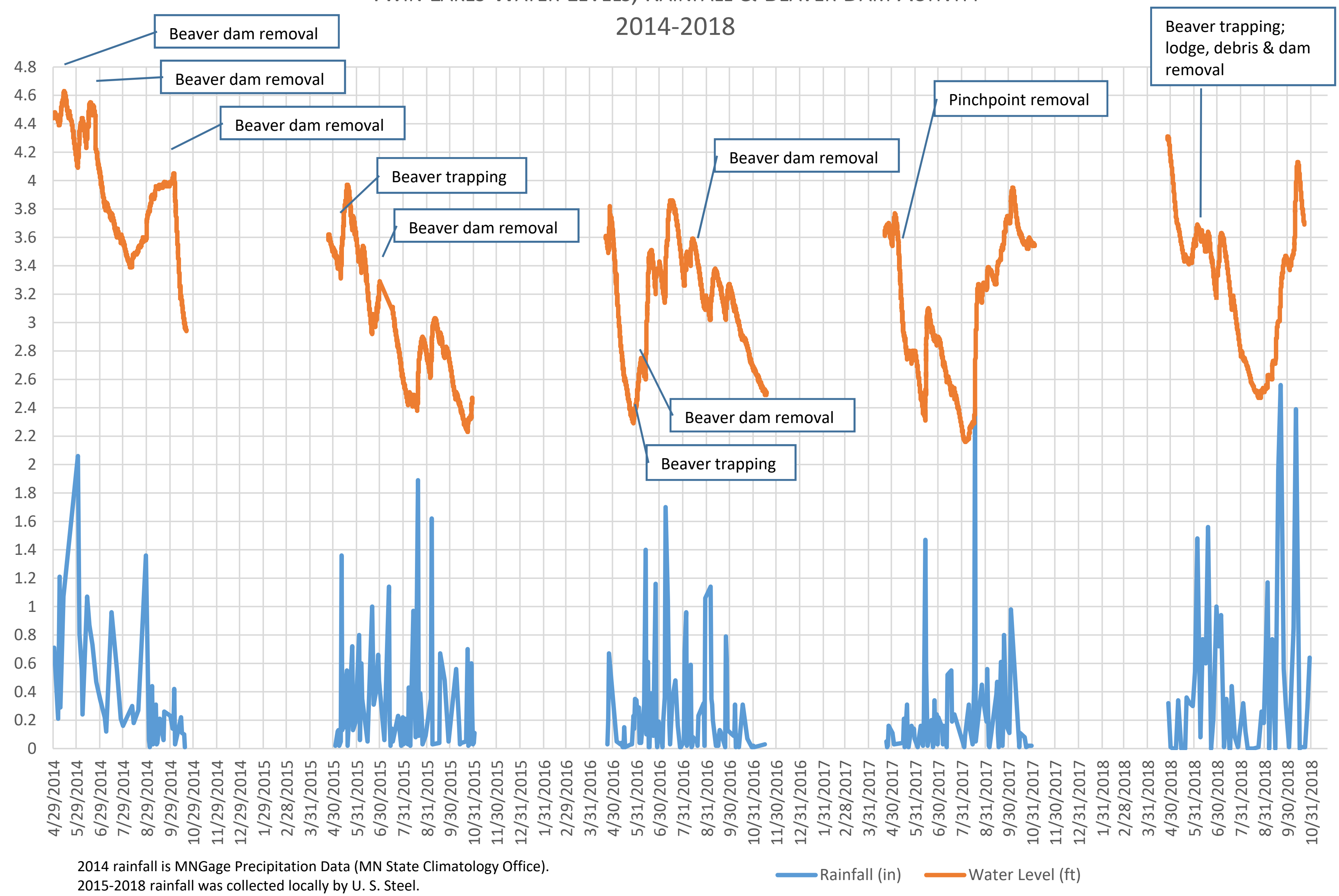
5.0 HYDROLOGY

5.1 TWIN LAKES WATER LEVELS

Water depth has been identified as one of the primary factors in the annual success, or failure, of wild rice growth. To provide a measure of the natural hydrologic inputs and outputs from the Twin Lakes system, and facilitate implementation of various aspects of the Plan, the depth of water at the steel bridge which connects the old county road between the two lakes has been recorded during the open water monitoring periods of 2014 – 2018. Continuous water level and water temperature measurements were collected via an OTT/Hach pressure transducer (PT). In general, the PT was deployed as soon as possible following ice-out during each of the Plan years and removed from service in mid- to late-October or early November prior to freeze-up. Typically, data from the PT was downloaded once each month during routine Plan sampling/monitoring events and calibrated against a manual water level/stream gauge mounted on the adjacent concrete bridge abutment. Daily precipitation totals were collected at a manual rain gauge located adjacent to the U. S. Steel Minntac Tailings Basin Return Pumphouse, approximately two miles south, southwest of the steel bridge and PT location. The results of 2014-2018 monitoring for rainfall and water depth are presented in Figure 37. For comparison purposes, gridded precipitation data was collected in 2018 from the High Spatial Density Precipitation Network (HIDEN) administered by Minnesota Department of Natural Resources (MNDNR) State Climatology Office. The rainfall data comparison for 2018 is presented in Figure 38. The majority of the data appears to align. However, one fairly large precipitation event in September was captured at the Minntac rain gauge that was not seen in the HIDEN data. This discrepancy demonstrates the potential for localized rain events that may affect the Twin Lakes water levels, but may not be captured by nearby weather stations.

The data in Figure 37 indicate that the Twin Lakes water depth is greatly influenced by rainfall, and the inability of inflows to efficiently move out of the Twin Lakes system. Water level data for each of the five Plan years is presented in Figure 39. There is ample documentation that water depth for optimum wild rice growth is in the range of 1.0 – 3.0 feet.

Figure 37
Twin Lakes Water Levels, Rainfall & Beaver Dam Activity
2014-2018



2014 rainfall is MNGage Precipitation Data (MN State Climatology Office).
2015-2018 rainfall was collected locally by U. S. Steel.

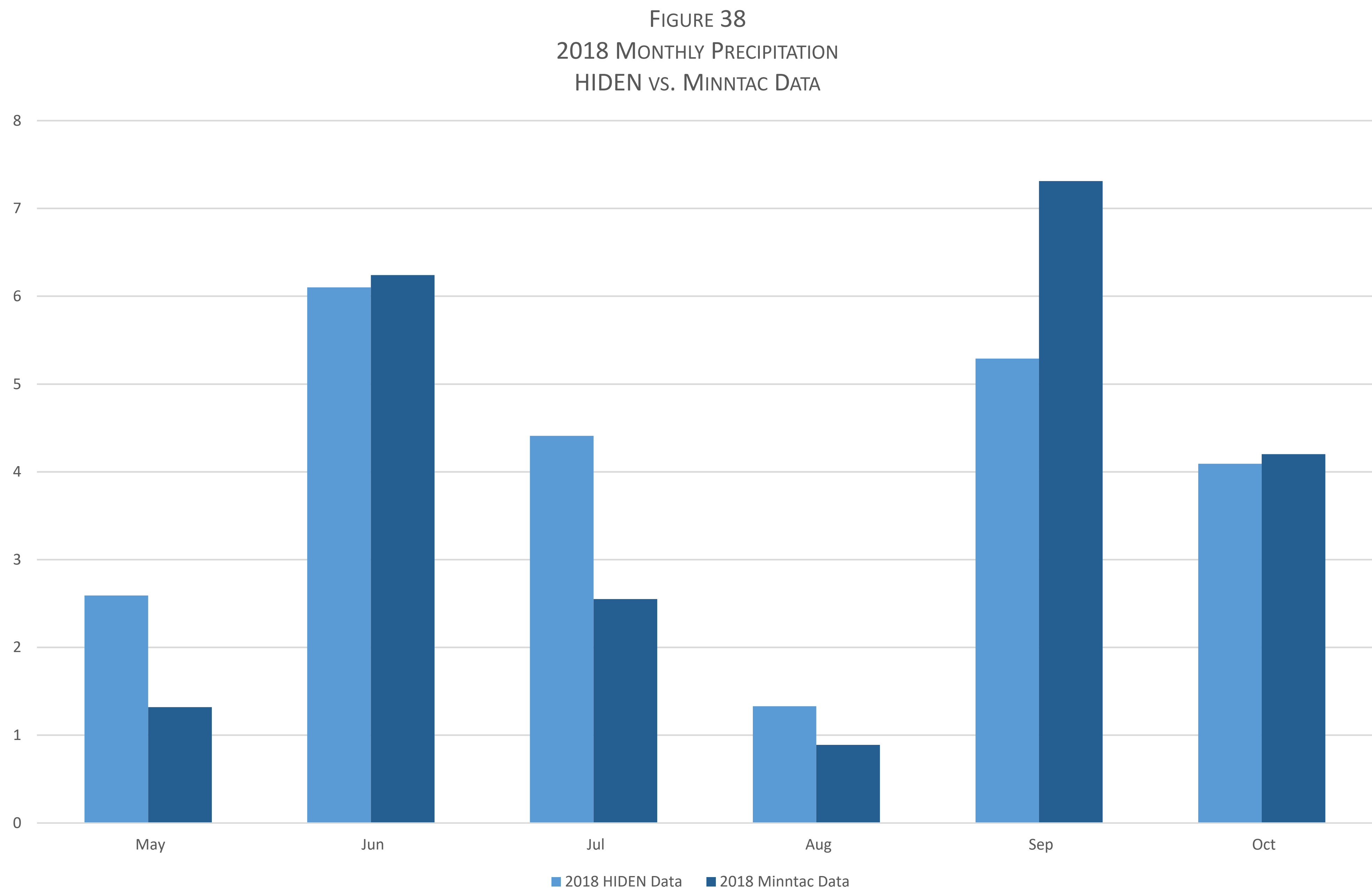
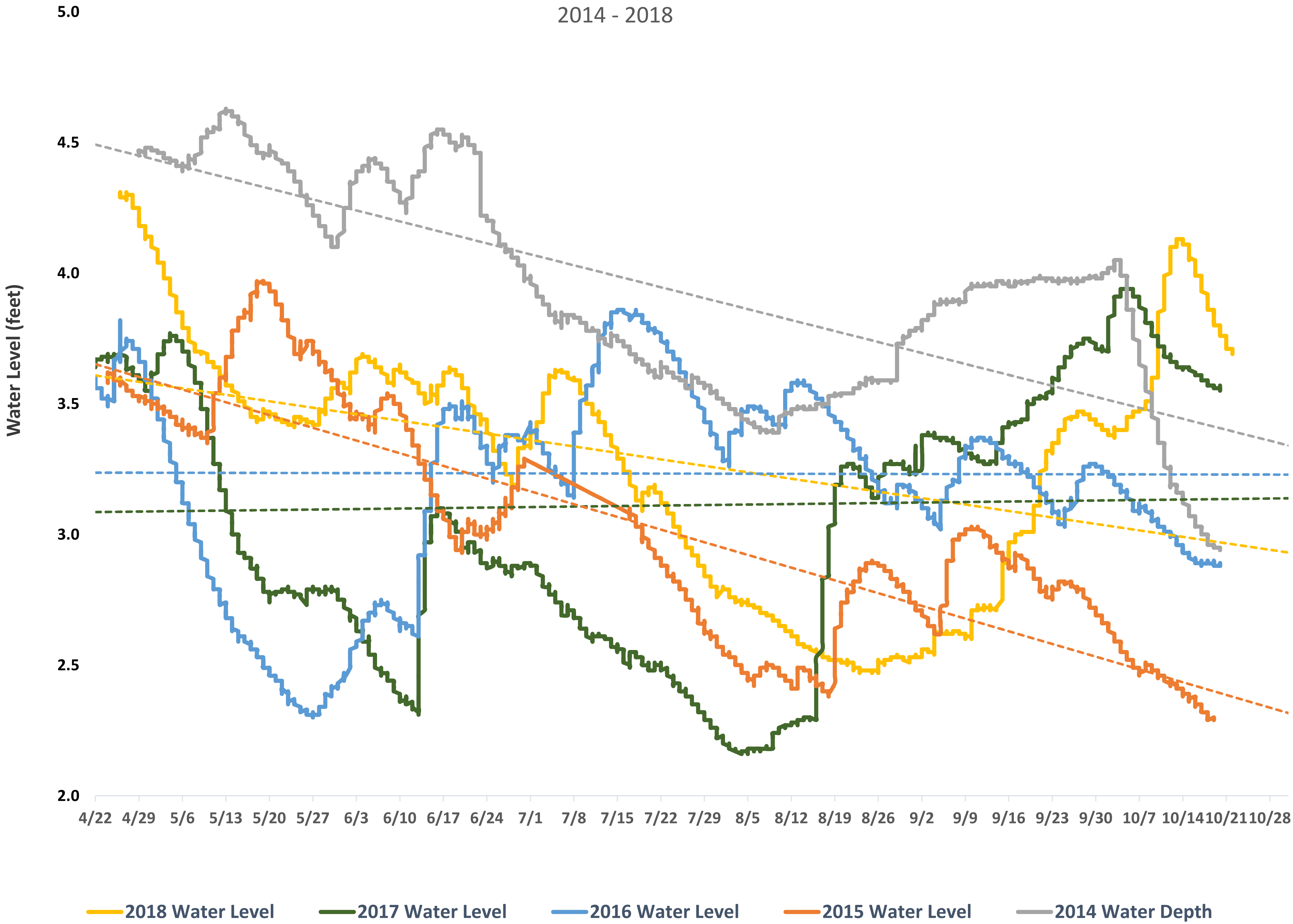


Figure 38
2018 Monthly Precipitation
HIDEN vs. Minntac Data
8
7
6
5
4
3
2
1
0
May
Jun
Jul
Aug
Sep
Oct
2018 HIDEN Data
2018 Minntac Data

Figure 39
Twin Lakes Yearly Water Levels
2014 - 2018



Based on estimated bathymetry of Little Sandy and Sandy lakes, the depth of water measured by the PT at the steel bridge should be no more than 0.5 feet, which would correspond with the maximum optimum depth for wild rice growth (~2.5 – 3.0 feet) across the majority of both lakes. As can be seen in Figure 3, at no time during the entire five-year Plan did the depth at the steel bridge decrease to optimum (~ 0.5 feet) for successful wild rice growth and development throughout this system. With the exception of a few short instances during abnormally dry periods, the depth of water at the steel bridge was consistently above 2.5 feet, which corresponds to water depths exceeding 4.5 – 5.0 feet within each lake. More importantly, measured water depth at the steel bridge within the critical April – May early seedling life-stage timeframe typically exceeds 3.0 – 3.5 feet, which corresponds to water depths of approximately 5.0 – 5.5 feet within each lake. These depths exceed the upper-end of optimal by over 2.0 feet.

5.2 GROUNDWATER FLOW MODEL

U. S. Steel investigated the hydrology of the Twin Lakes via two separate modeling exercises to evaluate the influences that various factors may have on the relatively high overall water levels observed during execution of the Plan. The first modeling exercise was completed by GHD (formerly CRA) and built upon a 2013 groundwater flow model developed for the Sand River Watershed (GHD 2013). The model results showed that a significant portion of water seeping from the east side of the tailings basin is collected by the seep collection and return system, while the remainder migrates further downgradient through the subsurface in groundwater and discharges to surface water, primarily along the northeastern corner of the tailings basin. The Twin Lakes receive water from subsurface groundwater discharge and inflow from surface water courses. Surface water inflow is the primary contributor to the Twin Lakes, while groundwater discharge is a relatively small contributor.

This modeling exercise confirmed that most of the water inputs to the Twin Lakes from the tailings basin are via surface water inputs, with relatively minor inputs from groundwater. It also confirmed a flow path to the Twin Lakes at the northeast corner of the tailings basin.

5.3 HYDROLOGIC FLOOD-ROUTING MODEL

The second modeling exercise evaluated the overall impact of the tailings basin on precipitation runoff and its effect on Twin Lakes water levels. A flood routing model was developed by Barr Engineering (Barr 2019) to evaluate relative differences in Twin Lakes water levels under a number of different scenarios, including:

1. Current Conditions
2. Pre-mining (i.e., pre-tailings basin) Conditions
3. Current Conditions with Beaver Dams
4. Current Conditions with Sand River Shortened

The Current Conditions model evaluated the effects of a 100-year, 24-hour rainfall event and the resulting precipitation runoff from the Upper Sand River Watershed through the Twin Lakes under the current condition of the Minntac tailings basin in place. The Pre-mining Conditions model evaluated the same rainfall event but with changes made to the upstream end of the model to represent the area as it was prior to construction of the tailings basin. The Current Conditions with Beaver Dams model was developed by adding weirs to the model to simulate beaver dams in two locations on the Sand River downstream of Sandy Lake, equivalent to the locations of chronic pinchpoints discussed in Section 6.0 below. The Current Conditions with Sand River Shortened model was developed to evaluate whether the Sand River channel was restricting outflow from the Twin Lakes. It should be noted that groundwater seepage from the Minntac tailings basin at a rate of 1000 gpm was added to the Current Conditions model and removed from the Pre-mining Conditions model to simulate tailings basin seepage inputs to Little Sandy Lake in addition to the design storm runoff volume.

Water levels for Little Sandy and Sandy lakes from the Current Conditions, Pre-mining Conditions, and Current Conditions with Beaver Dams models are shown on Figures 40 and 41 below. As shown on these figures, the Pre-mining Conditions lake level peak is higher than the Current Conditions lake level peak.

Additionally, the water levels take slightly longer to draw down after the storm event in the Pre-mining Conditions model when compared to the Current Conditions. Current Conditions with Beaver Dams shows that the lake level response to the rainfall event is similar, but the water level in the lake does not draw down as low due to the dams holding back water upstream in the Sand River and Little Sandy and Sandy lakes. Water levels for Little Sandy and Sandy lakes from the Current Conditions and Current Conditions with Shortened Sand River models are shown on Figures 42 and 43. These figures show that the model predicts essentially no differences in water level responses in Little Sandy and Sandy lakes as a result of the storm event when changing the length of the Sand River below Twin Lakes. This indicates that the unobstructed river is capable of conveying water out of the Twin Lakes and allowing water levels to recede.

These model results show that overall the Twin Lakes are receiving less water now than under pre-mining conditions. The model also indicates that if the Sand River is clear of obstructions and maintained as an open channel, water will move out of the system more efficiently and the water level in the Twin Lakes has the potential to drop to lower levels than what is currently observed.

FIGURE 40
LITTLE SANDY LAKE HYDROLOGIC MODELING RESULTS

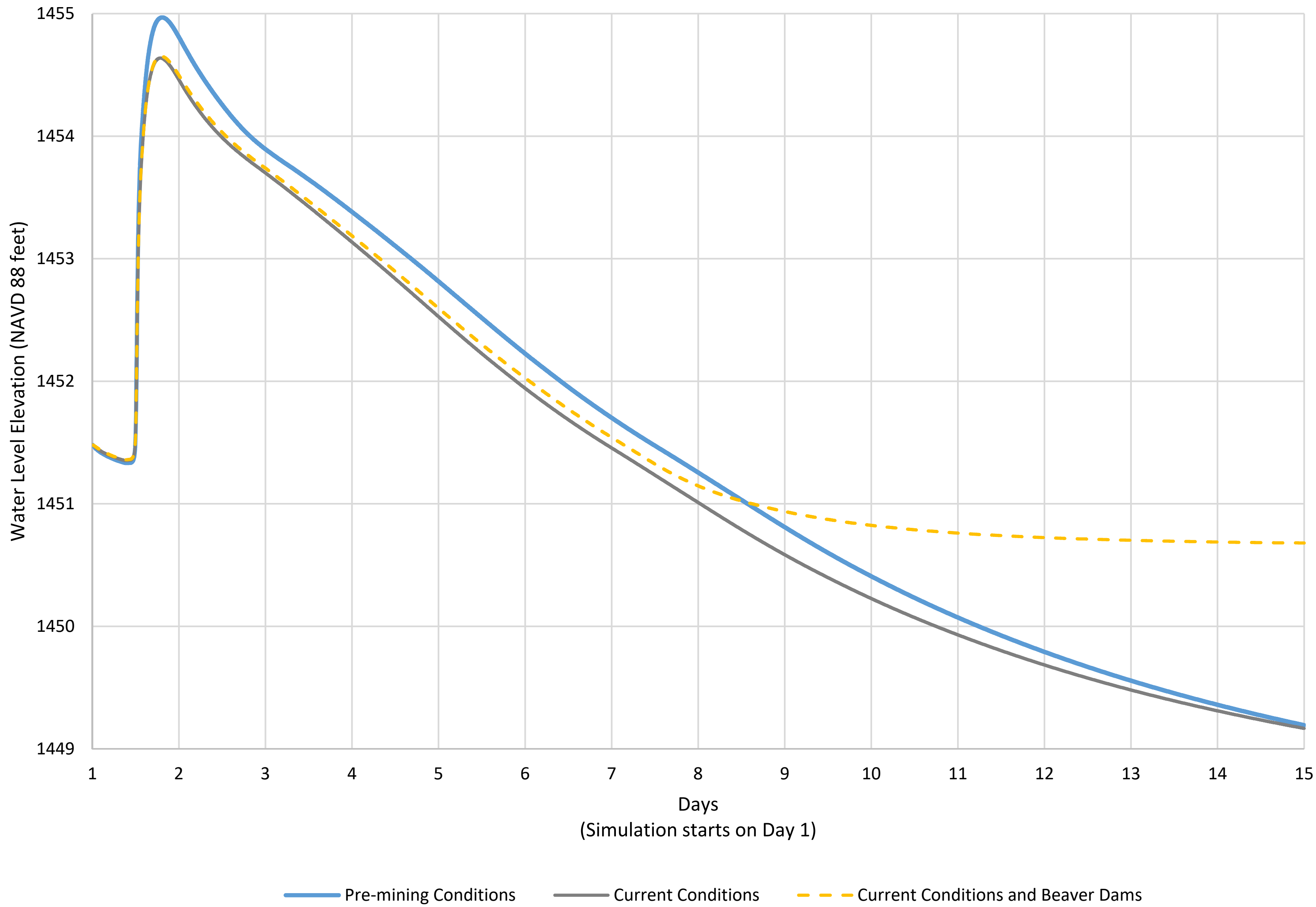


Figure 41
Sandy Lake Hydrologic Modeling Results

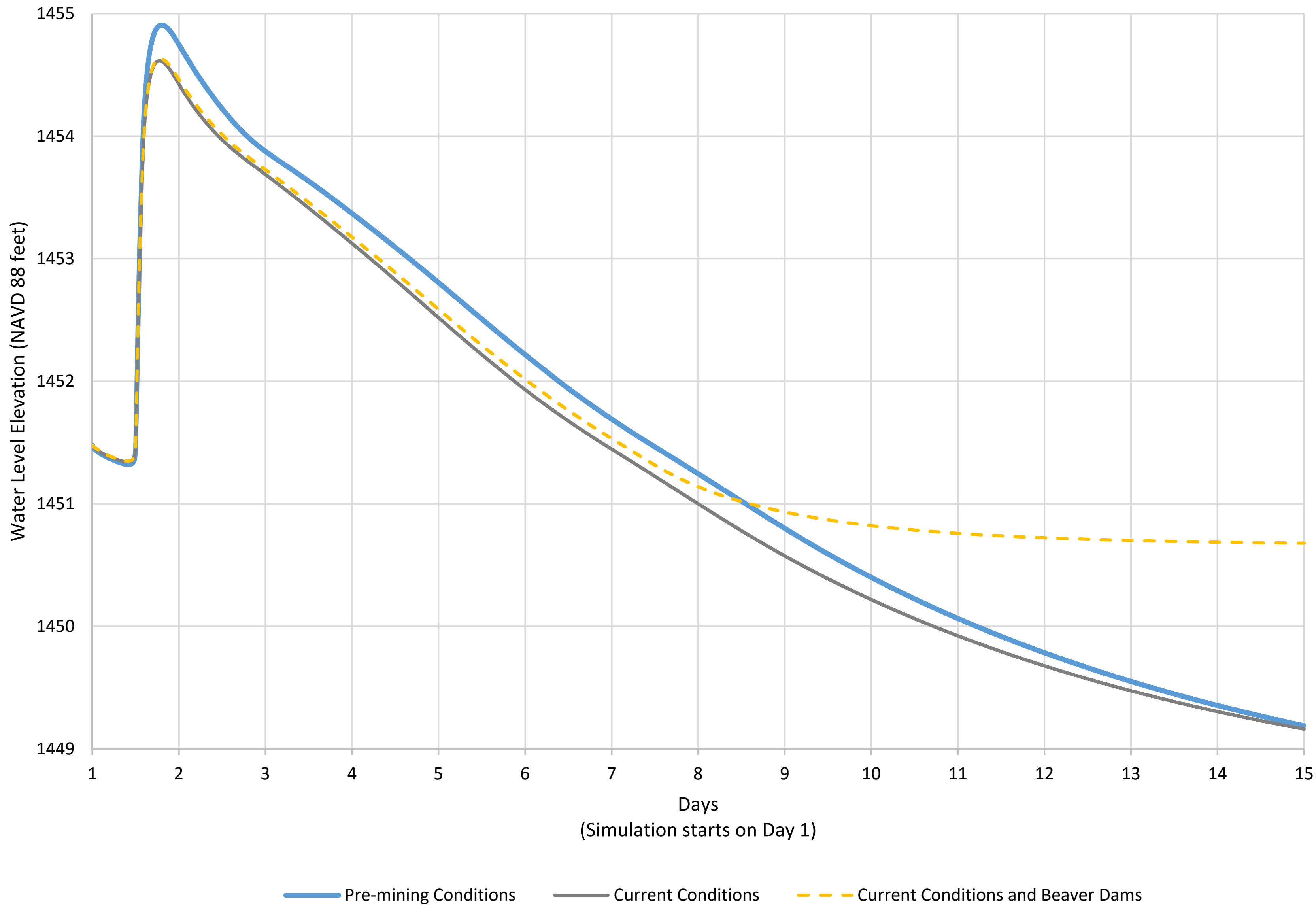


FIGURE 42
LITTLE SANDY LAKE SHORTENED SAND RIVER
MODELING RESULTS

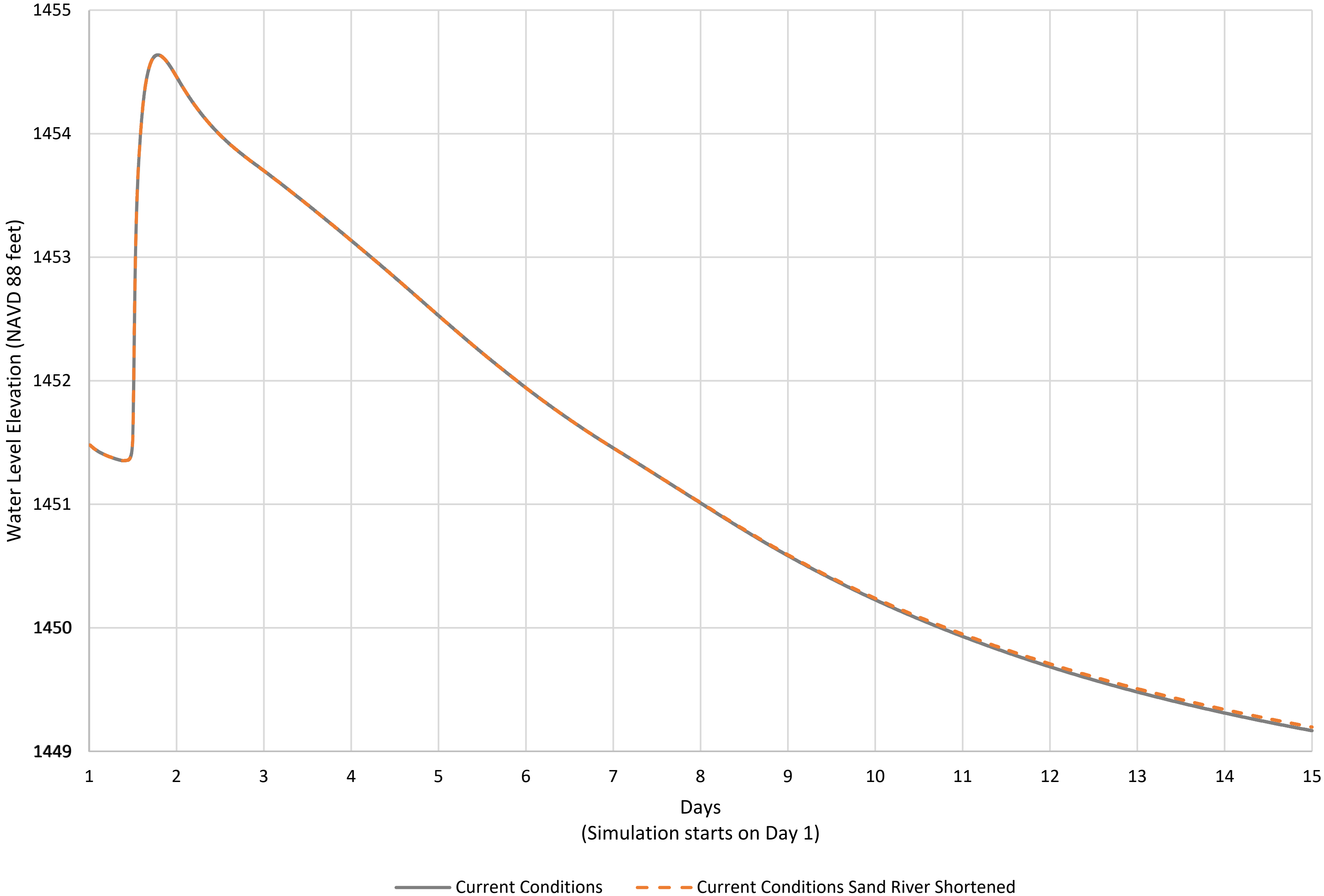
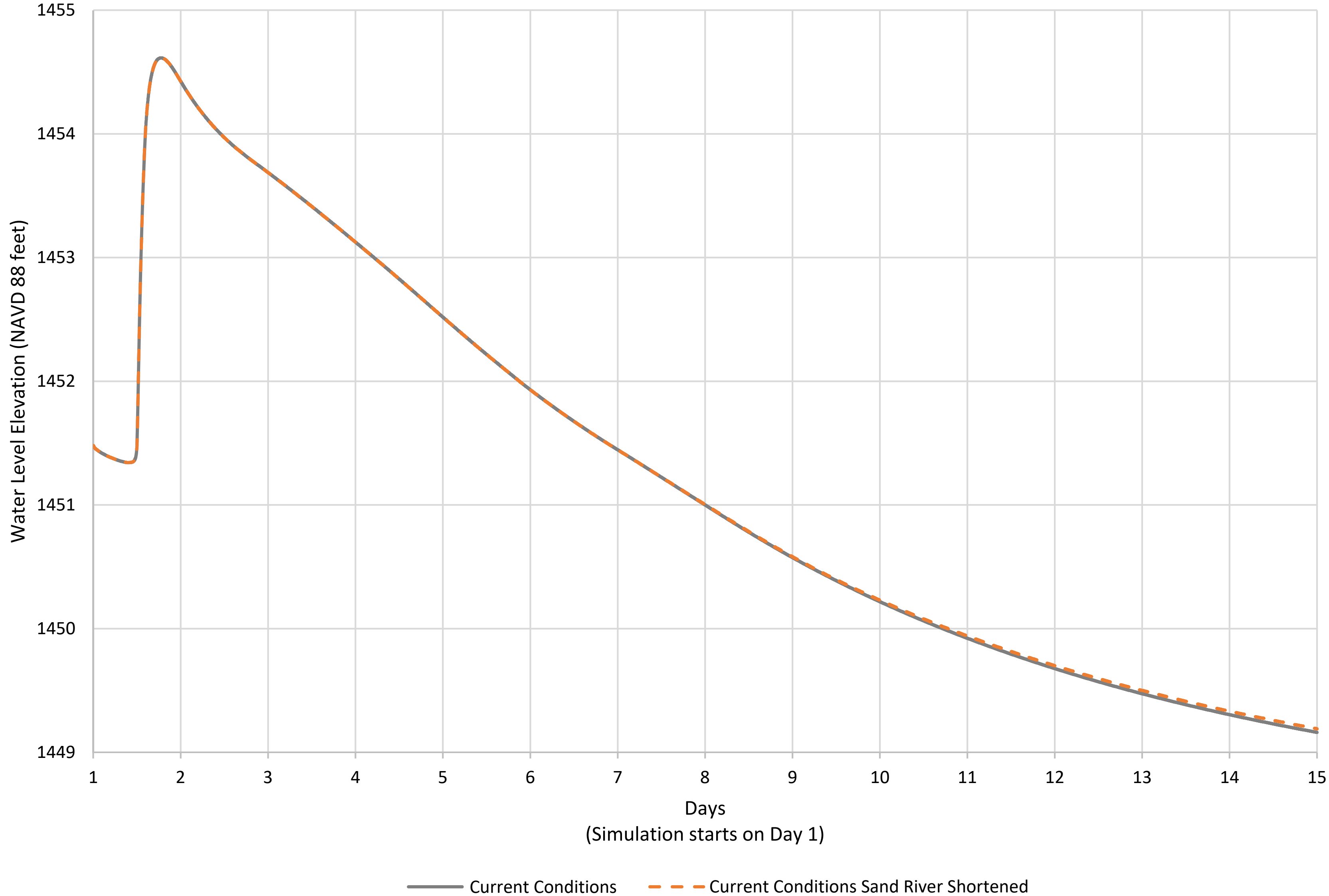


FIGURE 43
SANDY LAKE SHORTENED SAND RIVER
MODELING RESULTS



6.0 BEAVER AND ANIMAL EFFECTS

Due to the critical nature of water depth for wild rice success, beaver trapping and dam removal from the Sand River downstream of the Twin Lakes was pursued each year of Plan execution. During 2014, a private animal control contractor was hired to, in general, "remove beaver from the Twin Lakes area, including the Sand River from the outlet of Twin Lakes to U.S. Hwy 53". The contractor was also charged with removing any observed beaver dams influencing flows into and out of the Twin Lakes. An unspecified number of animals were removed from the system and dams located in the Sand River downstream of the Twin Lakes outlet were pulled by hand on three separate occasions. However, in each case, beavers returned and, at least partially, rebuilt the dams.

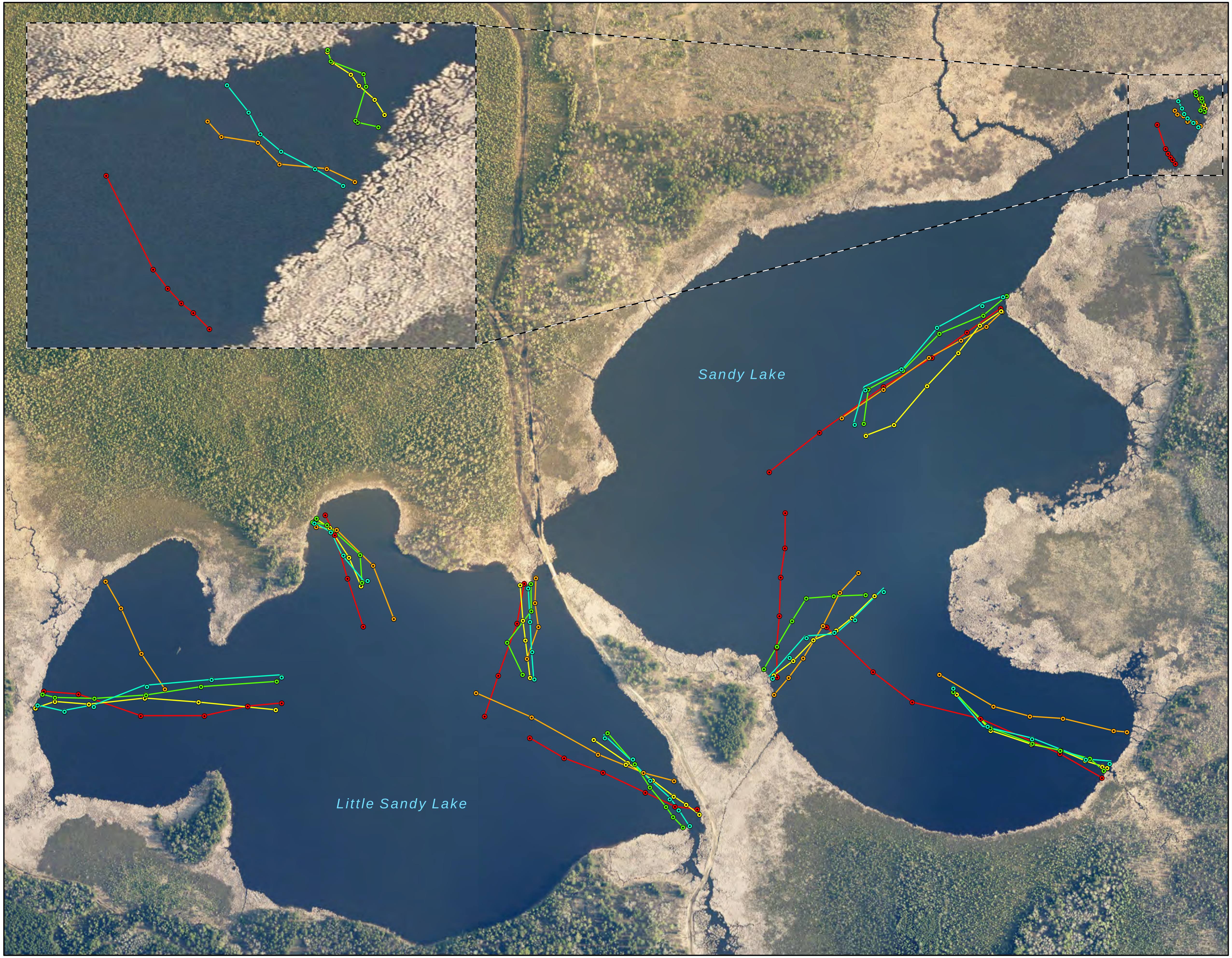
Beginning with the 2015 Plan year, and continuing through the final year of study, U. S. Steel contracted with the United States Department of Agriculture (USDA) Animal and Plant Health Inspection Service (APHIS) to conduct an intensive beaver and dam removal program. The removal activities of APHIS crew was much more effective than that realized during 2014. In 2015, a total of approximately 60 beavers were reported to have been removed from Admiral Lake, from near the head of the Sand River system down to County Road 303 (Rice River Road). The APHIS crew also noted the presence of a large number of beaver damps along the Sand River downstream of Sandy Lake, with on large dam downstream of U.S. Hwy 53 holding back 4 – 5 feet of water. In total, the APHIS crew removed 36 dams in early 2015, 29 by hand and 7 by blasting. Reports from the APHIS crew in late July 2015 indicated that there were no fresh beaver signs. A separate survey of the Sand River downstream of the Twin Lakes was completed by U. S. Steel and NTS personnel on June 21, 2015 to evaluate the presence of beaver dams and pinch points. The majority of observed channel obstructions were responsible for only small increases in water level immediately upstream. However, in aggregate, the old beaver dams and associated channel debris are causing water levels to be held up in the system, especially after significant rainfall events, as evidenced by pressure transducer data from the steel bridge.

The APHIS crew returned each of the following Plan years to ensure that any beaver that had returned, and any newly build dams, were removed. In spite of these continual animal control and beaver dam removal efforts, Twin Lakes water depths could not be controlled to the levels most conducive for optimum wild rice growth.

7.0 AQUATIC PLANT OBSERVATIONS

Between 2014 and 2018, aquatic plant surveys were completed in roughly the same locations each year (see Figure 44). Throughout the Plan, each transect in the Twin Lakes showed an increasing trend in number of aquatic taxa, with the exception of Sandy Lake Transect 4 and Little Sandy Lake Transect 4, each of which showed slightly decreasing trends (see Figure 45). Average percent rake coverage at each transect in Twin Lakes also showed an increasing trend between 2014 and 2018 (see Figure 46).

By comparison, transects in Sandy Lake showed more aquatic plant varieties than transects in Little Sandy Lake. Total aquatic plant types per transect in Sandy Lake ranged from 10 to 14, while the types



Legend

- 2018 Vegetation Survey Points
- 2017 Vegetation Survey Points
- 2016 Vegetation Survey Points
- 2015 Vegetation Survey Points
- 2014 Vegetation Survey Points
- 2018 Vegetation Survey Transects
- 2017 Vegetation Survey Transects
- 2016 Vegetation Survey Transects
- 2015 Vegetation Survey Transects
- 2014 Vegetation Survey Transects

Figure 44
Twin Lakes
Aquatic Plant Survey
Transect Locations
(2014-2018)

Twin Lakes Survey
US Steel Corporation-
Minnesota Ore Operations
Mt. Iron, Minnesota (St. Louis County)

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Drawn By : T. Muck
NTS Project #: 10170E

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Figure 45
Aquatic Plant Taxa Trends in Twin Lakes

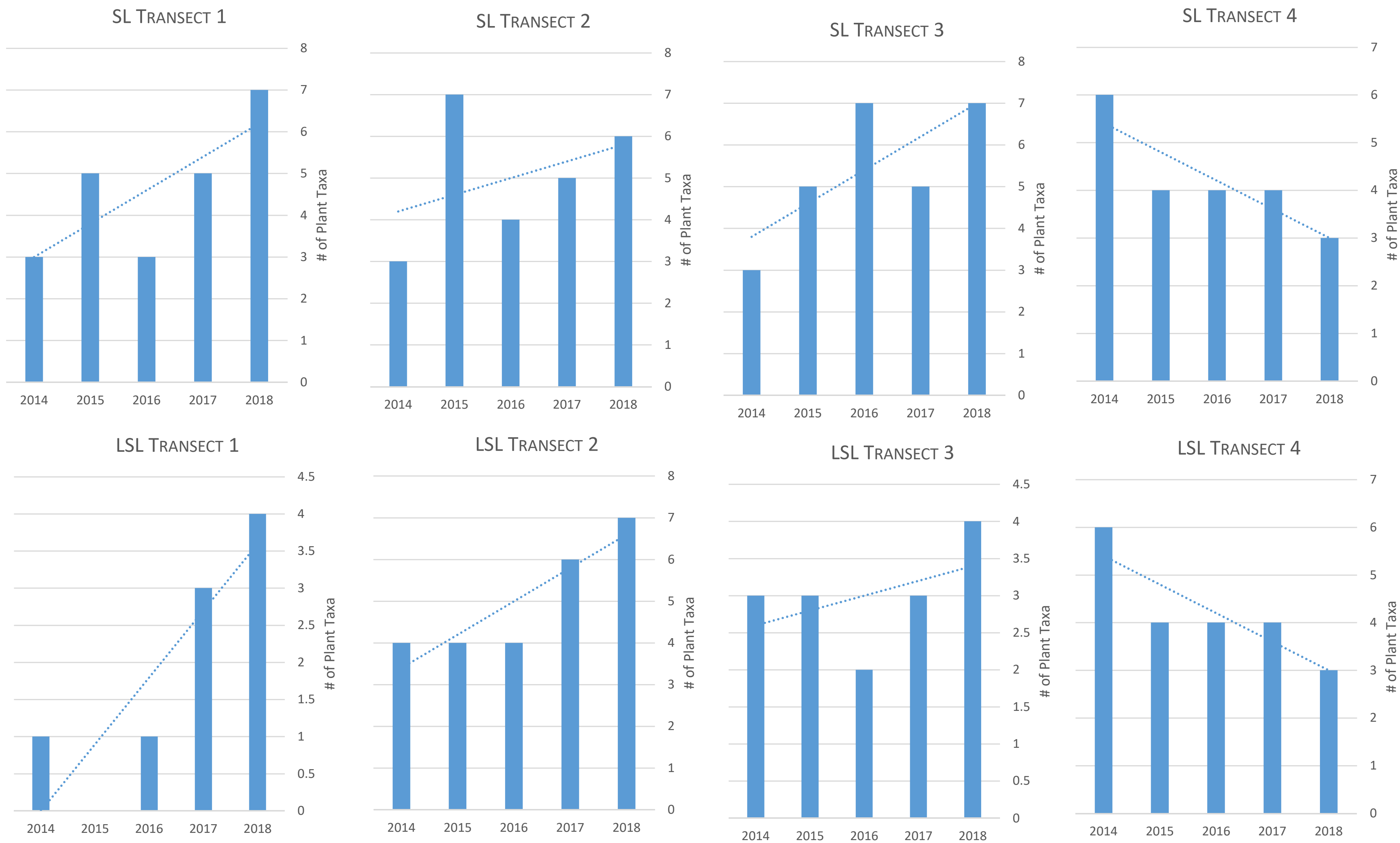
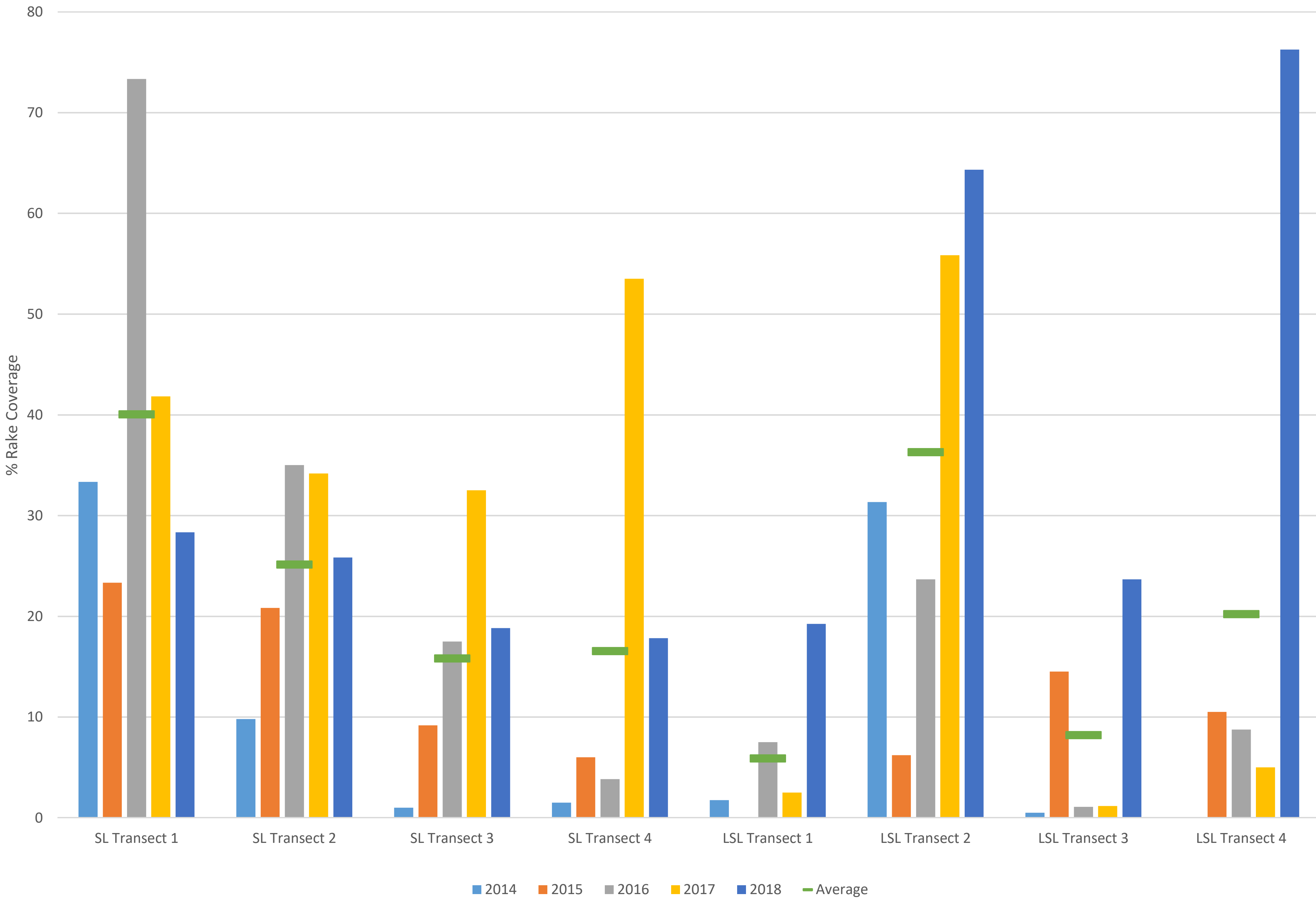


Figure 46
Aquatic Plant Survey
% Rake Coverage in Twin Lakes (2014-2018)



in Little Sandy Lake ranged between 5 and 7 per transect. Although there were more aquatic plant taxa in Sandy Lake than in Little Sandy Lake, it should be noted that Little Sandy Lake showed more consistent plant growth in each transect over the five-year Plan, with Northern Watermilfoil most commonly found in every transect. It was also noted that average percent rake coverage collected from transects in Sandy Lake was slightly greater than those collected in Little Sandy. Average percent rake coverage in Sandy Lake ranged from 15.8 to 40% per transect over the course of the five-year Plan, while average percent rake coverage ranged between 5.8 and 36.3%.

The types of aquatic vegetation found in each lake were similar. The majority in both lakes consisted of Northern Watermilfoil and Northern Bladderwort. Chara was also prominent in Sandy Lake, but not so much in Little Sandy Lake.

Cattails were present around the entire perimeter of each lake during each year of the Plan. In comments responding to the 2018 Sandy Lake and Little Sandy Lake Monitoring Report prepared by 1854 Treaty Authority, Mike Madden, local property owner near the Twin Lakes, noted that in the 1970's, no cattails existed in either lake (see Appendix F). The areas where cattails now grow were spruce bog, or cranberry bog as it was known by the locals. The cattails became more prevalent at approximately the same time wild rice began to decline, which is also when the Twin Lakes water levels started to rise. Mr. Madden also noted in his comments that even the creek to Admiral Lake (Sand River) was completely open in the 1970's and passable by small boat. Currently the Sand River upstream of Little Sandy Lake is choked with cattails and other aquatic vegetation and is essentially impassable. It is possible that allelopathy and competition with other aquatic plants may have been another factor in the decline of wild rice plants in the Twin Lakes.

8.0 WILD RICE SEEDING

Following successfully decreasing water depths during 2015, a decision was made to pursue limited "pilot-scale" wild rice seeding efforts in six locations in the Twin Lakes system. A conference call was held on August 21, 2015, to ensure that interested stakeholders were provided an opportunity to participate in the planning process for the proposed seeding. Representatives of the regional Native American communities (Bois Forte, Fond du Lac and the 1854 Treaty Authority), as well as the USACE, participated in the call and provided valuable input and advice. The primary topics of discussion during the conference call are provided below, along with details associated with each of the topics encountered throughout the process.

8.1 SOURCE AND AMOUNT OF WILD RICE FOR SEEDING

Abundant stands of wild rice had been observed in the Sand River downstream of Sandy Lake, between Rice River Road (County Road 303) and MN Hwy 169, during the preceding several years. Therefore, it was proposed that wild rice harvested during 2015 from that section of the Sand River be used as the seed source for any 2015 seeding activities. The primary reason for using Sand River seed was that it is likely most genetically similar to wild rice historically present in the Twin Lakes. There was general consensus among the conference call participants that this was an appropriate seed source. Darren Vogt, 1854 Treaty Authority, recommended that wild rice seed be distributed at a rate of 50 – 100 lbs. per acre.

In an effort to obtain wild rice seed, notices were placed in two locations along the Sand River on or about August 22, 2015, in areas that would be conspicuous to ricers, advertising the desire to obtain recently harvested wild rice. An advertisement was also placed on the 1854 Treaty Authority Wild Rice Web page. One call was received from a ricer on the Sand River. However, the ricer ultimately decided to keep the rice for personal use. Since no sources of Sand River wild rice were secured by the middle of the second week of September, plans were made to harvest rice from Sand River using project personnel.

8.2 SEED HARVEST AND STORAGE

Two individuals from U. S. Steel obtained the required DNR permits and collected wild rice from stands within the Sand River upstream of MN Hwy 169 on September 14, 2015. The wild rice plant density was fair to good, but the amount of seed remaining on the heads was sparse. Approximately 40 lbs. of raw wild rice was collected and immediately transported to Northeast Technical Services' Soils Lab in Virginia, MN. At that time, the wild rice was weighed, split into six equal amounts of about 2850 grams, and placed into woven poly bags. Each of the six bags of raw rice were then placed into separate five-gallon plastic buckets and filled with water collected from the Sand River at MN Hwy 169 the previous week. The buckets containing the raw wild rice and Sand River water were sealed and placed into a climate-controlled room where the air temperature was held at 56^{o}F for the duration of storage.

8.3 PERMITTING REQUIREMENTS

During the August 21, 2015, conference call, it was mentioned that seeding activities could not proceed without a permit from the DNR. U. S. Steel worked with the DNR and U.S. Forest Service to obtain the required permits. It should be noted that U. S. Steel could not get a permit for restoration of aquatic vegetation directly. Rather, as per DNR policy, only the landowner can be permitted for this type of activity. The majority of the Twin Lakes shoreline is owned by the federal government as part of the Superior National Forest. As such, U. S. Steel worked with U.S. Forest Service personnel from their Laurentian District Aurora, MN, office to secure the required permits.

DNR also specified that approval be sought from all minority riparian landowners on the Twin Lakes prior to proceeding with any seeding effort. A search of the St. Louis County tax records revealed that, besides the federally-owned land surrounding the majority of the two lakes, there were two privately-held parcels abutting the Twin Lakes, both on Sandy Lake. Letters were subsequently sent to each of the two minority riparian landowners seeking approval for the pilot-scale wild rice seeding effort. No response was received from one of the landowners, while the second expressed opposition to the proposed seeding because of the potential for damage to the resident fishery from decreased water depth(s). However, DNR allowed the permit to stay in effect since Sandy and Little Sandy lakes are primarily managed for waterfowl.

8.4 SPIRITUAL CEREMONY

Arrangements for a spiritual ceremony to be conducted as part of the seeding activities were made with members of the Bois Forte Band of Chippewa. Through the efforts of Bill Latady and Linda Tibbets-Barto, the spiritual ceremony was scheduled for, and held on, the morning of October 23, 2015, on a hill overlooking the canoe landing on the north side of Sandy Lake. Vernon Adams conducted the ceremony in the presence of representatives from Bois Forte, the 1854 Treaty Authority, U.S. Army Corps of Engineers, U. S. Steel, Northeast Technical Services, and members of the public.

8.5 WILD RICE SEEDING PROCEDURES AND RESULTS

Following the spiritual ceremony, pilot-scale seeding activities were initiated. Three separate areas in each of the Twin Lakes were identified for seeding based on previous known wild rice areas, and appropriate existing water depths and sediment type (i.e., organic substrate). A couple of the seeding plots were subsequently moved from the original plan based on input from area residents familiar with the lakes.

8.6 2016 WILD RICE SEEDED AREA OBSERVATIONS

Four of the six seeded plots produced variable amounts of emergent wild rice, with two of the six demonstrating fairly good growth (see **Appendix** G for photos of the wild rice seed plots and **Appendix** H for estimates of wild rice densities). The seeding efforts in the two plots on the north side of Little Sandy Lake resulted in no observed or very sparse growth. Interestingly, the seeding effort in the plot on the south side of Little Sandy Lake, close to the Inflow 1 location, resulted in fairly strong wild rice growth. In general, there is more aquatic vegetation competing with wild rice in Sandy Lake than in Little Sandy Lake, and there are areas of Little Sandy Lake in which more competing aquatic vegetation occurs than in other areas, possibly due to characteristics of the lakebed. There is historical documentation indicating areas of the Twin Lakes consistently produced good stands of wild rice, while other areas of the Twin Lakes produced poorly or not at all. Therefore, it is possible, if not probable, that portions of the Twin Lakes are not suitable for, and will not support, wild rice growth due to site specific conditions unrelated to water quality or water depth.

During the 2016 field season, wild rice test seeding plots were inspected for growth of wild rice plants. Floating leaf stage wild rice plants were observed during July 2016 and were confirmed during August 2016. Wild rice plants in at least the floating leaf stage were observed in all three seeded plots in Sandy Lake. Mature, aerial, seed-producing wild rice plants were observed in the Sandy Lake East (SLE) and Sandy Lake Southwest (SLSW) locations with ≥ 200 plants per plot area. Wild rice plants in the floating leaf stage were observed in the Sandy Lake Northwest location but with a density of only about 30 – 40 plants in the entire plot. Wild rice plants in the SLE and SLSW locations produced a sufficient number of seeds to have the capability of limited 'self-seeding' in those areas. Also within Sandy Lake during 2016, the presence of wild rice plants was observed near the Sandy Lake Inflow South location. These plants were not a result of the 2015 wild rice seeding effort, and were classified as natural wild rice growth. These plants were also mature, seed producing plants capable of limited self-seeding in that area. It was estimated that a total of 15 – 20 natural wild rice plants emerged into aerial phase near the mouth of the Sandy Lake Inflow South tributary.

Three plots were also seeded with wild rice in Little Sandy Lake. The test plot near Inflow 1 contained ≥ 100 mature, seed producing wild rice plants. Similar to seed producing plants in two plots in Sandy Lake, seed producing plants in Little Sandy Lake had the capability for limited self-seeding in that plot. Sparse floating leaf wild rice plants were observed in the Little Sandy Northeast test seeding plot, with 7 – 10 plants observed in the entire area. No wild rice plants were observed in the Little Sandy Lake test seeding plot near Inflow 3 (i.e., Little Sandy Lake Northwest).

Regardless of the lake in which they were observed, mature seed-producing wild rice plants appeared healthy. No indications of nutrient deficiencies such as chlorosis, or leaf discoloration associated with potential nitrogen or phosphorus deficiencies, were observed; and no evidence of diseased plants was observed (i.e., fungal brown spot disease).

Minnesota DNR surveys from 1966 indicate that only isolated areas of Little Sandy Lake contained areas of wild rice growth. Sandy Lake is documented to have had wild rice throughout the entire lake, with some areas of denser wild rice growth than others. One criterion of these lakes that has measurably changed since the 1966 survey is water depth throughout the entirety of each lake. A review of the 1966 survey results suggests that water depth throughout the Twin Lakes system did not extend past three feet. Over the course of the Twin Lakes Wild Rice Restoration Opportunities Plan study, water depths within each lake routinely exceeded four feet, and surpass five feet in the most central areas in each lake. During the time period from the 1966 survey and current, wild rice density has decreased to the point of very sparse 'natural' growth to complete absence from both lakes in some years. It is possible that as water depths throughout the Twin Lakes system increased, the ability of wild rice to compete for light during the seedling phenological stage has been adversely influenced resulting in a near complete lack of germination potential. However, given the success of the 2015 seeding studies, other areas of the twin Lakes with similar depth and sediment characteristics should be able to support wild rice growth given a viable seed source/seed bank. Another possibility is that although wild rice seeds historically may have germinated, increasing water depths in early spring could have resulted in decreased success of adult plant development and depletion of the viable wild rice seed bank throughout the Twin Lakes system. Overall, current physical conditions, such as increased water depth and fluctuations, and the presence of competing perennial aquatic vegetation may be preventing significant wild rice growth and development throughout the majority of the Twin Lakes system.

8.7 2017 Wild Rice Seeded Area Observations

All of the areas seeded during October 2015 were revisited during July and August of 2017 to observe follow-on wild rice growth. This follow-on wild rice growth could have resulted from seeds that remained dormant throughout 2016 or from seeds that originated from seed-producing plants observed in 2016. During the 2017 field season, wild rice growth was observed in all previously seeded areas, including the plot near Inflow 3. Wild rice growth/regrowth at the SLE plot was much less than the fairly strong growth observed in 2016, while the growth at the SLSW and SLN plots were relatively unchanged (moderate and sparse, respectively). The LSLS plot once again showed strong wild rice growth, similar to what was observed in 2016, with an observation of approximately 50 seed-producing plants present. One surprising observation was that while the Little Sandy Lake Northeast plot showed little growth in 2016, a large number of plants were observed in 2017, with a visual estimate of approximately 60 seed-producing plants. This wild rice growth likely resulted from seeds that remained dormant throughout 2016. These observations of wild rice growth in areas seeded during 2015 suggest that wild rice seeds can remain viable for multiple years in Little Sandy Lake sediment. Furthermore, due to the observed herbivory of reproductively viable plants during 2016, self-seeding as a source of the growth observed during 2017 in seeded areas is less likely than seeds broadcast during 2015 remaining viable for growth during 2017. Regardless of the source of seed for wild rice plants observed during 2017, in the absence of reproductively viable and successful plants, and self-seeding that exceeds the number of reproductively successful plants, a self-sustaining population of wild rice in these lakes will not develop.

Observations of wild rice plants achieving reproductive maturity in seeded areas suggests that a viable source of wild rice seed no longer exists in the sediment throughout the majority of this system.

9.0 CONCLUSIONS

9.1 SURFACE WATER QUALITY

- Concentrations of certain water quality constituents (e.g., hardness, sulfate, alkalinity and chloride) are elevated with respect to background levels.
- Mining-influenced inputs to the Twin Lakes are primarily in two locations: the Sand River at the inlet to Little Sandy Lake (Inflow 1) and the wetland channel at Inflow 2.
- Implementation of a seep collection and return system on the east side of the Minntac tailings basin resulted in a significant reduction in constituent loading to the Twin Lakes.
- In general, there were no significant differences in surface water quality between areas that supported wild rice growth and other areas of the lakes.

9.2 SEDIMENT QUALITY

- The majority of the sediment within the Twin Lakes is characteristic of that preferred by wild rice (i.e., organic-rich), and contains no identifiable characteristics directly detrimental to wild rice growth, development, or distribution.
- Over the course of two complete growing seasons, mature wild rice plants were observed in all six test seeding plots within the Twin Lakes, demonstrating that the sediment in multiple areas of the Twin Lakes is suitable for wild rice growth.
- The pilot seeding trials demonstrated that wild rice seeds are capable of maintaining viability through multiple winters in the sediment of both Sandy Lake and Little Sandy Lake.
- Certain areas of the Twin Lakes, in particular Little Sandy Lake, appear to have natural sediment characteristics that do not support wild rice growth.
- A review of other wild rice restoration projects indicates that sediment from other lakes with even greater mining industry influences than those measured in the Twin Lakes have been used to successfully grow wild rice plants to reproductive maturity.

9.3 SEDIMENT PORE WATER QUALITY

- Twin Lakes surface water quality did not correlate well with sediment pore water quality. The quality of sediment pore water in the majority of the Twin Lakes is relatively low in sulfide and relatively high in iron.
- The sediment pore water in all six Twin Lakes pilot seeding areas did not appear to adversely impact germination or growth. Over the course of two full wild rice growing seasons, all six seeded areas within the Twin Lakes supported growth of wild rice plants to maturity following a single seeding event.
- Sediment pore water at Inflow 2 is relatively high in sulfide and low in iron, suggesting the influence of anoxic conditions on inflow from the adjacent wetland channel.

- More detailed sediment pore water testing in the vicinity of Inflow 2 indicated that it is a localized condition confined to the extreme western portion of Little Sandy Lake.

9.4 Beaver and Animal Effects

- Beaver influences on the Twin Lakes are evident within the Sand River outflow channel downstream of Sandy Lake. Over the course of the Plan dozens of beavers and a large number of beaver dams were removed from the Sand River outflow channel.
- Beaver dams have an adverse effect on water depths within the Twin Lakes, resulting in deeper lake levels during spring melt (the more critical time for wild rice seedlings), and generally greater water depths in the Twin Lakes throughout the year.
- Continued management of beaver populations and removal of beaver dams within the Sand River outflow channel is imperative for maintenance of water depths conducive to wild rice growth and distribution within the Twin Lakes.

9.5 Aquatic Plant Observations

- Dense cattail growths have taken over large areas of the periphery of the Twin Lakes that contains sediment types and water depths preferable to wild rice growth and distribution.
- Dense growths of cattails in particular can cause depletion of sediment nitrogen, resulting in less preferred sediment and pore water conditions for wild rice growth and distribution. Nutrient limitation can also result in wild rice plants sensitized to known diseases such as fungal brown spot disease.
- Cattails and water lilies/lily pads may also have allelopathic influences on wild rice plants; generally excluding wild rice from areas in which cattails or lily pads are dominant.
- Perennial aquatic plants such as Coontail and pondweed, which can survive under ice and snow during winter, were observed throughout the Twin Lakes. These plants directly compete with wild rice seedlings for resources, specifically light, thus resulting in added stress to, if not mortality of, the seedling.
- Proper management, including removal, of perennial aquatic plants from areas with sediment and water depth characteristics preferred by wild rice is critical to successful restoration and maintenance of a self-sustaining wild rice population in the Twin Lakes.
- Observations indicate that rafts of cattail plants can become dislodged from the edge of typical growth areas, float downstream and accumulate in pinch points in the Sand River, contributing to the obstruction of flow out of the Twin Lakes system.

9.6 Hydrology

- Current Twin Lake water levels are significantly higher than what was reported from the mid-1960s and much greater than optimum for successful wild rice growth and propagation.
- The majority of seepage from the Minntac tailings basin enters the Twin Lakes as surface flow, primarily from the Sand River but also via wetland channels emanating from the northeast portion of the perimeter dike.
- Hydraulic modeling indicates that the Twin Lakes receives less overall inflow from precipitation runoff under current conditions than it did prior to tailings basin construction.

- Hydraulic modeling also indicates that the Sand River channel downstream of the Twin Lakes is capable of effectively moving precipitation runoff out of the system, but that dams and channel debris from cattails and decades of beaver activity is restricting outflow.

10.0 TWIN LAKES WILD RICE RESTORATION OPPORTUNITIES

The overall objective of the Twin Lakes Wild Rice Restoration Opportunities Plan was to evaluate the factors that have or are influencing wild rice growth in the Twin Lakes and identify opportunities to restore wild rice to both Little Sandy and Sandy lakes. Multiple adverse influences on wild rice growth and development have been identified, combined mitigation of which could result in an ultimate opportunity for restoration of wild rice to the Twin Lakes system. These influences are: 1) general lack of a viable wild rice seed bank in the sediment of Little Sandy and Sandy lakes; 2) water depth and fluctuations throughout the Twin Lakes system is not conducive to wild rice growth and development; and 3) competing aquatic vegetation has become established in large areas of the Twin Lakes system. A fourth likely adverse influence on wild rice growth and development in the Twin Lakes system are natural site-specific sediment conditions unrelated to surface water or sediment pore water characteristics. It is very likely that portions of the Twin Lakes, in particular Little Sandy Lake, have sediment characteristics that do not and will not support wild rice growth.

One mitigation tactic for the lack of a viable wild rice seed bank in the Twin Lakes system is to initiate an intensive, multi-year wild rice seeding effort focused initially in those areas with appropriate water depth, sediment type, and general lack of competing vegetation. Any areas seeded as a part of this initiative would likely require protection from herbivorous wildlife. During wild rice restoration efforts undertaken in other areas, protective netting has been placed around the seeded areas to prevent access by water fowl. In addition to aerial netting, underwater fencing such as chicken wire has been used to prevent herbivory from wildlife accessing wild rice plants from aquatic pathways. Successful protection of wild rice plants from herbivory in seeded plots is critical to development of wild rice plants into the final reproductive (seed producing) phenological stage. Since wild rice is an annual plant, self-seeding is required for the following year’s growth to ensure a self-sustaining wild rice population. Wild rice seeding efforts have been successfully used in previous studies to restore wild rice to areas from which it had been removed; and currently, wild rice seeding efforts are being used by Native American groups to restore wild rice to lakes under their respective management control.

Maintaining a more optimal water depth with minimal fluctuations throughout the growing season for wild rice growth and development within the Twin Lakes system is equally critical to successful wild rice restoration. Ideally, water depth during the late-spring would not be in excess of 2.0 feet in which wild rice had been seeded, or areas intended for wild rice restoration efforts. This is due to the need for light during the sensitive seedling phenological stage, the more typical limiting resource for wild rice seedlings. Subsequently, water depth in areas of desired wild rice growth and development would be managed to not exceed 2.0 feet during the floating leaf phenological stage; and no more than 3.0 feet following development of wild rice plants into the aerial phenological stage. Ideally, water depth would be managed to not exceed 2.0 – 2.5 feet throughout the wild rice growing season. Typically, the shallower the water depth in wild rice areas, the more successful individual plants will be with respect to growth and development; and overall individual plants will produce more seeds. This is due to more complete development of the primary stem, and the increased likelihood of 'tillering' (production of additional seed-producing stems) by individual plants.

Finally, another primary adverse influence observed in the Twin Lakes and related to the growth and propagation of wild rice is the presence of aquatic vegetation competing for limited resources. Removal of competing aquatic vegetation in areas intended for wild rice restoration would be critical. Some types of aquatic vegetation such as cattails, lily pads, and Coontail may become more widely and densely established than wild rice in areas of appropriate water depth and sediment type conducive for wild rice growth and development. This can substantially decrease the available area, light, and nutrient resources available, and needed, for successful wild rice restoration. Competing aquatic plants can adversely affect wild rice in several ways. Cattails and lily pads are adversely allelopathic to wild rice – in areas where dense growths of cattails and lily pads exist, wild rice plants tend to be excluded. Longer-term adverse influences on successful wild rice restoration may be associated with nutrient depletion, specifically nitrogen, in areas of dense aquatic plant growth (i.e., cattails). Therefore, removal and long-term (multi-year) management of competing aquatic vegetation is critical to successful restoration of wild rice.

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APPENDIX A

TWIN LAKES INFLOW / OUTFLOW WATER SAMPLING DATA

Twin Lakes
Inflow / Outflow Sampling Event

5/28/2014

Analytes - Cations	**Little Sandy Inflow 1**	**Little Sandy Inflow 2**	**Little Sandy Inflow 3**	**Sand River Outflow Trib 1**	**Sand River Outflow 2**	**Reporting Limits**	**Reporting Units**
Aluminum	<20.0	<20.0	<20.0	**41.9**	**32.9**	20.0	ug/L
Arsenic	<0.65	<0.65	<0.65	**1.2**	<0.65	0.65	ug/L
Barium	**24.9**	**19.4**	**22.3**	**28.2**	**18.9**	10.0	ug/L
Cadmium	<0.2	<0.2	<0.2	<0.2	<0.2	0.2	ug/L
Calcium	**39.1**	**26.0**	**24.6**	**10.7**	**19.1**	0.5	mg/L
Chromium	<5.0	<5.0	<5.0	<5.0	<5.0	5.0	ug/L
Cobalt	<5.0	<5.0	<5.0	<5.0	<5.0	5.0	ug/L
Copper	<5.0	<5.0	<5.0	<5.0	<5.0	5.0	ug/L
Gallium	<1.0	<1.0	<1.0	<1.0	<1.0	1.0	ug/L
Iron	**1030**	**475**	**224**	**3590**	**857**	50.0	ug/L
Lead	<0.5	<0.5	<0.5	<0.5	<0.5	0.5	ug/L
Magnesium	**47.6**	**34.4**	**36.1**	**3.7**	**23.7**	0.5	mg/L
Manganese	**95.2**	**23.9**	**25.5**	**258**	**67.6**	10.0	ug/L
Molybdenum	<10.0	<10.0	<10.0	<10.0	<10.0	10.0	ug/L
Nickel	<5.0	<5.0	<5.0	<5.0	<5.0	5.0	ug/L
Phosphorus	<0.10	<0.10	<0.10	<0.10	<0.10	0.10	mg/L
Potassium	**6.5**	**4.0**	**3.3**	**2.1**	**3.2**	0.25	mg/L
Rubidium	**2.8**	**2.5**	**3.0**	**1.8**	**2.4**	1.0	ug/L
Silver	<0.20	<0.20	<0.20	<0.20	<0.20	0.20	ug/L
Sodium	**19.5**	**12.0**	**9.3**	**3.2**	**9.3**	0.50	mg/L
Strontium	**135**	**85.5**	**78.2**	**44.2**	**66.5**	5.0	ug/L
Zinc	<10.0	<10.0	<10.0	<10.0	<10.0	10.0	ug/L
Analytes - Anions							
Chloride	**9.5**	**15.8**	**27.9**	**6.3**	**13.3**	1.0	mg/l
Nitrate as N	<0.20	<0.20	<0.20	<0.20	<0.20	0.20	mg/L
Nitrogen	<1.0	<1.0	<1.0	<1.0	<1.0	1.0	mg/L
Nitrogen, Kjeldahl, Total	<0.50	**0.68**	**0.59**	**0.56**	**0.52**	0.50	mg/L
Nitrogen, NO2 plus NO3	<0.10	<0.10	<0.10	<0.10	<0.10	0.10	mg/L
Ammonia as Nitrogen	<0.050	<0.050	<0.050	<0.050	<0.050	0.050	mg/L
Unionized Ammonia as N2	<6.9	<0.4	<4.6	<2.0	<8.2	varies	ug/L
Sulfate	**107**	**123**	**9.9**	<2.0	**84.3**	2.0	mg/L
Analytes - Other							
Total Dissolved Solids	**484**	**333**	**318**	**138**	**267**	10.0	mg/L
Alkalinity, Total as HCO3	**117**	**84.2**	**110**	**41.2**	**65.1**	12.2	mg/L
Alkalinity, Total as CaCO3	**95.7**	**69.0**	**90.2**	**33.8**	**53.4**	10.0	mg/L
Dissolved Organic Carbon	**13.5**	**15.6**	**20.2**	**20.9**	**16.7**	1.0	mg/L
Total Hardness by 2340B	**294**	**207**	**210**	**41.8**	**145**	10.0	mg/L
UV Absorbance @ 254 nm	**0.499**	**0.561**	**0.781**	**0.992**	**0.570**	0.009	cm^{-1}
SUVA	**3.7**	**3.6**	**3.9**	**4.7**	**4.0**	0.1	L/mg*m
YSI Data							
pH	**8.6**	**7.6**	**8.5**	**8.1**	**8.6**	± 0.2	Units
Temperature	**18.1**	**9.4**	**15.9**	**16.8**	**20.5**	± 0.1	ºC
Specific Conductance	**569**	**261**	**364**	**84**	**314**	± 1%	uS/cm
Dissolved Oxygen	**3.9**	**2.0**	**4.9**	**4.7**	**8.5**	± 0.01	mg/L
Calculations							
Total Cations	**6.9**	4.8	4.7	NM	3.4	-	meq
Total Anions	**4.4**	4.4	2.8	NM	3.2	-	meq
Calculated TDS	**348**	301	222	NM	219	-	mg/L
Actual TDS - Calc. (diff)	**136.4**	32.4	96.0	NM	47.5	-	mg/L
% Na to Tot. Cations	**10.9**	10.9	8.6	NM	11.8	-	%

Bold Print indicates the sample is above the detection limit
"<" indicates value below reporting limit
NM indicates that the analyte was not measured
Exceeds MN WQ Standard (shaded cells: Sulfate – Inflow 1, Inflow 2, Outflow 2; pH – Inflow 1, Outflow 2)

Twin Lakes
Inflow / Outflow Sampling Event

6/23/2014

Analytes - Cations	Little Sandy Inflow 1	Little Sandy Inflow 2	Little Sandy Inflow 3	Sand River Outflow Trib 1	Trib from Culvert	Sand River Outflow 2	Little Sandy Lake	Sandy Lake	Reporting Limits	Reporting Units
Aluminum	**52.0**	**27.7**	<20.0	**56.0**	**83.3**	**35.1**	**30.6**	**37.7**	20.0	ug/L
Arsenic	<0.50	<0.50	<0.50	**1.0**	**1.0**	**0.51**	<0.50	<0.50	0.50	ug/L
Barium	**23.1**	**23.8**	**26.1**	**27.7**	**27.8**	**22.6**	**23.3**	**21.4**	10.0	ug/L
Cadmium	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	0.20	ug/L
Calcium	**37.5**	**30.2**	**30.0**	**11.6**	**11.8**	**24.0**	**29.5**	**25.3**	0.50	mg/L
Chromium	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	5.0	ug/L
Cobalt	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	5.0	ug/L
Copper	<5.0	<5.0	<5.0	<5.0	**11.4**	<5.0	<5.0	<5.0	5.0	ug/L
Gallium	<1.0	<1.0	<1.0	<1.0	NM	<1.0	<1.0	<1.0	1.0	ug/L
Iron	**772**	**672**	**219**	**4590**	**4930**	**1050**	**717**	**800**	50.0	ug/l
Lead	<0.5	<0.5	<0.5	<0.5	**12.8**	<0.5	<0.5	<0.5	0.50	ug/L
Magnesium	**44.3**	**37.7**	**41.0**	**3.9**	**3.9**	**28.4**	**36.5**	**30.5**	0.50	mg/L
Manganese	**70.8**	**32.0**	ND	**160**	**195**	**41.8**	**42.7**	**42.5**	10.0	ug/L
Molybdenum	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0	10.0	ug/L
Nickel	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	5.0	ug/L
Phosphorus	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	0.10	mg/L
Potassium	**4.09**	**3.68**	**2.22**	**1.21**	**1.25**	**3.24**	**3.67**	**3.51**	0.25	mg/L
Rubidium	**2.0**	**2.5**	**2.5**	**1.2**	NM	**2.5**	**2.6**	**2.5**	1.0	ug/L
Silver	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	0.20	ug/L
Sodium	**18.4**	**13.1**	**10.3**	**3.1**	**3.2**	**11.0**	**12.9**	**11.8**	0.50	mg/L
Strontium	**133**	**101**	**95.9**	**48.7**	**50.2**	**82.5**	**98.5**	**86.3**	5.0	ug/L
Zinc	<10.0	<10.0	<10.0	<10.0	**172**	<10.0	<10.0	<10.0	10.0	ug/L
Analytes - Anions										
Chloride	**25.5**	**16.5**	**8.0**	**6.1**	**6.4**	**15.3**	**17.1**	**15.7**	1.0	mg/L
Nitrate as N	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	0.20	mg/L
Nitrogen (Total)	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	1.0	mg/L
Nitrogen, Kjeldahl, Total	**0.55**	**0.66**	**0.70**	**0.74**	**0.92**	**0.61**	**0.72**	**0.74**	0.50	mg/L
Nitrogen, NO2 plus NO3	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	0.10	mg/L
Ammonia as Nitrogen	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	0.050	mg/L
Unionized Ammonia as N2	<.020	<0.13	<0.48	<0.07	<0.11	<0.47	<.094	<1.1	varies	ug/L
Sulfate	**159**	**119**	**91.3**	<2.0	<2.0	**93.6**	**121**	**98.6**	2.0	mg/L
Analytes - Other										
Total Dissolved Solids	**431**	**374**	**368**	**147**	**190**	**324**	**366**	**315**	20.0	mg/L
Alkalinity, Total as HCO3	**127**	**111**	**161**	**42.0**	**40.9**	**88.6**	**116**	**90.4**	12.2	mg/L
Alkalinity, Total as CaCO3	**104**	**90.6**	**132**	**34.4**	**33.5**	**72.6**	**95.3**	**74.1**	10.0	mg/l
Dissolved Organic Carbon	**20.4**	**22.3**	**28.6**	**27.8**	**28.0**	**21.8**	**22.0**	**22.0**	1.0	mg/L
Total Hardness by 2340B	**276**	**231**	**244**	**44.8**	**45.3**	**177**	**224**	**189**	10.0	mg/L
UV Absorbance @ 254 nm	**0.846**	**0.990**	**1.4**	**1.7**	NM	**1.1**	**0.958**	**0.938**	0.009	cm^{-1}
SUVA	**4.1**	**4.4**	**4.7**	**6.0**	NM	**5**	**4.4**	**4.3**	0.1	L/mg*m
YSI Data										
pH	**7.0**	**6.8**	**7.3**	**6.5**	**6.7**	**7.3**	**7.6**	**7.7**	± 0.2	Units
Temperature	**20.9**	**20.7**	**21.6**	**20.0**	**22.8**	**21.6**	**23.6**	**22.6**	± 0.1	°C
Specific Conductance	**612**	**500**	**471**	**98**	**96**	**380**	**504**	**387**	± 1%	uS/cm
Dissolved Oxygen	NM	NM	NM	NM	NM	NM	NM	NM		
Calculations										
Total Cations	6.5	5.3	5.4	NM	1.3	4.1	NM	NM	-	meq
Total Anions	6.1	4.8	4.8	NM	0.8	3.9	NM	NM	-	meq
Calculated TDS	417	332	345	NM	69	266	NM	NM	-	mg/L
Actual TDS - Calc. (diff)	13.9	41.9	23.2	NM	120.7	58.2	NM	NM	-	mg/L
% Na to Tot. Cations	12.4	10.8	8.3	NM	11.0	11.6	NM	NM	-	%

Bold Print indicates the sample is above the detection limit
"<" indicates value below reporting limit
NM indicates that the analyte was not measured
[blue fill] Exceeds MN WQ Standard

Twin Lakes
Inflow / Outflow Sampling Event

7/21/2014

Analytes - Cations	**Little Sandy Inflow 1**	**Little Sandy Inflow 2**	**Little Sandy Inflow 3**	**Sand River Outflow Trib 1**	**Trib from Culvert**	**Sand River Outflow 2**	**Reporting Limits**	**Reporting Units**
Aluminum	**35.5**	**25.4**	<20.0	**65.5**	**72.8**	**30.3**	20.0	ug/L
Arsenic	<0.50	**0.98**	**0**	**1.3**	**1.1**	**0.62**	0.5	ug/L
Barium	**40.4**	**29.0**	**30.4**	**40.2**	**37.9**	**25.6**	10.0	ug/L
Cadmium	NM	NM	NM	NM	<0.2	NM	0.20	ug/L
Calcium	**59.2**	**33.0**	**33.9**	**15.5**	**14.9**	**23.9**	0.50	mg/L
Chromium	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	5.0	ug/L
Cobalt	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	5.0	ug/L
Copper	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	5.0	ug/L
Gallium	NM	NM	NM	NM	NM	NM	1.0	ug/L
Iron	**904**	**612**	**459**	**7290**	**7520**	**1470**	50.0	ug/L
Lead	NM	NM	NM	NM	<0.5	NM	0.50	ug/L
Magnesium	**78.1**	**42.4**	**43.8**	**5.1**	**4.8**	**26.5**	0.50	mg/L
Manganese	**218**	**63.8**	113	**337**	**300**	**27.6**	10.0	ug/L
Molybdenum	NM	NM	NM	NM	NM	NM	10.0	ug/L
Nickel	NM	NM	NM	NM	NM	NM	5.0	ug/L
Phosphorus	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	0.10	mg/L
Potassium	**2.5**	**3.3**	**3.5**	**0.91**	**0.93**	**2.8**	0.25	mg/L
Rubidium	**2.3**	**2.5**	**2.5**	**1.4**	ND	**2.3**	1.0	ug/L
Silver	NM	NM	NM	NM	NM	NM	0.20	ug/L
Sodium	**32.3**	**14.7**	**14.9**	**3.7**	**3.7**	**10.2**	0.50	mg/L
Strontium	**222**	**116**	**120**	**67.0**	**63.4**	**87.9**	5.0	ug/L
Zinc	NM	NM	NM	NM	<10.0	NM	10.0	ug/L
Analytes - Anions								
Chloride	**43.8**	**17.8**	**18.5**	**7.8**	**8.3**	**15.6**	1.0	mg/l
Nitrate as N	NM	NM	NM	NM	NM	NM	0.20	mg/L
Nitrogen	NM	NM	NM	NM	NM	NM	1.0	mg/L
Nitrogen, Kjeldahl, Total	<0.50	**1.2**	**1.3**	**1.5**	**1.2**	**0.99**	0.50	mg/L
Nitrogen, NO2 plus NO3	NM	NM	NM	NM	NM	NM	0.10	mg/L
Ammonia as Nitrogen	NM	NM	NM	NM	NM	NM	0.050	mg/L
Unionized Ammonia as N2	NM	NM	NM	NM	NM	NM	varies	ug/L
Sulfate	**277**	**113**	**119**	<2.0	<2.0	**87.0**	2.0	mg/L
Analytes - Other								
Total Dissolved Solids	**776**	**440**	**425**	**145**	**192**	**352**	10.0	mg/L
Alkalinity, Total as HCO3	**218**	**159**	**159**	**55.8**	**51.0**	**111**	12.2	mg/L
Alkalinity, Total as CaCO3	**179**	**130**	**130**	**45.7**	**41.8**	**91.2**	10.0	mg/L
Dissolved Organic Carbon	**19.8**	**26.5**	**24.8**	**28.9**	**30.4**	**26.2**	1.0	mg/L
Total Hardness by 2340B	**469**	**257**	**265**	**59.6**	**57.0**	**169**	10.0	mg/L
UV Absorbance @ 254 nm	**0.885**	**1.2**	**1.1**	**1.8**	**1.9**	**1.1**	0.009	cm^{-1}
SUVA	**4.5**	**4.6**	**4.4**	**6.2**	**1.3**	**4.4**	0.1	L/mg*m
YSI Data								
pH	**7.0**	**6.6**	**7.3**	**6.7**	**6.6**	**7.6**	± 0.2	Units
Temperature	**21.7**	**23.4**	**25.2**	**21.3**	**23.9**	**23.1**	± 0.1	ºC
Specific Conductance	**963**	**512**	**558**	**132**	**118**	**414**	± 1%	uS/cm
Dissolved Oxygen	NM	NM	NM	NM	NM	NM		
Calculations								
Total Cations	10.9	5.9	6.1	NM	1.6	3.9	-	meq
Total Anions	10.6	5.5	5.7	NM	1.0	4.1	-	meq
Calculated TDS	713	385	394	NM	86	280	-	mg/L
Actual TDS - Calc. (diff)	63.1	55.3	30.9	NM	105.7	72.2	-	mg/L
% Na to Tot. Cations	12.9	10.9	10.7	NM	10.0	11.3	-	%

Bold Print indicates the sample is above the detection limit
"<" indicates value below reporting limit
NM indicates that the analyte was not measured
Exceeds MN WQ Standard (shaded cells: Sulfate 277, 113, 119, 87.0; Total Dissolved Solids 776)

Twin Lakes
Inflow / Outflow Sampling Event

8/22/2014

Analytes - Cations	**Little Sandy Inflow 1**	**Little Sandy Inflow 2**	**Little Sandy Inflow 3**	**Sand River Outflow Trib 1**	**Trib from Culvert**	**Sand River Outflow 2**	**Reporting Limits**	**Reporting Units**
Aluminum	**28.9**	<20.0	<20.0	**28.6**	**39.1**	<20.0	20.0	ug/L
Arsenic	<0.50	<0.50	<0.50	**1.2**	**0.85**	**0.71**	0.5	ug/L
Barium	**58.9**	**35.4**	**35.5**	**35.9**	**38.2**	**31.2**	10.0	ug/L
Cadmium	NM	NM	NM	NM	<0.2	NM	0.2	ug/L
Calcium	**85.9**	**40.5**	**40.0**	**15.2**	**15.5**	**22.3**	0.5	mg/L
Chromium	NM	NM	NM	NM	<5.0	NM	5.0	ug/L
Cobalt	NM	NM	NM	NM	<5.0	NM	5.0	ug/L
Copper	NM	NM	NM	NM	<5.0	NM	5.0	ug/L
Gallium	**1.0**	<1.0	<1.0	<1.0	<1.0	<1.0	1.0	ug/L
Iron	**1980**	**232**	**217**	**5450**	**5530**	1260	50.0	ug/L
Lead	NM	NM	NM	NM	<0.5	NM	0.5	ug/L
Magnesium	**121**	**51.7**	**51.2**	**5.0**	**5.2**	21.3	0.5	mg/L
Manganese	**347**	**92.2**	**110**	**297**	**229**	138	10.0	ug/L
Molybdenum	NM	NM	NM	NM	NM	NM	10.0	ug/L
Nickel	NM	NM	NM	NM	NM	NM	5.0	ug/L
Phosphorus	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	0.10	mg/L
Potassium	**4.6**	**3.8**	**3.7**	**1.2**	**1.3**	2.4	0.25	mg/L
Rubidium	**2.9**	**2.6**	**2.6**	**1.0**	**1.1**	1.7	1.0	ug/L
Silver	NM	NM	NM	NM	NM	NM	0.20	ug/L
Sodium	**50.3**	**18.6**	**18.4**	**4.4**	**4.5**	**8.8**	0.50	mg/L
Strontium	**307**	**137**	**137**	**61.5**	**62.7**	**79.1**	5.0	ug/L
Zinc	NM	NM	NM	NM	<10.0	NM	10.0	ug/L
Analytes - Anions								
Chloride	**75.6**	**24.5**	**24.4**	**12.6**	**12.2**	**14.6**	1.0	mg/l
Nitrate as N	NM	NM	NM	NM	NM	NM	0.20	mg/L
Nitrogen	NM	NM	NM	NM	NM	NM	1.0	mg/L
Nitrogen, Kjeldahl, Total	**0.64**	**0.95**	**1.8**	<0.50	<0.50	<0.50	0.50	mg/L
Nitrogen, NO2 plus NO3	NM	NM	NM	NM	NM	NM	0.10	mg/L
Ammonia as Nitrogen	NM	NM	NM	NM	NM	NM	0.050	mg/L
Unionized Ammonia as N2	NM	NM	NM	NM	NM	NM	varies	ug/L
Sulfate	**419**	**143**	**142**	<2.0	<2.0	**44.6**	2.0	mg/L
Analytes - Other								
Total Dissolved Solids	**1030**	**438**	**447**	**130**	**125**	**221**	10.0	mg/L
Alkalinity, Total as HCO3	**312**	**185**	**185**	**55.3**	**56.0**	**107**	12.2	mg/L
Alkalinity, Total as CaCO3	**256**	**152**	**152**	**45.3**	**45.9**	**88.0**	10.0	mg/L
Dissolved Organic Carbon	**20.5**	**25.7**	**25.4**	**17.1**	**19.6**	**23.6**	1.0	mg/L
Total Hardness by 2340B	**712**	**314**	**311**	**58.6**	**60.0**	**143**	10.0	mg/L
UV Absorbance @ 254 nm	**0.930**	**0.945**	**0.912**	**1.0**	**1.0**	**0.958**	0.009	cm^{-1}
SUVA	**4.5**	**3.7**	**3.6**	**5.8**	**5.2**	**4.1**	0.1	L/mg*m
YSI Data								
pH	**7.2**	**8.4**	**8.2**	**6.6**	**6.6**	**7.0**	± 0.2	Units
Temperature	**18.4**	**22.7**	**22.1**	**18.5**	**17.4**	**19.9**	± 0.1	ºC
Specific Conductance	**1347**	**632**	**641**	**138**	**137**	**307**	± 1%	uS/cm
Dissolved Oxygen	NM	NM	NM	NM	NM	NM		
Calculations								
Total Cations	16.6	7.2	7.1	NM	**1.6**	**3.4**	-	meq
Total Anions	16.0	6.8	6.8	NM	**1.0**	**3.1**	-	meq
Calculated TDS	1072	469	467	NM	**91**	**223**	-	mg/L
Actual TDS - Calc. (diff)	-41.7	-30.8	-20.3	NM	**34.2**	**-2.3**	-	mg/L
% Na to Tot. Cations	13.2	11.2	11.2	NM	**12.0**	**11.4**	-	%

Note: cells shaded blue on the page: Sulfate (419, 143, 142, 44.6), Total Dissolved Solids 1030, Alkalinity as HCO3 312, Total Hardness 712, Specific Conductance 1347.

Bold Print indicates the sample is above the detection limit
"<" indicates value below reporting limit
NM indicates that the analyte was not measured
[blue shading] Exceeds MN WQ Standard

Twin Lakes
Inflow / Outflow Sampling Event

9/11/2014

Analytes - Cations	Little Sandy Inflow 1	Little Sandy Inflow 2	Little Sandy Inflow 3	Sand River Outflow Trib 1	Trib from Culvert	Sand River Outflow 2	Reporting Limits	Reporting Units
Aluminum	**21.2**	<20.0	<20.0	**31.5**	**42.3**	<20.0	20.0	ug/L
Arsenic	**0.75**	**1.1**	**0.57**	**0.68**	<0.50	**0.92**	0.50	ug/L
Barium	**43**	**31.9**	**31.5**	**24.3**	**28.2**	**26.4**	10.0	ug/L
Cadmium	NM	NM	NM	NM	<0.2	NM	0.2	ug/L
Calcium	**84.4**	**39.9**	**38.7**	**11.4**	**12.3**	**20.3**	0.5	mg/L
Chromium	NM	NM	NM	NM	<5.0	NM	5.0	ug/L
Cobalt	NM	NM	NM	NM	<5.0	NM	5.0	ug/L
Copper	NM	NM	NM	NM	<5.0	NM	5.0	ug/L
Gallium	**<1.0**	<1.0	<1.0	<1.0	<1.0	<1.0	1.0	ug/L
Iron	**229**	**169**	**173**	**2830**	**3380**	**803**	50.0	ug/L
Lead	NM	NM	NM	NM	<0.5	NM	0.5	ug/L
Magnesium	**124**	**52.8**	**51.2**	3.8	**4.2**	**19.7**	0.5	mg/L
Manganese	**66.3**	**62.7**	**77.0**	**113**	**111**	**66.6**	10.0	ug/L
Molybdenum	NM	NM	NM	NM	NM	NM	10.0	ug/L
Nickel	NM	NM	NM	NM	NM	NM	5.0	ug/L
Phosphorus	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	0.10	mg/L
Potassium	**7.4**	**3.6**	**3.4**	**1.3**	**1.5**	**2.2**	0.25	mg/L
Rubidium	**3.2**	**2.4**	**2.3**	**1.1**	**1.1**	**1.6**	1.0	ug/L
Silver	NM	NM	NM	NM	NM	NM	0.20	ug/L
Sodium	**50.9**	**19.5**	**18.8**	**3.8**	**4.1**	**8.3**	0.50	mg/L
Strontium	**302**	**142**	**138**	**47.3**	**52.7**	**76.0**	5.0	ug/L
Zinc	NM	NM	NM	NM	<10.0	NM	10.0	ug/L
Analytes - Anions								
Chloride	**86.3**	**28.5**	**27.7**	**11.1**	**11.7**	**15.1**	1.0	mg/l
Nitrate as N	NM	NM	NM	NM	NM	NM	0.20	mg/L
Nitrogen	NM	NM	NM	NM	NM	NM	1.0	mg/L
Nitrogen, Kjeldahl, Total	**0.75**	**0.85**	**0.82**	**0.53**	<0.50	**0.90**	0.50	mg/L
Nitrogen, NO2 plus NO3	NM	NM	NM	NM	NM	NM	0.10	mg/L
Ammonia as Nitrogen	NM	NM	NM	NM	NM	NM	0.050	mg/L
Unionized Ammonia as N2	NM	NM	NM	NM	NM	NM	varies	ug/L
Sulfide	<5.0	<5.0	<5.0	<5.0	<5.0	NM	5.0	mg/L
Sulfate	**465**	**162**	**156**	<2.0	<2.0	**48.4**	2.0	mg/L
Analytes - Other								
Total Dissolved Solids	**1080**	**465**	**476**	**132**	**134**	**255**	10.0	mg/L
Alkalinity, Total as HCO3	**316**	**194**	**193**	**41.6**	**46.2**	**99.1**	12.2	mg/L
Alkalinity, Total as CaCO3	**259**	**159**	**158**	**34.1**	**37.9**	**81.2**	10.0	mg/L
Dissolved Organic Carbon	**14.8**	**22.5**	**22.6**	**16.8**	**16.2**	**20.8**	1.0	mg/L
Total Hardness by 2340B	**721**	**317**	**307**	**44.1**	**48.0**	**132**	10.0	mg/L
UV Absorbance @ 254 nm	**0.550**	**0.818**	**0.838**	**0.812**	**0.814**	**0.826**	0.009	cm^{-1}
SUVA	**3.7**	**3.6**	**2.3**	**4.8**	**5.0**	4.0	0.1	L/mg*m
YSI Data								
pH	**7.3**	**7.9**	**7.6**	**6.6**	**6.6**	**7.1**	± 0.2	Units
Temperature	**11.4**	**13.7**	**13.8**	**9.8**	**11.8**	**12.2**	± 0.1	ºC
Specific Conductance	**1479**	**689**	**678**	**99**	**120**	**308**	± 1%	uS/cm
Dissolved Oxygen	NM	NM	NM	NM	NM	NM		
Calculations								
Total Cations	16.8	7.3	7.1	NM	1.3	3.1	-	meq
Total Anions	17.3	7.4	7.2	NM	0.8	3.1	-	meq
Calculated TDS	1135	501	490	NM	74	215	-	mg/L
Actual TDS - Calc. (diff)	-55.0	-36.4	-13.6	NM	59.7	40.2	-	mg/L
% Na to Tot. Cations	13.2	11.6	11.6	NM	13.7	11.7	-	%

Bold Print indicates the sample is above the detection limit
"<" indicates value below reporting limit
NM indicates that the analyte was not measured
[blue shading] Exceeds MN WQ Standard

Twin Lakes
Inflow / Outflow Sampling Event

10/13/2014

Analytes - Cations	**Little Sandy Inflow 1**	**Little Sandy Inflow 2**	**Little Sandy Inflow 3**	**Sand River Outflow Trib 1**	**Trib from Culvert**	**Sand River Outflow 2**	**Reporting Limits**	**Reporting Units**
Aluminum	**24.5**	**41.7**	**23.3**	**28.8**	**23.3**	**22.8**	20.0	ug/L
Arsenic	<0.50	<0.50	**0.53**	**0.86**	**0.63**	**0.81**	0.50	ug/L
Barium	**37.7**	**20.3**	**29.0**	**22.9**	**23.9**	**28.1**	10.0	ug/L
Cadmium	NM	NM	NM	NM	<0.2	NM	0.2	ug/L
Calcium	**95.0**	**25.4**	**44.4**	**10.6**	**11.0**	**34.8**	0.5	mg/L
Chromium	NM	NM	NM	NM	<5.0	NM	5.0	ug/L
Cobalt	NM	NM	NM	NM	<5.0	NM	5.0	ug/L
Copper	NM	NM	NM	NM	<5.0	NM	5.0	ug/L
Gallium	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	1.0	ug/L
Iron	**245**	**1100**	**399**	**2430**	**1870**	**409**	50.0	ug/L
Lead	NM	NM	NM	NM	<0.5	NM	0.5	ug/L
Magnesium	**140**	**37.5**	**62.3**	**3.9**	**4.0**	**44.9**	0.5	mg/L
Manganese	**54.4**	**64.3**	**127**	**119**	**82.3**	**47.1**	10.0	ug/L
Molybdenum	NM	NM	NM	NM	NM	NM	10.0	ug/L
Nickel	NM	NM	NM	NM	NM	NM	5.0	ug/L
Phosphorus	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	0.10	mg/L
Potassium	**11.4**	**1.7**	**3.7**	**1.7**	**1.9**	**3.4**	0.25	mg/L
Rubidium	**4.0**	**1.5**	**2.4**	**1.1**	**1.4**	**2.3**	1.0	ug/L
Silver	NM	NM	NM	NM	NM	NM	0.20	ug/L
Sodium	**58.2**	**15.2**	**23.1**	**4.2**	**4.5**	**17.8**	0.50	mg/L
Strontium	**327**	**87.5**	**154**	**42.7**	**44.2**	**123**	5.0	ug/L
Zinc	NM	NM	NM	NM	<10.0	NM	10.0	ug/L
Analytes - Anions								
Chloride	**103**	**24.9**	**30.1**	**12.2**	**13.1**	**25.8**	1.0	mg/l
Nitrate as N	NM	NM	NM	NM	NM	NM	0.20	mg/L
Nitrogen	NM	NM	NM	NM	NM	NM	1.0	mg/L
Nitrogen, Kjeldahl, Total	**0.64**	**1.2**	**1.2**	**0.72**	<0.50	**1.2**	0.50	mg/L
Nitrogen, NO2 plus NO3	NM	NM	NM	NM	NM	NM	0.10	mg/L
Ammonia as Nitrogen	NM	NM	NM	NM	NM	NM	0.050	mg/L
Unionized Ammonia as N2	NM	NM	NM	NM	NM	NM	varies	ug/L
Sulfate	**540**	**89.3**	**154**	<2.0	**3.1**	**124**	2.0	mg/L
Analytes - Other								
Total Dissolved Solids	**1170**	**369**	**489**	**98.0**	**114**	**375**	10.0	mg/L
Alkalinity, Total as HCO3	**309**	**309**	**229**	**40.1**	**39.2**	**157**	12.2	mg/L
Alkalinity, Total as CaCO3	**253**	**253**	**188**	**32.9**	**32.1**	**129**	10.0	mg/L
Dissolved Organic Carbon	**10.3**	**23.6**	**25.0**	**8.0**	**8.5**	**21.8**	1.0	mg/L
Total Hardness by 2340B	**814**	**218**	**368**	**42.4**	**43.7**	**272**	10.0	mg/L
UV Absorbance @ 254 nm	**0.320**	**0.864**	**0.896**	**0.346**	**0.360**	**0.786**	0.009	cm^{-1}
SUVA	**3.1**	**3.7**	**4.2**	**4.3**	**4.2**	**3.6**	0.1	L/mg*m
YSI Data								
pH	**7.5**	**7.4**	**6.9**	**6.8**	**6.8**	**7.8**	± 0.2	Units
Temperature	**7.2**	**7.7**	**7.3**	**7.4**	**7.3**	**7.9**	± 0.1	ºC
Specific Conductance	**1620**	**679**	**403**	**117**	**116**	**561**	± 1%	uS/cm
Dissolved Oxygen	NM	NM	NM	NM	NM	NM		
Calculations								
Total Cations	19.1	5.1	8.5	NM	1.2	6.3	-	meq
Total Anions	19.3	7.7	7.9	NM	0.7	6.0	-	meq
Calculated TDS	1257	505	549	NM	66	410	-	mg/L
Actual TDS - Calc. (diff)	-87.2	-136.0	-59.7	NM	47.9	-34.7	-	mg/L
% Na to Tot. Cations	13.3	13.0	11.9	NM	16.4	12.3	-	%

Bold Print indicates the sample is above the detection limit
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NM indicates that the analyte was not measured
Exceeds MN WQ Standard

Twin Lakes
Inflow / Outflow Sampling Event

5/22/2015

	Little Sandy Inflow 1	Little Sandy Inflow 2	Little Sandy Inflow 3	Little Sandy Middle	Sandy Middle	Twin Lakes Outflow	Culvert Inflow	Reporting Limits	Reporting Units
Analytes - Cations									
Aluminum	**29.7**	**15.2**	<10.0	NM	NM	**16.4**	**28.4**	10.0	ug / L
Arsenic	<0.50	<0.50	<0.50	NM	NM	<0.50	<0.50	0.50	ug / L
Barium	**19.0**	**23.7**	**26.5**	NM	NM	**24.4**	**17.5**	10.0	ug / L
Calcium	**38.4**	**42.6**	**34.0**	**45.2**	**40.7**	**41.6**	**9.0**	0.50	mg / L
Iron	**407**	**238**	**80**	NM	NM	**287**	**1180**	50.0	ug / L
Magnesium	**53**	**62.6**	**55.3**	**64.9**	**57.4**	**58**	**3.2**	0.50	mg / L
Manganese	**31.3**	**32.8**	**14.8**	NM	NM	**32.6**	**46.1**	10.0	ug / L
Phosphorus	<0.10	<0.10	<0.10	NM	NM	<0.10	<0.10	0.10	mg / L
Potassium	**6.27**	**5.73**	**3.38**	NM	NM	**6.03**	**1.88**	0.25	mg / L
Rubidium	**2.8**	**3.0**	**2.6**	NM	NM	**2.8**	**1.4**	1.0	ug / L
Sodium	**21.3**	**20.8**	**13.9**	**23**	**22.2**	**22.2**	**3.7**	0.50	mg / L
Strontium	**129**	**133**	**101**	NM	NM	**136**	**34.3**	10.0	ug / L
Analytes - Anions									
Chloride	**31.4**	**29.6**	**15.8**	**33.9**	**33.4**	**33.4**	**8.2**	1.0	mg / l
Nitrogen, Kjeldahl, Total	**0.62**	**0.73**	**0.59**	NM	NM	**0.57**	<0.50	0.50	mg / L
Ammonia as Nitrogen	NM	NM	NM	NM	NM	NM	NM	0.050	mg / L
Unionized Ammonia as N2	NM	NM	NM	NM	NM	NM	NM	varies	ug/L
Sulfate	**191**	**216**	**182**	**223**	**196**	**200**	**2.5**	2.0	mg / L
Analytes - Other									
Total Dissolved Solids	**457**	**506**	**418**	**530**	**466**	**473**	**97**	10.0	mg / L
Alkalinity, Total as HCO3	**114**	**128**	**113**	**134**	**117**	**119**	**30.0**	12.2	mg / L
Alkalinity, Total as CaCO3	**93.1**	**105**	**92.6**	**110**	**96.1**	**97.3**	**24.6**	10.0	mg / L
Dissolved Organic Carbon	**12.5**	**12.9**	**14.7**	NM	NM	**10.8**	**11.3**	1.0	mg / L
Total Hardness by 2340B	**314**	**364**	**313**	**380**	**338**	**343**	**35.7**	10.0	mg / L
UV Absorbance @ 254 nm	**0.429**	**0.408**	**0.468**	NM	NM	**0.36**	**0.478**	0.009	cm^{-1}
SUVA	**3.5**	**3.3**	**3.3**	NM	NM	**3.5**	**4.4**	0.1	L / mg*m
YSI Data									
pH	**7.1**	**7.7**	**7.3**	**8.1**	**8.0**	**7.8**	**6.7**	± 0.2	Units
Temperature	**9.8**	**14.2**	**8.5**	**15**	**14.9**	**13.6**	**14.5**	± 0.1	ºC
Specific Conductance	**632**	**735**	**601**	**775**	**668**	**698**	**85**	± 1%	uS / cm
Dissolved Oxygen	NM	NM	NM	NM	NM	NM	NM	± 0.01	mg / L
Calculations									
Total Cations	7.4	8.3	6.9	8.6	7.7	8.0	1.0	-	meq
Total Anions	6.8	7.5	6.1	7.8	6.9	7.1	0.8	-	meq
Calculated TDS	456	506	418	524	467	481	60	-	mg/L
Actual TDS - Calc. (diff)	1.0	-0.4	0.0	5.8	-0.9	-7.8	36.8	-	mg/L
% Na to Tot. Cations	12.6	10.9	8.7	11.6	12.5	12.1	16.7	-	%

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Exceeds MN WQ Standard

Twin Lakes
Inflow / Outflow Sampling Event

6/12/2015

Analytes - Cations	Little Sandy Inflow 1	Little Sandy Inflow 2	Little Sandy Inflow 3	Little Sandy Middle	Sandy Middle	Twin Lakes Outflow	Culvert Inflow	Reporting Limits	Reporting Units
Aluminum	**38.2**	**12.8**	<10.0	NM	NM	**12.4**	**32.0**	10.0	ug / L
Arsenic	<0.50	<0.50	<0.50	NM	NM	<0.50	**0.76**	0.50	ug / L
Barium	NM	NM	NM	NM	NM	NM	NM	10.0	ug / L
Calcium	**50.7**	**39.7**	**32.6**	**40.7**	**33.4**	**31.6**	**11.8**	0.50	mg / L
Iron	**582**	**259**	**106**	NM	NM	**350**	**2210**	50.0	ug / L
Magnesium	**69.3**	**57.7**	**49.9**	**57.7**	**47.2**	**43.6**	**4**	0.50	mg / L
Manganese	**126**	**97.9**	**24.8**	NM	NM	**61.8**	**139**	10.0	ug / L
Phosphorus	NM	NM	NM	NM	NM	NM	NM	0.10	mg / L
Potassium	**7.2**	**5.12**	**2.12**	NM	NM	**4.81**	**1.49**	0.10	mg / L
Rubidium	**2.9**	**3**	**2.4**	NM	NM	**2.8**	**1.2**	1.0	ug / L
Sodium	**28.1**	**19.2**	**12.6**	**20.2**	**17.9**	**16.8**	**3.8**	0.50	mg / L
Strontium	**175**	**128**	**102**	NM	NM	**107**	**45.1**	10.0	ug / L
Analytes - Anions									
Chloride	**42.8**	**28**	**13.7**	**31.4**	**28.5**	**27.4**	**8.5**	5.0	mg / l
Nitrogen, Kjeldahl, Total	**0.62**	**1.4**	**1.2**	**0.85**	**0.67**	**0.58**	**0.5**	0.50	mg / L
Ammonia as Nitrogen	<0.10	<0.10	**0.15**	<0.10	<0.10	<0.10	<0.10	0.10	mg / L
Unionized Ammonia as N2	<0.02	<0.18	**0.33**	<0.36	<0.48	<0.13	<0.02	varies	ug/L
Sulfate	**271**	**205**	**169**	**219**	**174**	**163**	**2.1**	10.0	mg / L
Analytes - Other									
Total Dissolved Solids	**594**	**486**	**400**	**475**	**399**	**375**	**121**	10.0	mg / L
Total Suspended Solids	**1.6**	NM	NM	<1.2	<1.2	**1.6**	NM	1.2	mg / L
Alkalinity, Total as HCO3	**167**	**140**	**140**	**142**	**114**	**111**	**44.8**	12.2	mg / L
Alkalinity, Total as CaCO3	**137**	**115**	**115**	**116**	**93.7**	**91.1**	**36.7**	5.0	mg / L
Dissolved Organic Carbon	**14.8**	**16.5**	**19.9**	NM	NM	**14.8**	**12.4**	1.0	mg / L
Total Hardness by 2340B	**412**	**337**	**287**	**339**	**278**	**259**	**45.9**	10.0	mg / L
UV Absorbance @ 254 nm	**0.502**	**0.544**	**0.679**	NM	NM	**0.484**	**0.572**	0.009	cm^{-1}
SUVA	**3.4**	**3.3**	**3.4**	NM	NM	**3.3**	**4.6**	0.1	L / mg*m
YSI Data									
pH	**6.9**	**7.6**	**6.9**	**7.9**	**8.0**	**7.5**	**6.7**	± 0.2	Units
Temperature	**16.4**	**22.1**	**16.5**	**21.9**	**21.3**	**19.9**	**18.8**	± 0.1	ºC
Specific Conductance	**892**	**707**	**583**	**730**	**610**	**590**	**106**	± 1%	uS / cm
Dissolved Oxygen	**3.4**	**8.5**	**5.1**	**9.1**	**8.98**	**7.68**	**8.23**	± 0.01	mg / L
Calculations									
Total Cations	9.7	7.7	6.3	7.7	6.3	6.0	1.2	-	meq
Total Anions	9.6	7.5	6.3	7.8	6.3	6.0	1.1	-	meq
Calculated TDS	638	497	422	511	416	399	79	-	mg/L
Actual TDS - Calc. (diff)	-43.6	-10.8	-21.6	-36.4	-17.0	-24.3	41.7	-	mg/L
% Na to Tot. Cations	12.6	10.8	8.6	11.5	12.3	12.1	13.7	-	%

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Twin Lakes
Inflow / Outflow Sampling Event

7/10/2015

	Little Sandy Inflow 1	Little Sandy Inflow 2	Little Sandy Inflow 3	Little Sandy Core	Little Sandy Middle	Sandy Middle	Twin Lakes Outflow	Culvert Inflow	Reporting Limits	Reporting Units
Analytes - Cations										
Aluminum	**54.2**	<50.0	<50.0	NM	NM	<50.0	<50.0	<50.0	50.0	ug / L
Arsenic	NM	NM	NM	NM	NM	NM	NM	NM	0.50	ug / L
Barium	NM	NM	NM	NM	NM	NM	NM	NM	10.0	ug / L
Calcium	**60.9**	**39.3**	**44.3**	**47.5**	**47.7**	**38.4**	**35.3**	**15.4**	0.50	mg / L
Iron	**459**	**836**	**249**	NM	NM	**285**	**371**	**3150**	50.0	ug / L
Magnesium	**84.3**	**56.5**	**63.5**	**67.2**	**67.7**	**53.3**	**48.3**	**5.3**	0.50	mg / L
Manganese	**28.5**	**128**	**143**	NM	NM	**129**	**42.5**	**180**	10.0	ug / L
Phosphorus	NM	NM	NM	NM	NM	NM	NM	NM	0.10	mg / L
Potassium	**5.6**	**4.1**	**4.4**	NM	NM	**4.8**	**4.6**	**1.2**	0.50	mg / L
Rubidium	NM	NM	NM	NM	NM	NM	NM	NM	1.0	ug / L
Sodium	**39.3**	**20**	**22.3**	**25**	**25**	**20.8**	**19.1**	**4.4**	0.50	mg / L
Strontium	NM	NM	NM	NM	NM	NM	NM	NM	10.0	ug / L
Analytes - Anions										
Chloride	**45.9**	**23.6**	**29.1**	**33.2**	**32.6**	**29.3**	**25.7**	**9.8**	2.0	mg / l
Nitrogen, Kjeldahl, Total	**0.64**	**0.85**	**0.66**	**0.7**	**0.79**	**0.65**	**0.72**	**0.51**	0.50	mg / L
Ammonia as Nitrogen	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	0.10	mg / L
Unionized Ammonia as N2	<0.11	<0.17	<.025	<0.61	<0.66	<0.54	<0.60	<0.03	varies	ug/L
Sulfate	**294**	**168**	**204**	**217**	**219**	**171**	**140**	<2.0	4.0	mg / L
Analytes - Other										
Total Dissolved Solids	**752**	**516**	**575**	**589**	**581**	**509**	**462**	**166**	10.0	mg / L
Total Suspended Solids	**1.6**	**3.5**	**1.6**	**2**	1.6	**2**	**1.6**	**3.2**	1.0	mg / L
Alkalinity, Total as HCO3	**173**	**149**	**153**	**155**	**154**	**133**	**122**	**56.4**	12.2	mg / L
Alkalinity, Total as CaCO3	**142**	**122**	**125**	**127**	**126**	**109**	**99.9**	**46.2**	5.0	mg / L
Dissolved Organic Carbon	**18.4**	**22**	**17.5**	NM	NM	**17**	**17.1**	**12.8**	1.0	mg / L
Total Hardness by 2340B	**499**	**331**	**372**	**395**	**398**	**315**	**287**	**60.6**	3.3	mg / L
UV Absorbance @ 254 nm	NM	NM	NM	NM	NM	NM	NM	NM	0.009	cm^{-1}
SUVA	NM	NM	NM	NM	NM	NM	NM	NM	0.1	L / mg*m
YSI Data										
pH	**7.5**	**7.6**	**7.8**	**8.1**	**8.2**	**8.1**	**8.1**	**7.1**	± 0.2	Units
Temperature	**19.7**	**21.6**	**21.6**	**22.7**	**22.3**	**22.7**	**23.1**	**14.0**	± 0.1	ºC
Specific Conductance	**969**	**703**	**719**	**644**	**765**	**644**	**581**	**129.6**	± 1%	uS / cm
Dissolved Oxygen	**8.2**	**8.2**	**10.1**	**9.1**	**10**	**9.1**	**9.7**	**7.96**	± 0.01	mg / L
Calculations										
Total Cations	11.8	7.6	8.5	NM	9.0	7.3	6.7	1.5	-	meq
Total Anions	10.3	6.7	7.6	NM	8.1	6.6	5.7	1.3	-	meq
Calculated TDS	704	462	521	NM	547	452	396	98	-	mg/L
Actual TDS - Calc. (diff)	47.6	53.8	53.8	NM	34.5	57.4	66.0	67.7	-	mg/L
% Na to Tot. Cations	14.4	11.4	11.4	NM	12.0	12.3	12.4	12.4	-	%

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[blue shading] Exceeds MN WQ Standard

Twin Lakes
Inflow / Outflow Sampling Event

8/21/2015

	Little Sandy Inflow 1	Little Sandy Inflow 2	Little Sandy Inflow 3	Little Sandy Middle	Sandy Middle	Twin Lakes Outflow	Culvert Inflow	Reporting Limits	Reporting Units
Analytes - Cations									
Aluminum	**84.8**	**10.1**	<10.0	<10.0	**18.1**	**21.2**	**53**	10.0	ug / L
Arsenic	NM	NM	NM	NM	NM	NM	NM	0.50	ug / L
Barium	NM	NM	NM	NM	NM	NM	NM	10.0	ug / L
Calcium	**68.7**	**56.6**	**53.1**	**52.8**	**35.3**	**15.6**	**13.4**	0.50	mg / L
Iron	**1170**	**249**	**179**	**121**	**171**	**1200**	**3800**	50.0	ug / L
Magnesium	**94.3**	**82.3**	**79.8**	**80.8**	**54.6**	**14.3**	**4.8**	0.50	mg / L
Manganese	**193**	**77.8**	**91**	**98.7**	**40.1**	**53.9**	**210**	10.0	ug / L
Phosphorus	NM	NM	NM	NM	NM	NM	NM	0.10	mg / L
Potassium	**5.8**	**3.81**	**4.17**	**5.11**	**4.14**	**1.79**	**1.35**	0.10	mg / L
Rubidium	NM	NM	NM	NM	NM	NM	NM	1.0	ug / L
Sodium	**34.6**	**25.5**	**25.5**	**28.9**	**20.3**	**6.9**	**4.3**	0.50	mg / L
Strontium	NM	NM	NM	NM	NM	NM	NM	10.0	ug / L
Analytes - Anions									
Chloride	**51.3**	**34.2**	**33.9**	**40.4**	**28.8**	**12.1**	**11.2**	5.0	mg / l
Nitrogen, Kjeldahl, Total	**0.53**	**0.86**	**0.88**	**0.72**	**1.1**	**0.61**	**0.54**	0.50	mg / L
Ammonium as Nitrogen	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	0.10	mg / L
Unionized Ammonia as N2	<.013	<.016	<.036	<0.78	<0.46	<0.03	<0.03	varies	ug/L
Sulfate	**366**	**276**	**250**	**260**	**162**	**33.8**	<2.0	2.0	mg / L
Analytes - Other									
Total Dissolved Solids	**Inflow 1**	**652**	**623**	**622**	**436**	**174**	**124**	10.0	mg / L
Total Suspended Solids	<1.0	<1.0	**1.6**	**1.2**	**2**	<1.2	**5.2**	1.0	mg / L
Alkalinity, Total as HCO3	**199**	**205**	**210**	**195**	**143**	**57.8**	**47.8**	**12.2**	mg / L
Alkalinity, Total as CaCO3	**163**	**168**	**172**	**160**	**117**	**47.4**	**39.2**	5.0	mg / L
Dissolved Organic Carbon	**12.9**	**18.8**	**19.3**	**17**	**18.8**	**17.5**	**16.2**	1.0	mg / L
Total Hardness by 2340B	**560**	**480**	**461**	**465**	**313**	**97.9**	**53.3**	10.0	mg / L
UV Absorbance @ 254 nm	NM	NM	NM	NM	NM	NM	NM	0.009	cm^{-1}
SUVA	NM	NM	NM	NM	NM	NM	NM	0.1	L / mg*m
YSI Data									
pH	**7.7**	**7.8**	**8.1**	**8.4**	**8.2**	**7.0**	**7.1**	± 0.2	Units
Temperature	**13.9**	**14.3**	**15.7**	**16.7**	**15.8**	**14.6**	**13.6**	± 0.1	ºC
Specific Conductance	**1074**	**976**	**866**	**890**	**632**	**219**	**119**	± 1%	uS / cm
Dissolved Oxygen	NM	NM	NM	NM	NM	NM	NM	± 0.01	mg / L
Calculations									
Total Cations	12.9	10.8	10.4	10.7	7.2	2.3	1.4	-	meq
Total Anions	12.4	10.1	9.7	9.8	6.6	2.0	1.2	-	meq
Calculated TDS	821	685	657	664	449	144	89	-	mg/L
Actual TDS - Calc. (diff)	-22.5	-32.6	-34.5	-42.1	-13.2	29.8	34.6	-	mg/L
% Na to Tot. Cations	11.7	10.3	10.6	11.8	12.2	12.8	13.1	-	%

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(shaded) Exceeds MN WQ Standard

Twin Lakes
Inflow / Outflow Sampling Event

9/25/2015

	Little Sandy Inflow 1	Little Sandy Inflow 2	Little Sandy Inflow 3	Little Sandy Middle	Sandy Middle	Twin Lakes Outflow	Culvert Inflow	Reporting Limits	Reporting Units
Analytes - Cations									
Aluminum	**124**	**54.3**	**16.4**	NM	**14.0**	**35.8**	**39.4**	10.0	ug / L
Arsenic	NM	NM	NM	NM	NM	NM	NM	0.50	ug / L
Barium	NM	NM	NM	NM	NM	NM	NM	10.0	ug / L
Calcium	**75.7**	**27.9**	**30.5**	**52.0**	**41.1**	**35.2**	**12.2**	0.50	mg / L
Iron	**2030**	**4170**	**352**	NM	**301**	**811**	**2860**	50.0	ug / L
Magnesium	**104**	**38.2**	**46.5**	**75.3**	**61.0**	**50.1**	**4.4**	0.50	mg / L
Manganese	**309**	**67.0**	**31.5**	NM	**61.5**	**67.5**	**97.6**	10.0	ug / L
Phosphorus	NM	NM	NM	NM	NM	NM	NM	0.10	mg / L
Potassium	**8.9**	**1.8**	**1.6**	NM	**4.2**	**3.8**	**1.8**	0.10	mg / L
Rubidium	NM	NM	NM	NM	NM	NM	NM	1.0	ug / L
Sodium	**42.2**	**13.7**	**11.1**	**27.6**	**23.6**	**20.3**	**4.4**	0.50	mg / L
Strontium	NM	NM	NM	NM	NM	NM	NM	10.0	ug / L
Analytes - Anions									
Chloride	**68.5**	**25.3**	**13.2**	**40.9**	**34.2**	**28.1**	**11.7**	5.0	mg / l
Nitrogen, Kjeldahl, Total	**0.98**	**1.6**	**1.2**	**1.1**	**0.95**	**1.0**	**0.83**	0.50	mg / L
Ammonia as Nitrogen	**0.10**	**0.17**	**0.12**	<0.10	<0.10	<0.10	<0.10	0.10	mg / L
Unionized Ammonia as N2	**0.03**	**0.03**	**0.03**	<0.22	<0.17	<0.08	<0.01	varies	ug/L
Sulfate	**338**	**157**	**52.5**	**238**	**195**	**147**	<2.0	10.0	mg / L
Analytes - Other									
Total Dissolved Solids	**838**	**399**	**309**	**576**	**447**	**371**	**95**	10.0	mg / L
Total Suspended Solids	**3.6**	**2.0**	<1.0	<1.0	<1.0	**2.4**	**1.2**	1.0	mg / L
Alkalinity, Total as HCO3	**246**	**156**	**245**	**216**	**163**	**140**	**47.8**	12.2	mg / L
Alkalinity, Total as CaCO3	**202**	**128**	**201**	**177**	**134**	**115**	**39.2**	5.0	mg / L
Dissolved Organic Carbon	**17.6**	**28.5**	**30.7**	**20.1**	**20.3**	**19.3**	**16.3**	1.0	mg / L
Total Hardness by 2340B	**615**	**227**	**268**	**440**	**354**	**294**	**48.5**	10.0	mg / L
UV Absorbance @ 254 nm	NM	NM	NM	NM	NM	NM	NM	0.009	cm^{-1}
SUVA	NM	NM	NM	NM	NM	NM	NM	0.1	L / mg*m
YSI Data									
pH	**7.1**	**7.0**	**7.1**	**7.9**	**7.8**	**7.5**	**6.7**	± 0.2	Units
Temperature	**14.6**	**14.6**	**13.8**	**15.3**	**15.2**	**14.8**	**13.1**	± 0.1	ºC
Specific Conductance	**1224**	**779**	**476**	**875**	**721**	**568**	**118**	± 1%	uS / cm
Dissolved Oxygen	NM	NM	NM	NM	NM	NM	NM	± 0.01	mg / L
Calculations									
Total Cations	14.5	5.3	5.9	10.0	8.2	6.9	1.3	-	meq
Total Anions	13.1	6.7	5.6	9.7	7.8	6.2	1.2	-	meq
Calculated TDS	887	426	402	651	524	427	88	-	mg/L
Actual TDS - Calc. (diff)	-49.0	-26.9	-93.2	-74.8	-76.8	-55.7	6.9	-	mg/L
% Na to Tot. Cations	12.7	11.2	8.2	12.0	12.5	12.8	14.6	-	%

Bold Print indicates the sample is above the detection limit
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[blue shading] Exceeds MN WQ Standard

Twin Lakes
Inflow / Outflow Sampling Event

10/19/2015

	Little Sandy Inflow 1	Little Sandy Inflow 2	Little Sandy Inflow 3	Little Sandy Middle	Sandy Middle	Twin Lakes Outflow	Culvert Inflow	Reporting Limits	Reporting Units
Analytes - Cations									
Aluminum	**80.8**	<50.0	<50.0	NM	<50.0	<50.0	<50.0	<50.0	ug / L
Arsenic	NM	NM	NM	NM	NM	NM	NM	0.50	ug / L
Barium	NM	NM	NM	NM	NM	NM	NM	10.0	ug / L
Calcium	**91.7**	**68.0**	**45.4**	**59.1**	**47.4**	**42.2**	**10.8**	0.50	mg / L
Iron	**1130**	**218**	**448**	NM	**315**	**479**	**2400**	50.0	ug / L
Magnesium	**133**	**97**	**66.2**	**83.9**	**69.5**	**59.1**	**4.0**	0.50	mg / L
Manganese	**237**	**55.7**	**258**	NM	**42.2**	**54.4**	**133**	10.0	ug / L
Phosphorus	NM	NM	NM	NM	NM	NM	NM	0.10	mg / L
Potassium	**11.6**	**4.1**	**3.3**	NM	**4.7**	**4.3**	**1.6**	0.10	mg / L
Rubidium	NM	NM	NM	NM	NM	NM	NM	1.0	ug / L
Sodium	**52.4**	**30.6**	**21.1**	**31.3**	**26.5**	**23.2**	**4.7**	0.50	mg / L
Strontium	NM	NM	NM	NM	NM	NM	NM	10.0	ug / L
Analytes - Anions									
Chloride	**85.4**	**43.5**	**33.3**	**47.6**	**39.1**	**35.4**	**13.4**	5.0	mg / l
Nitrogen, Kjeldahl, Total	<0.50	**0.86**	**0.86**	**0.81**	**0.86**	**0.77**	**<0.50**	0.50	mg / L
Ammonia as Nitrogen	<0.10	<0.10	<0.10	<0.10	**0.15**	<0.10	<0.10	0.10	mg / L
Unionized Ammonia as N2	<0.04	<0.02	<0.19	<0.38	**2.69**	<.018	<0.02	varies	ug/L
Sulfate	**498**	**340**	**215**	**279**	**223**	**192**	**2.8**	10.0	mg / L
Analytes - Other									
Total Dissolved Solids	**1040**	**737**	**514**	**649**	**546**	**473**	**121**	10.0	mg / L
Total Suspended Solids	**2.4**	**1.2**	**2**	**3.2**	**4**	**4**	**3.5**	1.0	mg / L
Alkalinity, Total as HCO3	**284**	**270**	**224**	**217**	**187**	**163**	**42.1**	12.2	mg / L
Alkalinity, Total as CaCO3	**233**	**221**	**184**	**178**	**153**	**134**	**34.5**	5.0	mg / L
Dissolved Organic Carbon	**9.4**	**17.7**	**21**	**17.8**	**18.9**	**349**	**7.5**	1.0	mg / L
Total Hardness by 2340B	**776**	**569**	**386**	**493**	**405**	**17.5**	**43.3**	10.0	mg / L
UV Absorbance @ 254 nm	NM	NM	NM	NM	NM	NM	NM	0.009	cm^{-1}
SUVA	NM	NM	NM	NM	NM	NM	NM	0.1	L / mg*m
YSI Data									
pH	**7.4**	**7.1**	**8.1**	**8.4**	**8.1**	**8.1**	**7.1**	± 0.2	Units
Temperature	**6.9**	**6.3**	**7.3**	**7.3**	**6.6**	**6.4**	**7.3**	± 0.1	ºC
Specific Conductance	**1435**	**1150**	**943**	**949**	**746**	**666**	**117**	± 1%	uS / cm
Dissolved Oxygen	NM	NM	NM	NM	NM	NM	NM	± 0.01	mg / L
Calculations									
Total Cations	18.1	12.8	8.7	11.2	9.4	8.1	1.2	-	meq
Total Anions	17.5	12.8	9.2	10.8	8.9	7.7	1.2	-	meq
Calculated TDS	1158	854	610	719	598	521	82	-	mg/L
Actual TDS - Calc. (diff)	-118.2	-117.0	-96.3	-69.9	-52.1	-48.0	38.6	-	mg/L
% Na to Tot. Cations	12.6	10.4	10.5	12.1	12.3	12.4	17.0	-	%

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[blue shading] Exceeds MN WQ Standard

Twin Lakes
Inflow / Outflow Sampling Event

5/26/2016

Analytes - Cations	**Little Sandy Inflow 1**	**Little Sandy Inflow 2**	**Little Sandy Inflow 3**	**Little Sandy Middle**	**Sandy Middle**	**Twin Lakes Outflow**	**Culvert Inflow**	**Reporting Limits**	**Reporting Units**
Aluminum	**55.8**	<0.50	<0.50	NM	NM	<0.50	<0.50	**0.50**	ug / L
Arsenic	NM	NM	NM	NM	NM	NM	NM	**0.05**	ug / L
Barium	NM	NM	NM	NM	NM	NM	NM	**10.0**	ug / L
Calcium	**64.7**	**30.7**	**34.5**	**28.2**	**38.3**	**24.3**	**11.3**	**0.50**	mg / L
Iron	**1270**	**531**	**381**	NM	NM	**502**	**1560**	**50.0**	ug / L
Magnesium	**86.4**	**41.9**	**47.5**	**38.3**	**51.3**	**31.2**	**4.1**	**0.50**	mg / L
Manganese	**183**	**51.9**	**77.2**	NM	NM	**46.8**	**62.9**	**10.0**	ug / L
Phosphorus	NM	NM	NM	NM	NM	NM	NM	**0.10**	mg / L
Potassium	**9.5**	**4.6**	**4.3**	**4.0**	**5.2**	**3.5**	**1.6**	**0.50**	mg / L
Rubidium	NM	NM	NM	NM	NM	NM	NM	**1.0**	ug / L
Sodium	**34.8**	**14.3**	**14.8**	**13.5**	**17.5**	**11.5**	**4.1**	**0.50**	mg / L
Strontium	NM	NM	NM	NM	NM	NM	NM	**10.0**	ug / L
Analytes - Anions									
Chloride	**51.8**	**20.5**	**21.7**	**19.8**	**26.4**	**16.4**	**9.4**	**1.0**	mg / l
Nitrogen, Kjeldahl, Total	**0.68**	**0.96**	**0.92**	**0.80**	**0.76**	**0.71**	<0.50	**0.50**	mg / L
Ammonia as Nitrogen	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	**0.10**	mg / L
Unionized ammonia as N	<0.05	<0.06	<0.04	<0.58	<0.42	<0.12	<0.03	varies	ug/L
Sulfate	**338**	**216**	**156**	**129**	**183**	**92.7**	**<2.0**	**2.0**	mg / L
Analytes - Other									
Total Dissolved Solids	**761**	**407**	**417**	**363**	**438**	**295**	**141**	**10.0**	mg / L
Total Suspended Solids	**4.0**	**18.7**	**6.5**	**2.0**	**2.8**	**1.6**	**2.4**	**1.0**	mg / L
Alkalinity, Total as HCO3-	**212**	**146**	**171**	**129**	**168**	**113**	**45.3**	**7.4**	mg / L
Alkalinity, Total as CaCO3	**174**	**120**	**140**	**106**	**138**	**92.4**	**37.1**	**6.1**	mg / L
Dissolved Organic Carbon	**10.5**	**15.6**	**16.2**	NM	NM	**14.8**	**13.9**	**1.0**	mg / L
Total Hardness by 2340B	**517**	**249**	**282**	**228**	**307**	**189**	**45.1**	**3.3**	mg / L
UV Absorbance @ 254 nm	NM	NM	NM	NM	NM	NM	NM	**0.009**	cm^{-1}
SUVA	NM	NM	NM	NM	NM	NM	NM	**0.1**	L / mg*m
YSI Data									
pH	**7.3**	**7.3**	**7.2**	**8.2**	**8.1**	**7.6**	**7.0**	**± 0.2**	Units
Temperature	**15.0**	**16.6**	**15.3**	**18.2**	**17.6**	**16.2**	**14.2**	**± 0.1**	ºC
Specific Conductance	**1109**	**574**	**560**	**682**	**517**	**359**	**112**	**± 1%**	uS / cm
Dissolved Oxygen	NM	NM	NM	NM	NM	NM	NM	**± 0.01**	mg / L
Calculations									
Total Cations	12.1	5.7	6.4	5.1	6.1	4.4	1.2	-	meq
Total Anions	12.0	7.5	6.7	5.4	7.3	4.3	1.1	-	meq
Calculated TDS	800	476	451	358	745	294	80	-	mg/L
Actual TDS - Calc. (diff)	-38.6	-68.9	-34.0	4.9	NM	1.4	61.1	-	mg/L
% Na to Tot. Cations	12.5	10.8	10.1	11.4	12.4	11.4	15.1	-	%

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[blue fill] Exceeds MN WQ Standard

Twin Lakes
Inflow / Outflow Sampling Event

6/24/2016

	Little Sandy	Little Sandy	Little Sandy	Little Sandy	Sandy	Twin Lakes	Culvert	Reporting	Reporting
Analytes - Cations	**Inflow 1**	**Inflow 2**	**Inflow 3**	**Middle**	**Middle**	**Outflow**	**Inflow**	**Limits**	**Units**
Aluminum	<50.0	<200	<200	NM	NM	<200	<200	**200**	ug / L
Arsenic	NM	NM	NM	NM	NM	NM	NM	**0.05**	ug / L
Barium	NM	NM	NM	NM	NM	NM	NM	**10.0**	ug / L
Calcium	**43.6**	**34.0**	**34.4**	**35.5**	**31.5**	**25.2**	**11.8**	**0.50**	mg / L
Iron	**2590**	**929**	**439**	NM	NM	**724**	**5360**	**50.0**	ug / L
Magnesium	**54.5**	**47.5**	**49.0**	**48.9**	**42.9**	**33.4**	**3.9**	**0.50**	mg / L
Manganese	**81.3**	**101**	**82.8**	NM	NM	**70.6**	**411**	**5.0**	ug / L
Phosphorus	NM	NM	NM	NM	NM	NM	NM	**0.10**	mg / L
Potassium	**4.87**	**3.52**	**3.2**	NM	**3.62**	**3.05**	<2.5	**2.50**	mg / L
Rubidium	NM	NM	NM	NM	NM	NM	NM	**1.0**	ug / L
Sodium	**22.5**	**14.9**	**14.6**	**15.9**	**15.2**	**12.4**	**3.1**	**1.0**	mg / L
Strontium	NM	NM	NM	NM	NM	NM	NM	**10.0**	ug / L
Analytes - Anions									
Chloride	**31.8**	21.0	**20.6**	**23.0**	**22.0**	**19.5**	**7.1**	**1.0**	mg / L
Nitrogen, Kjeldahl, Total	**0.73**	0.70	**0.60**	<0.50	<0.50	<0.50	**0.67**	**0.50**	mg / L
Ammonia as Nitrogen	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	**0.10**	mg / L
Unionized ammonia as N	<0.04	<0.07	<0.07	<0.23	<0.22	<0.10	<0.01	varies	ug/L
Sulfate	**212**	160	**163**	**170**	**147**	**114**	<2.0	**2.0**	mg / L
Analytes - Other									
Total Dissolved Solids	**530**	**447**	**447**	**465**	**389**	**316**	**145**	**10.0**	mg / L
Total Suspended Solids	**1.5**	**3.5**	**2.8**	**3.2**	**1.2**	**2.0**	**10**	**1.0**	mg / L
Alkalinity, Total as HCO3-	**182**	**185**	**199**	**182**	**155**	**128**	**49.8**	**7.4**	mg / L
Alkalinity, Total as CaCO3	**149**	**152**	**163**	**149**	**127**	**105**	**40.8**	**6.1**	mg / L
Dissolved Organic Carbon	**23.4**	**26.1**	**21.5**	NM	NM	**18.3**	**25.7**	**1.0**	mg / L
Total Hardness by 2340B	**333**	**281**	**287**	**290**	**255**	201	**45.6**	**3.3**	mg / L
UV Absorbance @ 254 nm	NM	NM	NM	NM	NM	NM	NM	**0.009**	cm^{-1}
SUVA	NM	NM	NM	NM	NM	NM	NM	**0.1**	L / mg*m
YSI Data									
pH	**7.0**	**7.1**	**7.2**	**7.7**	**7.7**	**7.4**	**6.5**	**± 0.2**	Units
Temperature	**19.1**	**22.5**	**20.3**	**22.8**	**22.3**	**21.3**	**19.8**	**± 0.1**	ºC
Specific Conductance	**743**	**606**	**644**	**637**	**540**	**445**	**102**	**± 1%**	uS / cm
Dissolved Oxygen	NM	NM	NM	NM	NM	NM	NM	**± 0.01**	mg / L
Calculations									
Total Cations	7.9	6.4	6.5	6.5	5.8	4.7	1.3	-	meq
Total Anions	8.3	7.0	7.3	7.2	6.3	5.1	1.1	-	meq
Calculated TDS	554	468	485	476	656	337	87	-	mg / L
Actual TDS - Calc. (diff)	-24.5	-21.1	-37.8	-10.6	NM	-20.9	58.4	-	mg / L
% Na to Tot. Cations	12.5	10.2	9.8	10.7	11.5	11.6	10.3	-	%

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Exceeds MN WQ Standard

Twin Lakes
Inflow / Outflow Sampling Event

7/22/2016

	Little Sandy Inflow 1	Little Sandy Inflow 2	Little Sandy Inflow 3	Little Sandy Middle	Sandy Middle	Twin Lakes Outflow	Culvert Inflow	Reporting Limits	Reporting Units
Analytes - Cations									
Aluminum	**284**	**55.0**	**69.1**	NM	NM	**51.0**	**107**	**50.0**	ug / L
Arsenic	NM	NM	NM	NM	NM	NM	NM	**0.50**	ug / L
Barium	NM	NM	NM	NM	NM	NM	NM	**10.0**	ug / L
Calcium	**39.4**	**36.1**	**36.6**	**30.1**	**36.5**	**27.4**	**14.1**	**0.50**	mg / L
Iron	**20700**	**2320**	**3270**	NM	NM	**2510**	**10400**	**50.0**	ug / L
Magnesium	**45.6**	**48.7**	**49.2**	**39.7**	**49.1**	**35.3**	**4.7**	**0.50**	mg / L
Manganese	**429**	**179**	**197**	NM	NM	**138**	**419**	**10.0**	ug / L
Phosphorus	NM	NM	NM	NM	NM	NM	NM	**0.10**	mg / L
Potassium	**2.6**	**2.9**	**2.9**	**2.9**	**3.0**	**2.8**	**0.94**	**0.50**	mg / L
Rubidium	NM	NM	NM	NM	NM	NM	NM	**1.0**	ug / L
Sodium	**17.1**	**15.1**	**15.1**	**13.8**	**15.6**	**12.6**	**3.4**	**0.50**	mg / L
Strontium	NM	NM	NM	NM	NM	NM	NM	**10.0**	ug / L
Analytes - Anions									
Chloride	**20.9**	**17.9**	**17.6**	**17.8**	**18.4**	**16.8**	**7.5**	**1.0**	mg / l
Nitrogen, Kjeldahl, Total	**2.6**	**1.5**	**1.6**	**1.4**	**1.3**	**1.3**	**1.3**	**0.50**	mg / L
Ammonia as Nitrogen	**0.36**	**0.15**	**0.12**	**0.15**	**0.11**	**0.13**	**0.12**	**0.10**	mg / L
Unionized ammonia as N	**0.85**	**0.61**	**1.1**	**1.7**	**1.2**	**1.5**	**0.14**	varies	ug/L
Sulfate	**120**	**121**	**121**	**104**	**125**	**92.1**	**2.3**	**2.0**	mg / L
Analytes - Other									
Total Dissolved Solids	**431**	**409**	**372**	**378**	**398**	**276**	**126**	**10.0**	mg / L
Total Suspended Solids	**14.0**	<2.5	<2.5	**2.0**	<1.0	**3.6**	**5.0**	**1.0**	mg / L
Alkalinity, Total as HCO3-	**187**	**214**	**218**	**139**	**195**	**153**	**49.0**	**7.4**	mg / L
Alkalinity, Total as CaCO3	**153**	**175**	**179**	**114**	**160**	**125**	**40.2**	**6.1**	mg / L
Dissolved Organic Carbon	**63.7**	**36.1**	**38.2**	NM	NM	**31.6**	**35.4**	**1.0**	mg / L
Total Hardness by 2340B	**286**	**291**	**294**	**239**	**293**	**214**	**54.5**	**3.3**	mg / L
UV Absorbance @ 254 nm	NM	NM	NM	NM	NM	NM	NM	**0.009**	cm^{-1}
SUVA	NM	NM	NM	NM	NM	NM	NM	**0.1**	L / mg*m
YSI Data									
pH	**6.7**	**6.9**	**7.3**	**7.3**	**7.3**	**7.3**	**6.5**	**± 0.2**	Units
Temperature	**21.4**	**24.2**	**23.6**	**25.1**	**24.8**	**25.0**	**19.2**	**± 0.1**	ºC
Specific Conductance	**547**	**572**	**585**	**567**	**459**	**422**	**107**	**± 1%**	uS / cm
Dissolved Oxygen	NM	NM	NM	NM	NM	NM	NM	**± 0.01**	mg / L
Calculations									
Total Cations	7.3	6.6	6.7	5.4	6.6	5.0	1.6	-	meq
Total Anions	6.3	6.6	6.7	5.0	6.4	5.0	1.2	-	meq
Calculated TDS	456	459	466	346	717	343	94	-	mg/L
Actual TDS - Calc. (diff)	-25.0	-50.2	-93.8	32.1	NM	-67.4	31.9	-	mg/L
% Na to Tot. Cations	10.2	9.9	9.8	11.2	10.3	11.0	9.0	-	%

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Twin Lakes
Inflow / Outflow Sampling Event

8/25/2016

Analytes - Cations	**Little Sandy Inflow 1**	**Little Sandy Inflow 2**	**Little Sandy Inflow 3**	**Little Sandy Middle**	**Sandy Middle**	**Twin Lakes Outflow**	**Culvert Inflow**	**Reporting Limits**	**Reporting Units**
Aluminum	**70.5**	**111**	<10.0	NM	NM	**57.3**	**132**	50.0	ug / L
Arsenic	NM	NM	NM	NM	NM	NM	NM	0.50	ug / L
Barium	NM	NM	NM	NM	NM	NM	NM	10.0	ug / L
Calcium	**69.6**	**38.6**	**40.0**	NM	NM	**28.0**	**14.2**	0.50	mg / L
Iron	**2060**	**2250**	**1650**	NM	NM	**3280**	**10700**	50.0	ug / L
Magnesium	**99.3**	**53.5**	**56.0**	NM	NM	**33.4**	**4.9**	0.50	mg / L
Manganese	**138**	**214**	**220**	NM	NM	**136**	**304**	10.0	ug / L
Phosphorus	NM	NM	NM	NM	NM	NM	NM	0.10	mg / L
Potassium	**5.5**	**2.3**	**2.5**	NM	NM	**2.2**	**1.1**	0.50	mg / L
Rubidium	NM	NM	NM	NM	NM	NM	NM	1.0	ug / L
Sodium	**39.0**	**15.4**	**16.8**	NM	NM	**11.7**	**4.1**	0.50	mg / L
Strontium	NM	NM	NM	NM	NM	NM	NM	10.0	ug / L
Analytes - Anions									
Chloride	**56.5**	**18.6**	**20.2**	NM	NM	**15.4**	**9.5**	1.0	mg / l
Nitrogen, Kjeldahl, Total	**0.87**	**2.1**	**1.3**	NM	NM	**1.5**	**0.99**	0.50	mg / L
Ammonia as Nitrogen	<0.10	**0.29**	**0.16**	NM	NM	**0.32**	<0.10	0.10	mg / L
Unionized ammonia as N	<0.50	**2.94**	**0.91**	NM	NM	**2.5**	<0.14	varies	ug/L
Sulfate	**314**	**96.7**	**108**	NM	NM	**64.3**	<2.0	2.0	mg / L
Analytes - Other									
Total Dissolved Solids	**836**	**434**	**473**	NM	NM	**356**	**155**	10.0	mg / L
Total Suspended Solids	**2.8**	**22.0**	**5.2**	NM	NM	<1.0	**26.0**	1.7	mg / L
Alkalinity, Total as HCO3-	**339**	**293**	**289**	NM	NM	**185**	**59**	7.4	mg / L
Alkalinity, Total as CaCO3	**278**	**240**	**237**	NM	NM	**152**	**48.4**	6.1	mg / L
Dissolved Organic Carbon	**22.1**	**38.9**	**37.1**	NM	NM	**39.1**	**26.9**	1.0	mg / L
Total Hardness by 2340B	**582**	**317**	**330**	NM	NM	**207**	**55.5**	3.3	mg / L
UV Absorbance @ 254 nm	NM	NM	NM	NM	NM	NM	NM	0.009	cm^{-1}
SUVA	NM	NM	NM	NM	NM	NM	NM	0.1	L / mg*m
YSI Data									
pH	**7.1**	**7.4**	**7.2**	NM	NM	**7.3**	**6.7**	± 0.2	Units
Temperature	**19.1**	**20.2**	**19.8**	NM	NM	**20.0**	**16.1**	± 0.1	ºC
Specific Conductance	**1141**	**600**	**576**	NM	NM	**417**	**119**	± 1%	uS / cm
Dissolved Oxygen	NM	NM	NM	NM	NM	NM	NM	± 0.01	mg / L
Calculations									
Total Cations	13.6	7.1	7.5	NM	NM	4.8	1.7	-	meq
Total Anions	13.8	7.5	7.7	NM	NM	4.9	1.3	-	meq
Calculated TDS	926	522	536	NM	NM	345	107	-	mg/L
Actual TDS - Calc. (diff)	-90.1	-88.5	-62.8	NM	NM	10.6	48.2	-	mg/L
% Na to Tot. Cations	12.5	9.4	9.8	NM	NM	10.5	10.4	-	%

Bold Print indicates the sample is above the detection limit
"<" indicates value below reporting limit
NM indicates that the analyte was not measured
[blue fill] Exceeds MN WQ Standard

TWIN LAKES
INFLOW / OUTFLOW SAMPLING EVENT

9/28/2016

ANALYTES - CATIONS	Little Sandy Inflow 1	Little Sandy Inflow 2	Little Sandy Inflow 3	Little Sandy Middle	Sandy Middle	Twin Lakes Outflow	Culvert Inflow	Reporting Limits	Reporting Units
Aluminum	**84.6**	<50.0	<50.0	NM	NM	<50.0	**54.5**	**50.0**	ug / L
Arsenic	NM	NM	NM	NM	NM	NM	NM	**0.50**	ug / L
Barium	NM	NM	NM	NM	NM	NM	NM	**10.0**	ug / L
Calcium	**54.4**	**47.4**	**30.9**	NM	NM	**28.6**	**10.4**	**0.50**	mg / L
Iron	**1150**	**455**	**353**	NM	NM	**1420**	**2750**	**50.0**	ug / L
Magnesium	**72.6**	**65.9**	**49.4**	NM	NM	**36.0**	**3.7**	**0.50**	mg / L
Manganese	**84.7**	**84.0**	**90.6**	NM	NM	**54.1**	**101**	**10.0**	ug / L
Phosphorus	NM	NM	NM	NM	NM	NM	NM	**0.10**	mg / L
Potassium	**5.8**	**3.3**	**1.5**	NM	NM	**2.6**	**1.5**	**0.50**	mg / L
Rubidium	NM	NM	NM	NM	NM	NM	NM	**1.0**	ug / L
Sodium	**28.4**	**20.9**	**9.2**	NM	NM	**13.3**	**4.0**	**0.50**	mg / L
Strontium	NM	NM	NM	NM	NM	NM	NM	**10.0**	ug / L
ANALYTES - ANIONS									
Chloride	**47.0**	**31.5**	**12.5**	NM	NM	**21.1**	**10.4**	**1.0**	mg / l
Nitrogen, Kjeldahl, Total	**0.71**	**0.88**	**0.85**	NM	NM	**0.94**	<0.60	**0.60**	mg / L
Ammonia as Nitrogen	<0.10	<0.10	<0.10	NM	NM	**0.11**	<0.10	**0.10**	mg / L
Unionized ammonia as N	<0.36	<1.3	<0.59	NM	NM	**1.0**	<0.12	varies	ug/L
Sulfate	**229**	**165**	**39.6**	NM	NM	**81.9**	<2.0	**2.0**	mg / L
ANALYTES - OTHER									
Total Dissolved Solids	**661**	**561**	**367**	NM	NM	**346**	**120**	**10.0**	mg / L
Total Suspended Solids	**3.2**	**3.6**	**2.4**	NM	NM	**2.4**	**3.5**	**1.0**	mg / L
Alkalinity, Total as HCO3-	**253**	**306**	**311**	NM	NM	**177**	**42**	12.3	mg / L
Alkalinity, Total as CaCO3	**207**	**251**	**255**	NM	NM	**145**	**34.8**	**6.1**	mg / L
Dissolved Organic Carbon	**19.5**	**27.7**	**32.2**	NM	NM	**27.9**	**16.9**	**1.0**	mg / L
Total Hardness by 2340B	**435**	**390**	**280**	NM	NM	**220**	**41.2**	**3.3**	mg / L
UV Absorbance @ 254 nm	NM	NM	NM	NM	NM	NM	NM	**0.009**	cm^{-1}
SUVA	NM	NM	NM	NM	NM	NM	NM	**0.1**	L / mg*m
YSI DATA									
pH	**7.3**	**7.8**	**7.4**	NM	NM	**7.6**	**6.8**	**± 0.2**	Units
Temperature	**10.9**	**11.7**	**11.8**	NM	NM	**11.0**	**11.2**	**± 0.1**	ºC
Specific Conductance	**895**	**781**	**517**	NM	NM	**462**	**103**	**± 1%**	uS / cm
Dissolved Oxygen	NM	NM	NM	NM	NM	NM	NM	**± 0.01**	mg / L
CALCULATIONS									
Total Cations	10.1	8.8	6.1	NM	NM	5.1	1.1	-	meq
Total Anions	10.3	9.4	6.3	NM	NM	5.3	1.1	-	meq
Calculated TDS	692	642	455	NM	NM	363	78	-	mg/L
Actual TDS - Calc. (diff)	-30.7	-80.6	-88.5	NM	NM	-16.8	41.8	-	mg/L
% Na to Tot. Cations	12.2	10.3	6.6	NM	NM	11.4	15.2	-	%

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(blue shading) Exceeds MN WQ Standard

Twin Lakes
Inflow / Outflow Sampling Event

10/20/2016

Analytes - Cations	Little Sandy Inflow 1	Little Sandy Inflow 2	Little Sandy Inflow 3	Little Sandy Middle	Sandy Middle	Twin Lakes Outflow	Culvert Inflow	Reporting Limits	Reporting Units
Aluminum	**83.1**	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	**50.0**	ug / L
Arsenic	NM	NM	NM	NM	NM	NM	NM	**0.50**	ug / L
Barium	NM	NM	NM	NM	NM	NM	NM	**10.0**	ug / L
Calcium	**63.7**	**47.2**	**30.1**	**46.0**	**38.7**	**33.4**	**10.0**	**0.50**	mg / L
Iron	**1250**	**442**	**268**	**388**	**650**	**880**	**2220**	**50.0**	ug / L
Magnesium	**92.4**	**69.1**	**54.2**	**67.2**	**55.6**	**46.5**	**3.8**	**0.50**	mg / L
Manganese	**143**	**96.1**	**94.1**	**63.3**	**38.4**	**68.1**	**98.7**	**10.0**	ug / L
Phosphorus	NM	NM	NM	NM	NM	NM	NM	**0.10**	mg / L
Potassium	**7.7**	**3.9**	**1.5**	**4.1**	**3.6**	**3.1**	**1.6**	**0.50**	mg / L
Rubidium	NM	NM	NM	NM	NM	NM	NM	**1.0**	ug / L
Sodium	**35.7**	**23.0**	**10.6**	**23.0**	**20.1**	**17.1**	**4.2**	**0.50**	mg / L
Strontium	NM	NM	NM	NM	NM	NM	NM	**10.0**	ug / L
Analytes - Anions									
Chloride	**53.6**	**33.7**	**15.1**	**34.7**	**30.2**	**26.1**	**10.6**	**1.0**	mg / l
Nitrogen, Kjeldahl, Total	<0.60	**0.80**	**0.66**	**0.75**	**0.79**	**0.79**	<0.60	**0.60**	mg / L
Ammonia as Nitrogen	<0.10	<0.10	<0.10	<0.10	<.010	<0.10	<0.10	**0.10**	mg / L
Unionized ammonia as N	<0.18	<0.10	<0.20	<1.4	<1.3	<0.59	<0.13	varies	ug/L
Sulfate	**294**	**172**	**84.3**	**176**	**135**	**109**	**<2.0**	**2.0**	mg / L
Analytes - Other									
Total Dissolved Solids	**739**	**532**	**375**	**548**	**460**	**392**	**113**	**10.0**	mg / L
Total Suspended Solids	**2.4**	**4.4**	**2.0**	**2.4**	**1.6**	**2.0**	**3.2**	**1.0**	mg / L
Alkalinity, Total as HCO3-	**262**	**264**	**260**	**271**	**218**	**179**	**44.7**	7.4	mg / L
Alkalinity, Total as CaCO3	**215**	**216**	**213**	**222**	**179**	**147**	**36.6**	**6.1**	mg / L
Dissolved Organic Carbon	**15.0**	**22.3**	**24.0**	**21.6**	**25.1**	**23.8**	**11.7**	**1.0**	mg / L
Total Hardness by 2340B	**540**	**402**	**298**	**392**	**326**	**275**	**40.4**	**3.3**	mg / L
UV Absorbance @ 254 nm	NM	NM	NM	NM	NM	NM	NM	**0.009**	cm^{-1}
SUVA	NM	NM	NM	NM	NM	NM	NM	**0.1**	L / mg*m
YSI Data									
pH	**7.1**	**6.9**	**7.2**	**8.0**	**8.0**	**7.6**	**7.0**	**± 0.2**	Units
Temperature	**5.8**	**6.0**	**5.4**	**7.6**	**7.3**	**6.5**	**5.8**	**± 0.1**	ºC
Specific Conductance	**1057**	**632**	**526**	**732**	**619**	**527**	**105**	**± 1%**	uS / cm
Dissolved Oxygen	NM	NM	NM	NM	NM	NM	NM	**± 0.01**	mg / L
Calculations									
Total Cations	12.6	9.2	5.8	8.9	7.5	6.3	1.1	-	meq
Total Anions	12.0	8.9	5.2	9.1	7.3	6.0	1.1	-	meq
Calculated TDS	811	614	358	352	610	416	80	-	mg/L
Actual TDS - Calc. (diff)	-72.4	-81.8	-44.3	195.8	NM	-24.3	33.2	-	mg/L
% Na to Tot. Cations	12.3	10.9	9.4	11.2	11.7	11.7	16.3	-	%

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Twin Lakes
Inflow / Outflow Sampling Event

5/25/2017

Analytes - Cations	Little Sandy Inflow 1	Little Sandy Inflow 2	Sandy South Inflow	Little Sandy Middle	Sandy Middle	Twin Lakes Outflow	Culvert Inflow	Reporting Limits	Reporting Units
Calcium	**48.2**	**30.0**	**4.8**	**37.3**	**27.3**	**25.8**	**11.0**	0.50	mg / L
Iron	**831**	**784**	**448**	**408**	**377**	**527**	**1610**	50.0	ug / L
Magnesium	**65.1**	**44.1**	**5.8**	**53.1**	**38.3**	**34.7**	**3.8**	0.50	mg / L
Manganese	**48.1**	**32.7**	<10.0	**24.7**	**22.7**	**38.5**	**86.7**	10.0	ug / L
Potassium	**6.9**	**3.4**	**0.69**	**4.8**	**3.6**	**3.4**	**1.7**	0.50	mg / L
Sodium	**25.8**	**12.5**	**5.6**	**17.4**	**12.6**	**11.7**	**4.0**	0.50	mg / L
Analytes - Anions									
Chloride	**39.1**	**16.6**	**10.4**	**24.4**	**18.2**	**17.5**	**10.4**	1.0	mg / l
Nitrogen, Kjeldahl, Total	**<0.60**	**0.89**	**0.64**	<0.60	**1.3**	**0.66**	<0.60	0.60	mg / L
Ammonia as Nitrogen	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	0.10	mg / L
Unionized ammonia as N	<0.05	<1.0	<0.38	<0.08	<0.04	<0.14	<0.17	varies	ug/L
Sulfate	**250**	**126**	**6.9**	**173**	**122**	**110**	**2.1**	2.0	mg / L
Analytes - Other									
Total Dissolved Solids	**534**	**314**	**74.0**	**367**	**281**	**269**	**61.0**	10.0	mg / L
Total Suspended Solids	**1.2**	**2.0**	**1.6**	**<1.0**	<1.0	**1.2**	**2.0**	1.2	mg / L
Alkalinity, Total as HCO3-	**134**	**124**	**17.9**	**132**	**100**	**94.0**	**30.9**	12.3	mg / L
Alkalinity, Total as CaCO3	**110**	**102**	**14.7**	**108**	**82**	**77.0**	**25.3**	10.1	mg / L
Dissolved Organic Carbon	**13.1**	**23.3**	**19.4**	**15.2**	**16.2**	**15.5**	**12.0**	1.0	mg / L
Total Hardness by 2340B	**388**	**257**	**36.0**	**312**	**226**	**207**	**43.0**	3.3	mg / L
YSI Data									
pH	**7.4**	**7.6**	**7.3**	**7.6**	**7.3**	**7.8**	**7.9**	± 0.2	Units
Temperature	**10.6**	**13.5**	**9.4**	**12.6**	**12.7**	**11.5**	**11.6**	± 0.1	ºC
Specific Conductance	**802**	**527**	**97**	**620**	**472**	**430**	**105**	± 1%	uS / cm
Calculations									
Total Cations	**9.1**	**5.8**	**1.0**	**7.1**	**5.2**	**4.8**	**1.1**	-	meq
Total Anions	**8.5**	**5.2**	**0.8**	**6.5**	**4.8**	**4.4**	**0.9**	-	meq
Calculated TDS	**571**	**358**	**53**	**443**	**324**	**298**	**66**	-	mg/L
Actual TDS - Calc. (diff)	**-36.6**	**-44.3**	**20.8**	**-76.0**	**-42.7**	**-29.3**	**-5.2**	-	mg/L
% Na to Tot. Cations	**12.3**	**9.4**	**24.5**	**10.6**	**10.6**	**10.7**	**15.3**	-	%

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Exceeds MN WQ Standard (blue shading)

Twin Lakes
Inflow / Outflow Sampling Event

6/22/2017

	Little Sandy Inflow 1	Little Sandy Inflow 2	Sandy South Inflow	Little Sandy Middle	Sandy Middle	Twin Lakes Outflow	Culvert Inflow	Reporting Limits	Reporting Units
Analytes - Cations									
Calcium	**47.0**	**34.6**	**7.8**	**40.4**	**34.1**	**29.0**	**10.8**	0.50	mg / L
Iron	**1780**	**1160**	**2380**	**387**	**325**	**740**	**3270**	50.0	ug / L
Magnesium	**63.1**	**50.3**	**9.0**	**58.7**	**47.6**	**37.9**	**3.6**	0.50	mg / L
Manganese	**87.9**	**95.9**	**59.6**	**121**	**111**	**125**	**143**	10.0	ug / L
Potassium	**4.3**	**3.1**	**0.79**	**3.8**	**4.0**	**3.4**	**0.99**	0.50	mg / L
Sodium	**24.4**	**14.4**	**8.3**	**17.3**	**15.9**	**13.2**	**4.0**	0.50	mg / L
Analytes - Anions									
Chloride	**31.5**	**17.7**	**16.1**	**23.7**	**22.7**	**19.6**	**8.8**	varies	mg / L
Nitrogen, Kjeldahl, Total	**0.77**	**1.0**	**0.94**	**0.73**	**0.94**	**0.84**	**0.68**	0.60	mg / L
Ammonia as Nitrogen	<0.10	<0.10	**0.14**	<0.10	<0.10	<0.10	<0.10	0.10	mg / L
Unionized ammonia as N	<0.08	<0.53	**0.14**	<0.29	<0.21	<0.14	<0.02	varies	ug/L
Sulfate	**217**	**136**	**<2.0**	**170**	**145**	**116**	<2.0	varies	mg / L
Analytes - Other									
Total Dissolved Solids	**598**	**434**	**154**	**490**	**437**	**387**	**115**	10.0	mg / L
Total Suspended Solids	**2.0**	**5.6**	**2.4**	**1.6**	**1.2**	**2.4**	**6.0**	1.0/5.0	mg / L
Alkalinity, Total as HCO3-	**143**	**138**	**45.2**	**158**	**129**	**108**	**28.4**	12.3	mg / L
Alkalinity, Total as CaCO3	**117**	**113**	**37.0**	**130**	**106**	**88.5**	**23.3**	10.1	mg / L
Dissolved Organic Carbon	**21.4**	**24.0**	**31.3**	**19.0**	**17.5**	**17.2**	**21.8**	1.0	mg / L
Total Hardness by 2340B	**377**	**293**	**56.6**	**343**	**281**	**228**	**41.9**	3.3	mg / L
YSI Data									
pH	**7.4**	**7.1**	**6.6**	**7.9**	**7.7**	**7.6**	**6.7**	± 0.2	Units
Temperature	**18.0**	**20.7**	**14.7**	**20.0**	**19.8**	**18.7**	**16.4**	± 0.1	ºC
Specific Conductance	**748**	**496**	**135**	**655**	**560**	**473**	**91.5**	± 1%	uS / cm
Calculations									
Total Cations	**8.8**	**6.6**	**1.6**	**7.7**	**6.4**	**5.3**	**1.2**	-	meq
Total Anions	**7.8**	**5.7**	**1.3**	**6.9**	**5.8**	**4.8**	**0.8**	-	meq
Calculated TDS	**533**	**396**	**91**	**473**	**400**	**329**	**63**	-	mg/L
Actual TDS - Calc. (diff)	**65.1**	**37.6**	**63.4**	**16.9**	**37.3**	**58.2**	**52.3**	-	mg/L
% Na to Tot. Cations	**12.1**	**9.5**	**22.6**	**9.8**	**10.8**	**10.9**	**15.0**	-	%

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[blue shading] Exceeds MN WQ Standard

Note: In the Sulfate row, the values for Little Sandy Inflow 1 (217), Little Sandy Inflow 2 (136), Little Sandy Middle (170), Sandy Middle (145) and Twin Lakes Outflow (116) are shaded blue.

Twin Lakes
Inflow / Outflow Sampling Event

7/27/2017

	Little Sandy Inflow 1	Little Sandy Inflow 2	Sandy South Inflow	Little Sandy Middle	Sandy Middle	Twin Lakes Outflow	Culvert Inflow	Reporting Limits	Reporting Units
Analytes - Cations									
Calcium	**74.6**	**49.5**	**14.7**	**47.1**	**37.2**	**32.1**	**15.9**	0.50	mg / L
Iron	**1180**	**609**	**15000**	**257**	**421**	**657**	**3410**	50.0	ug / L
Magnesium	**109**	**69.9**	**14.6**	**68.1**	**53.1**	**41.9**	**5.2**	0.50	mg / L
Manganese	**18.5**	**141**	**313**	**85**	**99.7**	**88.3**	**158**	10.0	ug / L
Potassium	**3.7**	**2.2**	**1.3**	**3.0**	**3.1**	**2.8**	**1.4**	0.50	mg / L
Sodium	**42**	**18.8**	**8.4**	**21.1**	**17.5**	**14.6**	**4.7**	0.50	mg / L
Analytes - Anions									
Chloride	**58.2**	**25.3**	**15.9**	**27.6**	**24.0**	**21.0**	**14.2**	1.0/4.0	mg / l
Nitrogen, Kjeldahl, Total	**0.94**	**1.0**	**2.3**	**0.79**	**0.97**	**0.89**	<0.60	0.60	mg / L
Ammonia as Nitrogen	<0.10	<0.10	**0.62**	<0.10	<0.10	<0.10	<0.10	0.10	mg / L
Unionized ammonia as N	<0.11	<0.40	**0.77**	<0.96	<0.13	<0.19	<0.02	varies	ug/L
Sulfate	**388**	**183**	<2.0	**195**	**149**	**113**	**2.8**	2.0/8.0	mg / L
Analytes - Other									
Total Dissolved Solids	**863**	**511**	**218**	**461**	**412**	**330**	**116**	10.0	mg / L
Total Suspended Solids	**<2.5**	**5.0**	**22**	**4.0**	<2.5	**3.0**	**6.0**	2.5/5.0	mg / L
Alkalinity, Total as HCO3-	**246**	**218**	**85.5**	**205**	**162**	**146**	**46.7**	12.3	mg / L
Alkalinity, Total as CaCO3	**202**	**179**	**70.1**	**168**	**133**	**120**	**38.3**	12.3	mg / L
Dissolved Organic Carbon	**25.6**	**25.1**	**55.6**	**23.8**	**26.2**	**23.6**	**13.2**	1.0/2.0	mg / L
Total Hardness by 2340B	**636**	**411**	**96.6**	**398**	**311**	**253**	**61**	3.3	mg / L
YSI Data									
pH	**7.4**	**7.0**	**6.6**	**8.3**	**7.4**	**7.6**	**6.7**	± 0.2	Units
Temperature	**22.5**	**20.0**	**17.1**	**24.0**	**23.0**	**21.7**	**18.2**	± 0.1	ºC
Specific Conductance	**1228**	**796**	**219**	**788**	**606**	**514**	**143**	± 1%	uS / cm
Calculations									
Total Cations	**14.7**	**9.1**	**2.9**	**9.0**	**7.1**	**5.8**	**1.6**	-	meq
Total Anions	**13.8**	**8.2**	**2.0**	**8.3**	**6.5**	**5.4**	**1.3**	-	meq
Calculated TDS	**924**	**568**	**158**	**568**	**447**	**373**	**95**	-	mg/L
Actual TDS - Calc. (diff)	**-60.6**	**-57.5**	**60.0**	**-107.0**	**-35.4**	**-43.0**	**20.9**	-	mg/L
% Na to Tot. Cations	**12.5**	**9.0**	**12.7**	**10.2**	**10.7**	**11.0**	**12.9**	-	%

Bold Print indicates the sample is above the detection limit

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NM indicates that the analyte was not measured

(blue shading) Exceeds MN WQ Standard

Twin Lakes
Inflow / Outflow Sampling Event

8/24/2017

	Little Sandy Inflow 1	Little Sandy Inflow 2	Sandy South Inflow	Little Sandy Middle	Sandy Middle	Twin Lakes Outflow	Culvert Inflow	Reporting Limits	Reporting Units
Analytes - Cations									
Calcium	**57.9**	**45.4**	**10.6**	**46.6**	**36.4**	**30.5**	**14.0**	0.50	mg / L
Iron	**1090**	**327**	**4000**	**233**	**208**	**450**	**3040**	50.0	ug / L
Magnesium	**80.5**	**69.5**	**12.6**	**71.1**	**54.2**	**42.8**	**4.7**	0.50	mg / L
Manganese	**54.0**	**68.3**	**170**	**69.3**	**34.1**	**41.7**	**120**	10.0	ug / L
Potassium	**3.8**	**2.8**	**1.6**	**3.0**	**2.9**	**2.6**	**1.4**	0.50	mg / L
Sodium	**30.3**	**21.2**	**9.3**	**22.6**	**18.8**	**15.4**	**4.6**	0.50	mg / L
Analytes - Anions									
Chloride	**44.1**	**26.9**	**19.6**	**29.8**	**24.6**	**22.2**	**12.5**	1.0/2.0	mg / l
Nitrogen, Kjeldahl, Total	**0.63**	**0.81**	**0.97**	<0.60	**0.70**	**0.86**	<0.60	0.60	mg / L
Ammonia as Nitrogen	<0.10	<0.10	**0.13**	<0.10	<0.10	<0.10	<0.10	0.10	mg / L
Unionized ammonia as N	<0.04	<2.2	**0.09**	<4.2	<4.0	<1.5	<0.38	varies	ug/L
Sulfate	**290**	**186**	**<2.0**	**201**	**146**	**117**	**3.0**	2.0/4.0	mg / L
Analytes - Other									
Total Dissolved Solids	**647**	**505**	**157**	**507**	**399**	**340**	**109**	10.0	mg / L
Total Suspended Solids	**2.0**	**3.6**	<1.7	**1.6**	<1.0	**2.0**	**2.8**	1.0/1.7	mg / L
Alkalinity, Total as HCO3-	**186**	**217**	**64.6**	**211**	**170**	**144**	**48.9**	6.1	mg / L
Alkalinity, Total as CaCO3	**152**	**178**	**53.0**	**173**	**139**	**118**	**40.1**	6.1	mg / L
Dissolved Organic Carbon	**22.6**	**23.6**	**35.0**	**21.8**	**22.6**	**22.0**	**15.3**	1.0/2.0	mg / L
Total Hardness by 2340B	**476**	**399**	**78.1**	**409**	**314**	**253**	**54.2**	3.3	mg / L
YSI Data									
pH	**7.2**	**7.8**	**6.5**	**8.1**	**8.1**	**7.7**	**7.2**	± 0.2	Units
Temperature	**14.7**	**18.9**	**13.1**	**18.4**	**18.0**	**16.3**	**13.7**	± 0.1	ºC
Specific Conductance	**943**	**700**	**182**	**780**	**600**	**521**	**121**	± 1%	uS / cm
Calculations									
Total Cations	**11.0**	**9.0**	**2.2**	**9.2**	**7.2**	**5.8**	**1.4**	-	meq
Total Anions	**10.4**	**8.2**	**1.7**	**8.5**	**6.6**	**5.5**	**1.3**	-	meq
Calculated TDS	**694**	**570**	**123**	**586**	**454**	**376**	**93**	-	mg/L
Actual TDS - Calc. (diff)	**-47.4**	**-65.0**	**33.6**	**-79.0**	**-54.8**	**-35.9**	**16.1**	-	mg/L
% Na to Tot. Cations	**12.0**	**10.3**	**18.7**	**10.6**	**11.4**	**11.6**	**13.9**	-	%

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[blue shading] Exceeds MN WQ Standard

Twin Lakes
Inflow / Outflow Sampling Event

9/28/2017

Analytes - Cations	Little Sandy Inflow 1	Little Sandy Inflow 2	Sandy South Inflow	Little Sandy Middle	Sandy Middle	Twin Lakes Outflow	Culvert Inflow	Reporting Limits	Reporting Units
Calcium	**50.7**	**42.8**	**8.6**	**44.3**	**37.3**	**28.0**	**11**	**0.50**	mg / L
Iron	**1810**	**671**	**3880**	**479**	**1050**	**1330**	**3550**	**50.0**	ug / L
Magnesium	**70.7**	**66.8**	**10.2**	**68.8**	**56**	**39.0**	**3.8**	0.50	mg / L
Manganese	**76.6**	**58.6**	**142**	**56.5**	**57.6**	**68.2**	**156**	10.0	ug / L
Potassium	**5.9**	**2.9**	**2.3**	**3.4**	**3.1**	**2.5**	**1.6**	0.50	mg / L
Sodium	**26.8**	**18.6**	**8.7**	**21.1**	**18.6**	**13.9**	**4.1**	0.50	mg / L
Analytes - Anions									
Chloride	**43.2**	**27.7**	**21.6**	**32.3**	**28.4**	**22.1**	**11.4**	varies	mg / l
Nitrogen, Kjeldahl, Total	**0.64**	**0.86**	**0.69**	**0.61**	**0.80**	**0.68**	**0.57**	0.60/0.50	mg / L
Ammonia as Nitrogen	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	0.10	mg / L
Unionized ammonia as N	<0.06	<1.0	**<0.32**	**<2.4**	**<1.3**	**<1.1**	**<0.17**	varies	ug/L
Sulfate	**230**	**170**	**<2.0**	**192**	**153**	**99.5**	<2.0	2.0/8.0	mg / L
Analytes - Other									
Total Dissolved Solids	**360**	**468**	**116**	**472**	**376**	**272**	**80**	40.0	mg / L
Total Suspended Solids	**1.2**	**2.0**	**1.6**	**1.6**	**1.6**	**1.6**	**4.0**	1.0	mg / L
Alkalinity, Total as HCO3-	**181**	**223**	**52.3**	**220**	**178**	**132**	**36.2**	12.3	mg / L
Alkalinity, Total as CaCO3	**148**	**183**	**42.9**	**180**	**146**	**108**	**29.7**	12.3	mg / L
Dissolved Organic Carbon	**21.6**	**24.2**	**26.2**	**22.7**	**24.9**	**24.1**	**20.4**	1.0/2.0	mg / L
Total Hardness by 2340B	**418**	**382**	**63.5**	**394**	**324**	**231**	**42.9**	3.3	mg / L
YSI Data									
pH	**7.4**	**7.6**	**7.1**	**7.9**	**7.7**	**7.6**	**6.9**	**± 0.2**	Units
Temperature	**13.1**	**14.8**	**12.7**	**15.1**	**14.7**	**13.6**	**11.6**	**± 0.1**	ºC
Specific Conductance	**863**	**763**	**171**	**802**	**673**	**480**	**65.5**	**± 1%**	uS / cm
Calculations									
Total Cations	**9.7**	**8.5**	**1.8**	**8.9**	**7.4**	**5.3**	**1.2**	-	meq
Total Anions	**9.0**	**8.0**	**1.5**	**8.6**	**7.0**	**4.9**	**1.0**	-	meq
Calculated TDS	**611**	**553**	**108**	**583**	**476**	**339**	**74**	-	mg/L
Actual TDS - Calc. (diff)	**-250.8**	**-85.4**	**7.6**	**-111.0**	**-100.3**	**-67.1**	**5.6**	-	mg/L
% Na to Tot. Cations	**12.0**	**9.5**	**20.5**	**10.3**	**10.9**	**11.4**	**14.7**	-	%

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[blue shading] Exceeds MN WQ Standard

Twin Lakes
Inflow / Outflow Sampling Event

10/26/2017

	Little Sandy Inflow 1	Little Sandy Inflow 2	Sandy South Inflow	Little Sandy Middle	Sandy Middle	Twin Lakes Outflow	Culvert Inflow	Reporting Limits	Reporting Units
Analytes - Cations									
Calcium	**56.4**	**41.1**	**7.8**	**41.2**	**34.5**	**31.3**	**11.2**	0.50	mg / L
Iron	**1840**	**1020**	**3750**	**722**	**1100**	**1080**	**2710**	50.0	ug / L
Magnesium	**81.5**	**63.8**	**9.7**	**62.3**	**52.2**	**45.2**	**3.9**	0.50	mg / L
Manganese	**106**	**42.4**	**128**	**29.5**	**43.3**	**41.6**	**129**	10.0	ug / L
Potassium	**7.2**	**3.4**	**1.8**	**3.9**	**3.5**	**3.1**	**1.5**	0.50	mg / L
Sodium	**30.7**	**18.0**	**7.8**	**19.4**	**17.2**	**15.6**	**4.4**	0.50	mg / L
Analytes - Anions									
Chloride	**50.1**	**28.6**	**16.7**	**31.4**	**28.3**	**26.0**	**12.9**	2.0	mg / l
Nitrogen, Kjeldahl, Total	**0.70**	**0.83**	**0.83**	**0.65**	**0.76**	**0.82**	**0.46**	0.20	mg / L
Ammonia as Nitrogen	<0.10	**0.14**	**0.19**	**0.10**	**0.18**	**0.15**	**0.16**	0.10	mg / L
Unionized ammonia as N	<0.03	**0.58**	**0.11**	**1.8**	**2.8**	**1.3**	**0.13**	varies	ug/L
Sulfate	**282**	**176**	**2.3**	**190**	**152**	**128**	**2.8**	4.0	mg / L
Analytes - Other									
Total Dissolved Solids	**674**	**474**	**126**	**446**	**412**	**390**	**84.0**	10.0	mg / L
Total Suspended Solids	**1.2**	**1.6**	**2.0**	<1.0	<1.0	**1.2**	**3.2**	1.0	mg / L
Alkalinity, Total as HCO3-	**174**	**171**	**42.6**	**162**	**133**	**119**	**36.3**	10.0	mg / L
Alkalinity, Total as CaCO3	**143**	**140**	**34.9**	**133**	**109**	**97.5**	**29.8**	10.0	mg / L
Dissolved Organic Carbon	**20.4**	**25.6**	**25.7**	**23.1**	**25.4**	**24.7**	**12.2**	1.0	mg / L
Total Hardness by 2340B	**477**	**365**	**59.3**	**359**	**301**	**264**	**44.2**	3.3	mg / L
YSI Data									
pH	**7.3**	**7.5**	**6.6**	**8.1**	**8.0**	**7.8**	**6.8**	± 0.2	Units
Temperature	**5.8**	**6.1**	**6.1**	**6.9**	**6.8**	**6.9**	**6.2**	± 0.1	ºC
Specific Conductance	**989**	**719**	**158**	**730**	**721**	**558**	**118**	± 1%	uS / cm
Calculations									
Total Cations	**11.1**	**8.2**	**1.7**	**8.2**	**6.9**	**6.1**	**1.2**	-	meq
Total Anions	**10.2**	**7.3**	**1.3**	**7.5**	**6.2**	**5.4**	**1.1**	-	meq
Calculated TDS	**685**	**504**	**93**	**512**	**423**	**370**	**76**	-	mg/L
Actual TDS - Calc. (diff)	**-10.5**	**-29.8**	**32.6**	**-65.6**	**-10.6**	**19.9**	**7.7**	-	mg/L
% Na to Tot. Cations	**12.0**	**9.5**	**19.8**	**10.4**	**10.9**	**11.2**	**15.8**	-	%

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[blue shading] Exceeds MN WQ Standard

Twin Lakes
Inflow / Outflow Sampling Event
5/31/2018

	Little Sandy Inflow 1	Little Sandy Inflow 2	Sandy South Inflow	Little Sandy Middle	Sandy Middle	Culvert Inflow	Twin Lakes Outflow	Reporting Limits	Reporting Units
Analytes - Cations									
Calcium	**43.4**	**40.4**	**5.6**	**31.1**	**40.0**	**11.3**	**30.6**	0.50	mg / L
Iron	**1440**	**335**	**2310**	**243**	**329**	**2930**	**521**	50.0	ug / L
Magnesium	**57.0**	**60.1**	**6.2**	**46.0**	**59.6**	**3.8**	**43.9**	0.50	mg / L
Manganese	**75.6**	**99**	**54.3**	**64.6**	130	**153**	**105**	10.0	ug / L
Potassium	**6.7**	**5.5**	**1.7**	**4.4**	**5.5**	**1.8**	**4.3**	0.50	mg / L
Sodium	**23.9**	**18.9**	**6.6**	**15.3**	**18.8**	**4.5**	**14.7**	0.50	mg / L
Analytes - Anions									
Chloride	**35.9**	**29.3**	**9.2**	**26**	**30.1**	**11.1**	< 1.0	1.0	mg / l
Nitrogen, Kjeldahl, Total	**0.85**	**0.65**	**0.97**	NM	NM	< 0.60	**0.65**	0.60	mg / L
Ammonia as Nitrogen	< 0.10	< 0.10	**0.13**	NM	NM	**0.11**	< 0.10	0.10	mg / L
Unionized ammonia as N	0.42	0.29	**0.20**	NM	NM	**0.35**	2.24	varies	ug/L
Sulfate	**193**	**186**	< 2.0	**148**	**186**	< 2.0	**6.0**	2.0/40.0	mg / L
Analytes - Other									
Total Dissolved Solids	**546**	**480**	**140**	NM	NM	**136**	**368**	10.0/20.0	mg / L
Total Suspended Solids	**2.0**	**5.3**	**10**	NM	NM	**7.3**	**4.7**	1.7	mg / L
Alkalinity, Total as HCO3-	**138**	**173**	**40.5**	NM	NM	**38.4**	**134**	12.2	mg / L
Alkalinity, Total as CaCO3	**113**	**142**	**33.2**	NM	NM	**31.5**	**110**	10.0	mg / L
Dissolved Organic Carbon	**18.9**	**15.5**	**27.8**	NM	NM	**17.0**	**14.2**	1.0	mg / L
Total Hardness by 2340B	**343**	**348**	**39.7**	NM	NM	**43.8**	**257**	3.3	mg / L
YSI Data									
pH	**7.1**	**6.8**	**6.7**	**7.8**	**7.8**	**7.1**	**7.7**	± 0.2	Units
Temperature	**17.0**	**21.0**	**15.6**	**22.4**	**22.4**	**14.7**	**21.6**	± 0.1	ºC
Specific Conductance	**734**	**712**	**553**	**721**	**605**	**115**	**553**	± 1%	uS / cm
Calculations									
Total Cations	**8.1**	**6.2**	**1.2**	**6.1**	**7.9**	**1.2**	**5.9**	-	meq
Total Anions	**7.4**	**6.4**	**1.0**	NM	NM	**1.0**	**2.4**	-	meq
Calculated TDS	**500**	**433**	**75**	NM	NM	**77**	**236**	-	mg/L
Actual TDS - Calc. (diff)	**45.9**	**-1.2**	**64.9**	NM	NM	**59.4**	**132.0**	-	mg/L
% Na to Tot. Cations	**12.8**	**10.1**	**23.8**	NM	NM	**15.9**	**10.8**	-	%

Note: Sulfate values 193, 186 (Little Sandy Inflow 1 and 2), 148 (Little Sandy Middle) and 186 (Sandy Middle) are highlighted as exceeding WQ Standard.

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[blue highlight] Exceeds WQ Standard

Twin Lakes
Inflow / Outflow Sampling Event

6/29/2018

	Little Sandy Inflow 1	Little Sandy Inflow 2	Sandy South Inflow	Little Sandy Middle	Sandy Middle	Culvert Inflow	Twin Lakes Outflow	Reporting Limits	Reporting Units
Analytes - Cations									
Calcium	**35.5**	**31.9**	**6.2**	**37.2**	**29.2**	**8.5**	**26.7**	0.50	mg / L
Iron	**2100**	**923**	**2490**	**417**	**414**	**3520**	**916**	50.0	ug / L
Magnesium	**47.3**	**47.0**	**7.3**	**56.3**	**43.7**	**2.9**	**37.7**	0.50	mg / L
Manganese	**64.0**	**101**	**69.6**	**117**	**96.1**	**133**	**102**	5.0	ug / L
Potassium	**3.4**	**3.2**	< 2.5	**3.9**	**3.9**	< 2.5	**3.4**	2.5	mg / L
Sodium	**18.9**	**14.4**	**3.9**	**17.3**	**15.1**	**3.5**	**13.2**	1.0	mg / L
Analytes - Anions									
Chloride	**27.1**	**22.0**	**3.8**	**26.4**	**24.4**	**8.0**	**21.7**	1.0	mg / L
Nitrogen, Kjeldahl, Total	**1.1**	**0.96**	**1.1**	**0.71**	**0.76**	**0.78**	**0.66**	0.50	mg / L
Ammonia as Nitrogen	**0.14**	**0.15**	**0.20**	< 0.11	< 0.11	**0.12**	**0.16**	0.11	mg / L
Unionized ammonia as N	**0.57**	**0.77**	**0.14**	<2.5	<2.0	**0.19**	**2.55**	varies	ug/L
Sulfate	**164**	**137**	< 2.0	**164**	**135**	< 2.0	**109**	2.0	mg / L
Analytes - Other									
Total Dissolved Solids	**459**	**432**	**120**	NM	NM	**104**	**345**	10.0/20.0	mg / L
Total Suspended Solids	**1.2**	< 1.0	**6.4**	NM	NM	**5.3**	**1.6**	1.0/1.7	mg / L
Alkalinity, Total as HCO3-	**154**	**176**	**44.4**	NM	NM	**33.1**	**131**	12.2	mg / L
Alkalinity, Total as CaCO3	**126**	**144**	**36.4**	NM	NM	**27.1**	**107**	10.0	mg / L
Dissolved Organic Carbon	**28.8**	**25.1**	**33.0**	NM	NM	**22.0**	**17.8**	1.0	mg / L
Total Hardness by 2340B	**283**	**273**	**45.7**	NM	NM	**33.3**	**222**	3.3	mg / L
YSI Data									
pH	**7.1**	**7.1**	**6.4**	**7.7**	**7.6**	**6.8**	**7.6**	± 0.2	Units
Temperature	**18.8**	**20.7**	**16.6**	**22.0**	**21.4**	**15.2**	**20.4**	± 0.1	ºC
Specific Conductance	**625**	**606**	**94**	**678**	**571**	**83.4**	**481**	± 1%	uS / cm
Calculations									
Total Cations	**6.6**	**6.2**	**1.2**	**7.4**	**5.8**	**1.0**	**5.1**	-	meq
Total Anions	**-6.8**	**-6.4**	**-1.3**	NM	NM	**-0.9**	**-5.1**	-	meq
Calculated TDS	**453**	**433**	**86**	NM	NM	**65**	**344**	-	mg/L
Actual TDS - Calc. (diff)	**5.8**	**-1.2**	**33.9**	NM	NM	**39.1**	**1.1**	-	mg/L
% Na to Tot. Cations	**12.4**	**10.1**	**13.7**	NM	NM	**15.1**	**11.2**	-	%

Bold Print indicates the sample is above the detection limit
"<" indicates value below reporting limit
NM indicates that the analyte was not measured
[blue shading] Exceeds WQ Standard

Twin Lakes
Inflow / Outflow Sampling Event
7/27/2018

	Little Sandy Inflow 1	Little Sandy Inflow 2	Sandy South Inflow	Little Sandy Middle	Sandy Middle	Culvert Inflow	Twin Lakes Outflow	Reporting Limits	Reporting Units
Analytes - Cations									
Calcium	**59.2**	**38.7**	**10**	**37.7**	**29.9**	**13.6**	**27.2**	0.10	mg / L
Iron	**1560**	**2670**	**8730**	**2580**	**1120**	**3000**	**1320**	50.0	ug / L
Magnesium	**76.8**	**51.9**	**10.4**	**52.2**	**43.9**	**4.9**	**36.6**	0.10	mg / L
Manganese	**160**	**201**	**186**	**200**	**59.2**	**144**	**55.7**	0.50	ug / L
Potassium	**3.2**	**2.5**	**0.5**	**2.7**	**2.9**	**1.3**	**2.6**	0.1	mg / L
Sodium	**31.4**	**16.4**	**3.5**	**17.4**	**15.4**	**5.2**	**12.9**	0.10	mg / L
Analytes - Anions									
Chloride	**44.9**	**22.7**	**3.6**	**24.1**	**21.3**	**15.1**	**19.3**	1.0	mg / l
Nitrogen, Kjeldahl, Total	**0.53**	**1.0**	**1.5**	NM	NM	< 0.50	**0.61**	0.50	mg / L
Ammonia as Nitrogen	**0.12**	**0.18**	**0.75**	NM	NM	**0.16**	**0.18**	0.11	mg / L
Unionized ammonia as N	**0.53**	**0.54**	**0.95**	NM	NM	**0.22**	**1.40**	varies	ug/L
Sulfate	**214**	**131**	< 2.0	**136**	**113**	**2.9**	**92.6**	2.0/6.0	mg / L
Analytes - Other									
Total Dissolved Solids	**716**	**478**	**188**	NM	NM	**118**	**328**	20.0	mg / L
Total Suspended Solids	< 1.0	**7.0**	< 2.5	NM	NM	**3.0**	**1.2**	1.0/2.5	mg / L
Alkalinity, Total as HCO3-	**285**	**238**	**72.7**	NM	NM	**49.4**	**161**	12.2	mg / L
Alkalinity, Total as CaCO3	**234**	**195**	**59.6**	NM	NM	**40.5**	**132**	10.0	mg / L
Dissolved Organic Carbon	**26.7**	**35.4**	**52.1**	NM	NM	**12.1**	**28.4**	1.0/4.0	mg / L
Total Hardness by 2340B	**464**	**310**	**67.7**	NM	NM	**54.0**	**219**	0.66	mg / L
YSI Data									
pH	**7.1**	**6.9**	**6.6**	**7.7**	**7.8**	**6.7**	**7.4**	± 0.2	Units
Temperature	**17.5**	**19.7**	**15.8**	**19.5**	**19.0**	**14.0**	**17.9**	± 0.1	ºC
Specific Conductance	**1024**	**672**	**150**	**673**	**553**	**147.8**	**487**	± 1%	uS / cm
Calculations									
Total Cations	**10.8**	**7.1**	**1.8**	**7.1**	**5.9**	**1.5**	**5.0**	-	meq
Total Anions	**-10.4**	**-7.3**	**-1.4**	**-3.5**	**-3.0**	**-1.3**	**-5.2**	-	meq
Calculated TDS	**717**	**505**	**113**	NM	NM	**96**	**354**	-	mg/L
Actual TDS - Calc. (diff)	**-1.3**	**-27.0**	**74.9**	NM	NM	**22.0**	**-26.2**	-	mg/L
% Na to Tot. Cations	**12.7**	**10.1**	**8.3**	NM	NM	**15.6**	**11.1**	-	%

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(blue shading) Exceeds WQ Standard

Twin Lakes
Inflow / Outflow Sampling Event
8/29/2018

	Little Sandy Inflow 1	Little Sandy Inflow 2	Sandy South Inflow	Little Sandy Middle	Sandy Middle	Culvert Inflow	Twin Lakes Outflow	Reporting Limits	Reporting Units
Analytes - Cations									
Calcium	**105**	**49.3**	**10.0**	**34.8**	**49.4**	**14.6**	**27.5**	0.50	mg / L
Iron	**656**	**177**	**10900**	**144**	**114**	**2010**	**652**	50.0	ug / L
Magnesium	**334**	**74.3**	**9.0**	**52.0**	**75.0**	**4.7**	**35.3**	0.50	mg / L
Manganese	**53.1**	**65.7**	**188**	**33.9**	**34.1**	**105**	**88.7**	5.0	ug / L
Potassium	**11.1**	**3.4**	< 2.5	**3.0**	**3.5**	< 2.5	**2.5**	2.5	mg / L
Sodium	**67.3**	**24.3**	**3.4**	**17.2**	**25.1**	**5.2**	**12.6**	1.0	mg / L
Analytes - Anions									
Chloride	**111**	**35.0**	**3.5**	**24.6**	**36.9**	**17.9**	**22.2**	1.0	mg / l
Nitrogen, Kjeldahl, Total	< 0.50	**0.64**	**1.7**	**0.75**	**0.61**	< 0.50	**0.53**	0.50	mg / L
Ammonia as Nitrogen	**0.18**	**0.23**	**1.1**	**0.18**	**0.18**	**0.20**	**0.22**	0.11	mg / L
Unionized ammonia as N	**3.35**	**4.47**	**0.61**	**14.37**	**4.95**	**0.36**	**1.41**	varies	ug/L
Sulfate	**652**	**188**	< 2.0	**121**	**199**	**4.1**	**79.1**	2.0/10.0	mg / L
Analytes - Other									
Total Dissolved Solids	**1440**	**580**	**150**	NM	NM	**120**	**318**	20.0	mg / L
Total Suspended Solids	**2.0**	**2.4**	**15.0**	NM	NM	**2.4**	**2.0**	1.0/2.5	mg / L
Alkalinity, Total as HCO3-	**407**	**290**	**75.6**	NM	NM	**57.2**	**161**	12.2	mg / L
Alkalinity, Total as CaCO3	**334**	**238**	**62.0**	NM	NM	**46.9**	**132**	10.0	mg / L
Dissolved Organic Carbon	**10.7**	**27.0**	**29.6**	NM	NM	**6.8**	**20.2**	1.0	mg / L
Total Hardness by 2340B	**986**	**429**	**62.0**	NM	NM	**55.6**	**214**	3.3	mg / L
YSI Data									
pH	**7.8**	**7.8**	**6.3**	**8.4**	**7.9**	**6.9**	**7.3**	± 0.2	Units
Temperature	**17.2**	**18.1**	**14.5**	**17.6**	**17.2**	**13.4**	**16.2**	± 0.1	ºC
Specific Conductance	**1925**	**921**	**171**	**890**	**635**	**164**	**480**	± 1%	uS / cm
Calculations									
Total Cations	**23.0**	**9.7**	**1.8**	**6.8**	9.8	1.5	**4.9**	-	meq
Total Anions	**23.4**	**9.7**	**1.5**	NM	NM	1.6	**5.0**	-	meq
Calculated TDS	**1531**	**666**	**119**	NM	NM	109	**342**	-	mg/L
Actual TDS - Calc. (diff)	**-91.1**	**-85.5**	**31.2**	NM	NM	11.2	**-23.5**	-	mg/L
% Na to Tot. Cations	**12.8**	**10.9**	**8.0**	NM	NM	15.3	**11.1**	-	%

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NM indicates that the analyte was not measured
Exceeds WQ Standard

Twin Lakes
Inflow / Outflow Sampling Event
9/26/2018

	Little Sandy Inflow 1	Little Sandy Inflow 2	Sandy South Inflow	Little Sandy Middle	Sandy Middle	Culvert Inflow	Twin Lakes Outflow	Reporting Limits	Reporting Units
Analytes - Cations									
Calcium	**53.5**	**50.7**	**5**	**50.3**	**46.2**	**9.8**	**34.2**	0.50	mg / L
Iron	**634**	**245**	**1110**	**201**	**250**	**1420**	**386**	50.0	ug / L
Magnesium	**65.6**	**72.5**	**5.3**	**71.8**	**64**	**3.4**	**46.4**	0.50	mg / L
Manganese	**67.2**	**35.2**	**13.9**	**26.3**	**31.2**	**61.4**	**40.4**	5.0	ug / L
Potassium	**4.85**	**3.93**	**0.89**	**4.12**	**4.07**	**1.56**	**3.27**	2.5	mg / L
Sodium	**25.7**	**24.1**	**2.9**	**25.2**	**23.2**	**5.8**	**17.6**	1.0	mg / L
Analytes - Anions									
Chloride	**44.6**	**38.2**	**4.6**	**41.1**	**37.3**	**15.1**	**26.5**	1.0	mg / l
Nitrogen, Kjeldahl, Total	< 0.5	< 0.5	**0.56**	< 0.5	< 0.5	< 0.5	< 0.5	0.50	mg / L
Ammonia as Nitrogen	< 0.11	< 0.11	**0.15**	< 0.11	0.11	**0.11**	**0.13**	0.11	mg / L
Unionized ammonia as N	0.57	0.44	**0.34**	2.33	**1.22**	**0.12**	**0.59**	varies	ug/L
Sulfate	**292** (exceeds WQ standard)	**220** (exceeds WQ standard)	< 2.0	**241** (exceeds WQ standard)	**207** (exceeds WQ standard)	< 2.0	**127** (exceeds WQ standard)	2.0/10.0	mg / L
Analytes - Other									
Total Dissolved Solids	**638**	**632**	**109**	NM	NM	**98**	**400**	20.0	mg / L
Total Suspended Solids	< 1.0	< 1.0	< 1.0	NM	NM	< 1.0	< 1.0	1.0/2.5	mg / L
Alkalinity, Total as HCO3-	**150**	**264**	**36.5**	NM	NM	**35.0**	**193**	12.2	mg / L
Alkalinity, Total as CaCO3	**123**	**216**	**29.9**	NM	NM	**28.7**	**158.0**	10.0	mg / L
Dissolved Organic Carbon	**14.3**	**21**	**30.8**	NM	NM	**14.5**	**21.5**	1.0	mg / L
Total Hardness by 2340B	**404**	**425**	**34.3**	NM	NM	**38.6**	**276**	3.3	mg / L
YSI Data									
pH	**7.5**	**7.4**	**7.1**	**8.1**	**7.8**	**6.8**	**7.4**	± 0.2	Units
Temperature	**9.3**	**10.0**	**9.4**	**10.5**	**10.4**	**9.1**	**10.0**	± 0.1	ºC
Specific Conductance	**914**	**910**	**80**	**927**	**830**	**116**	**612**	± 1%	uS / cm
Calculations									
Total Cations	**9.3**	**9.7**	**0.9**	**9.6**	**8.7**	**1.1**	**6.4**	-	meq
Total Anions	**-9.8**	**-10.0**	**-0.8**	NM	NM	**-1.1**	**-6.6**	-	meq
Calculated TDS	**638**	**674**	**59**	NM	NM	**75**	**449**	-	mg/L
Actual TDS - Calc. (diff)	**0.5**	**-41.7**	**50.1**	NM	NM	**23.3**	**-48.7**	-	mg/L
% Na to Tot. Cations	**12.0**	**10.9**	**14.4**	NM	NM	**22.6**	**12.0**	-	%

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[blue shading] Exceeds WQ Standard

Twin Lakes
Inflow / Outflow Sampling Event
10/22/2018

	Little Sandy Inflow 1	Little Sandy Inflow 2	Sandy South Inflow	Little Sandy Middle	Sandy Middle	Culvert Inflow	Twin Lakes Outflow	Reporting Limits	Reporting Units
Analytes - Cations									
Calcium	**44.3**	**23.0**	**3.69**	**38.9**	**34.8**	**9.4**	**33.1**	0.50	mg / L
Iron	**541**	**5760**	**871**	**354**	**561**	**1010**	**522**	100.0	ug / L
Magnesium	**67.9**	**34.8**	**4.46**	**67.4**	**55.8**	**3.37**	**52.0**	0.50	mg / L
Manganese	**26.8**	**227**	**8.31**	**18.6**	**25.2**	**55.6**	**23.5**	10.0	ug / L
Potassium	**5.61**	**1.58**	**0.652**	**3.43**	**0.107**	**1.40**	**3.22**	0.50	mg / L
Sodium	**27.1**	**9.14**	**2.35**	**19.1**	**17.9**	**5.02**	**16.9**	0.50	mg / L
Analytes - Anions									
Chloride	**40.9**	**20.7**	**2.8**	**28.4**	**31.3**	**12.7**	**27.4**	2.0	mg / l
Nitrogen, Kjeldahl, Total	< 0.50	**1.4**	**0.62**	**0.57**	**0.52**	< 0.5	< 0.5	0.50	mg / L
Ammonia as Nitrogen	< 0.11	**0.14**	**0.13**	< 0.11	< 0.11	**0.12**	**0.11**	0.11	mg / L
Unionized ammonia as N	0.19	**0.64**	**0.16**	0.95	0.69	**0.02**	**0.77**	varies	ug/L
Sulfate	**246**	**165**	**3.8**	**181**	**223**	**2.5**	**165**	4.0	mg / L
Analytes - Other									
Total Dissolved Solids	**552**	**394**	**72.0**	NM	NM	**74.0**	**382**	10.0	mg / L
Total Suspended Solids	< 1.0	**2.4**	**6.0**	NM	NM	< 1.0	**2.4**	1.0	mg / L
Alkalinity, Total as HCO3-	**155**	**80.5**	**24.5**	NM	NM	**31.8**	**137**	12.2	mg / L
Alkalinity, Total as CaCO3	**127**	**66.0**	**20.1**	NM	NM	**26.1**	**112**	10.0	mg / L
Dissolved Organic Carbon	**12.0**	**37.2**	**21.9**	NM	NM	**10.7**	**18**	1.0	mg / L
Total Hardness by 2340B	**390**	**201**	**27.6**	**375**	**317**	**37.3**	**297**	2.5	mg / L
YSI Data									
pH	**7.3**	**7.6**	**7.1**	**7.9**	**7.8**	**6.3**	**7.8**	± 0.2	Units
Temperature	**2.0**	**4.0**	**2.5**	**3.6**	**3.9**	**3.4**	**4.3**	± 0.1	ºC
Specific Conductance	**805**	**683**	**56.9**	**726**	**614**	**102**	**573**	± 1%	uS / cm
Calculations									
Total Cations	**9.1**	**4.7**	**0.7**	**8.4**	**7.1**	**1.0**	**6.8**	-	meq
Total Anions	**8.9**	**5.4**	**0.6**	NM	NM	**1.0**	**6.5**	-	meq
Calculated TDS	**588**	**342**	**44**	NM	NM	**68**	**435**	-	mg/L
Actual TDS - Calc. (diff)	**-35.8**	**51.9**	**28.2**	NM	NM	**6.2**	**-53.3**	-	mg/L
% Na to Tot. Cations	**12.9**	**8.5**	**14.6**	NM	NM	**21.1**	**10.9**	-	%

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(blue shading) Exceeds WQ Standard

APPENDIX B

RESULTS OF WILD RICE GROWTH STUDIES IN SEDIMENT FROM MINING-INFLUENCED LAKES IN ONTARIO, CANADA

Results of Wild Rice Growth Studies in Sediment from Mining-Influenced Lakes in Ontario, Canada

Separate studies related to wild rice restoration have been completed on two mining-influenced lakes in Ontario, Canada. The subject Canadian lakes are significantly different from the Twin Lakes in that they are both meromictic (i.e., chemically stratified), with diverse and complex chemical characteristics below the chemocline, and receive significantly greater inputs of dissolved constituents. Similar to the studies described above, sediment from the two subject Canadian lakes were used to evaluate the growth potential of wild rice in contrast to sediment from a non-industry influenced aquatic system. Results of the evaluation indicated that there were no significant differences in wild rice seed germination between the three sediment sources. Subsequent mesocosm growth studies using sediment from the subject mining-influenced, as well as non-industry influenced, Canadian lakes resulted in the successful growth of wild rice seedlings into reproductively mature plants from all three sediment sources.

Two lakes in Ontario, Canada, which have received similar mining influences for a similar duration of time, have been subjects of various studies focused on remediation and restoration, and the potential for complete mixing – both lakes are meromictic, with diverse and complex chemical characteristics below the chemocline. Tables 1 – 3 (below) detail specific chemical and physical characteristics of sediment obtained from cores of Sandy Lake (SL), Little Sandy Lake (LSL), and the two mining influenced lakes in Ontario, Canada, referred to as 'Lake A' and 'Lake B' to protect site and client confidentiality.

Sediment samples from Lakes A and B were used, and continue to be used, in a series of experiments designed to determine responses of wild rice to exposures of these sediments. During winter 2017-2018, Lake A and Lake B sediments were used in wild rice growth experiments in a greenhouse at Lakehead University in Thunder Bay, Ontario. One overall conclusion obtained during these experiments was that there appeared to be no germination difference between wild rice seeds exposed to Lake A or Lake B sediment, and sediment from Rat River Bay, a non-industry influenced aquatic system. Therefore, based on these germination data, during summer 2018 wild rice seeds were germinated into seedlings inside a temperature / light / humidity-controlled incubator, and planted in multiple buckets in three different mesocosms each, mesocosm containing a different sediment (Lake A, B, or Rat River Bay).

Despite obvious differences in chemical characteristics between Lakes A and B and the Twin Lakes (Sandy and Little Sandy Lakes; most often orders of magnitude difference in measured concentrations of specific elements), wild rice seedlings grew and developed into reproductively mature plants in both Lake A and Lake B sediments in these mesocosm studies. Mature, seed-producing wild rice plants grown in Lake A (Figures 1-4) and Lake B (Figures 5-8) are detailed below.

Based on these observations, and observations of wild rice seedlings having grown in Sandy Lake sediment in 2013 and 2014 bioassay tests, Sandy Lake, and likely Little Sandy Lake, sediments will support germination, growth, and development of wild rice into mature reproductively viable (i.e., seed producing) plants under field conditions.

Based on the data collection and observations obtained during the Plan between 2013 and 2015, wild rice seeding events of select areas within each lake were developed and completed. Specifics of these wild rice seeding efforts are detailed in Section 8.0 of this report. However, in summary, over the course of two years of observations of wild rice seeded areas, wild rice plants in the aerial developmental stage were observer in all areas seeded within the Twin Lakes system. Therefore, in areas of appropriate water depth and lack of competing vegetation, both Little Sandy and Sandy Lakes' sediment will support germination, growth, and development of wild rice into mature, seed producing plants. Overall, the quality of the sediment in both Little Sandy and Sandy Lakes is more than sufficient to support germination, growth, and development of wild rice into reproductively mature, seed producing plants. With proper management of water depth and competing vegetation, and sufficiently intense, multi-year seeding efforts, development of a self-sustaining population of wild rice in the Twin Lakes is entirely possible.

TABLE 1. CHARACTERISTICS OF SEDIMENT CORE SAMPLES FROM LITTLE SANDY LAKE (LSL), SANDY LAKE (SL) – THE CURRENT STUDY TWIN LAKES SYSTEM – AND TWO INDUSTRY-INFLUENCED LAKES IN ONTARIO. SEDIMENT CORES WERE OBTAINED NEAR AQUEOUS INFLOWS TO EACH RESPECTIVE SYSTEM. CONCENTRATIONS ARE AVERAGES OF TWO SEPARATE CORE SECTIONS. TWIN LAKES CONCENTRATIONS ARE THE AVERAGE OF 0-5 AND 6-10 CM SECTIONS OF THE SAME CORE; 'LAKE A' AND 'LAKE B' CONCENTRATIONS ARE THE AVERAGE OF 0-4 AND 5-8 CM SECTION OF THE SAME CORE.

	SL INFLOW (S10; 0-10 CM AVG.)	LSL INFLOW 1 (LSL2; 0-10 CM AVG.)	LSL INFLOW 2 (LSL10; 0-10 CM AVG.)	* 'LAKE A' INFLOW (0-8 CM AVG.)	* 'LAKE B' INFLOW (0-8 CM AVG.)
% MOISTURE	39.005	85.145	87.43	28.405	46.3
AVS (UMOL/G)	4.835	117.7785	5.865	** NC	NC
SEM [CD,CU,NI,PB,ZN] (UMOL/G)	0.035	0.1135	0.0975	9.376	1.0831
BULK DENSITY (G/CM^3)	1.045	0.18	0.155	0.49	0.16
AS, TOTAL (UG/G)	NC	0.01028	0.00828	NC	NC
CD, TOTAL (UG/G)	NC	0.00039	0.000675	1.16	0.94
CO, TOTAL (UG/G)	0.002465	0.009945	0.00438	12.275	17.275
CR, TOTAL (UG/G)	0.007275	0.023025	0.01561	20.595	38.635
CU, TOTAL (UG/G)	0.00252	0.011735	0.01001	33.745	67.515
FE, TOTAL (UG/G)	10.503375	85.9214	37.7677	11801.15	15987.45
MN, TOTAL (UG/G)	0.059625	0.53445	0.404295	221.12	401.19
MO, TOTAL (UG/G)	NC	NC	NC	NC	24.98
NI, TOTAL (UG/G)	0.00353	0.01088	0.008045	14.45	39.945
PB, TOTAL (UG/G)	0.00744	0.037365	0.02286	NC	43.025
S, TOTAL (UG/G)	5.91756	71.9824	44.87095	607.43	8300.325
SE, TOTAL (UG/G)	NC	NC	NC	NC	NC
ZN, TOTAL (UG/G)	0.01864	0.091185	0.07302	282.77	141.59
TOTAL CARBON (%C)	2.44	16.445	19.925	3.23	18.485
N IN SEDIMENT (%N)	0.2	1.35	1.715	0.15	1.22

* Labeled 'Lake A' and 'Lake B' to protect site and client confidentiality. 'Lake A' is a legacy mining industry influenced lake at the further-more upstream position in a chain of lakes; 'Lake B' is a currently industry-influenced lake in a chain of lakes. Outflow from lakes in these two discreet systems terminate into Lake Superior.
** Not Calculable.

Table 2. Characteristics of sediment core samples from Little Sandy Lake, Sandy Lake – the current study Twin Lakes system – and two industry-influenced lakes in Ontario. Sediment cores were obtained near the middle of each respective system. Concentrations are averages of two separate core sections. Twin Lakes concentrations are the average of 0-5 and 6-10 cm sections of the same core; 'Lake A' and 'Lake B' concentrations are the average of 0-4 and 5-8 cm sections of the same core.

	SL MID (S5; 0-10 CM AVG.)	SL MID (S8; 0-10 CM AVG.)	LSL MID (LSL4; 0-10 CM AVG.)	LSL MID (LSL7; 0-10 CM AVG.)	* 'LAKE A' MID (0-8 CM AVG.)	* 'LAKE B' MID (0-8 CM AVG.)
% MOISTURE	86.945	80.875	86.305	86.635	48.42	49.57
AVS (UMOL/G)	9.67	7.8	43.1845	33.435	441.56	89.18
SEM [CD,CU,NI,PB,ZN] (UMOL/G)	1.3325	0.103	0.0935	0.094	3.15275	0.87115
BULK DENSITY (G/CM^3)	0.09	0.22	0.18	0.16	0.145	0.155
AS, TOTAL (UG/G)	0.006995	0.00671	0.00692	0.00935	** NC	NC
CD, TOTAL (UG/G)	0.00103	0.00101	0.00059	0.00044	2.635	0.805
CO, TOTAL (UG/G)	0.006785	0.00721	0.00519	0.004795	29.975	14.365
CR, TOTAL (UG/G)	0.021725	0.021285	0.020355	0.019005	33.765	30.805
CU, TOTAL (UG/G)	0.01294	0.010705	0.010865	0.009805	108.82	60.395
FE, TOTAL (UG/G)	36.3702	29.25135	38.63325	44.6435	28235.25	12226.85
MN, TOTAL (UG/G)	0.3416	0.24049	0.41017	0.381715	427.53	223.665
MO, TOTAL (UG/G)	NC	NC	NC	NC	NC	14.24
NI, TOTAL (UG/G)	0.0155	0.01368	0.01109	0.0094	23.85	35.395
PB, TOTAL (UG/G)	0.021855	0.01268	0.018545	0.019	17.2	27.635
S, TOTAL (UG/G)	31.22735	20.3085	37.2311	42.1746	7554.09	9050.5
SE, TOTAL (UG/G)	NC	NC	NC	NC	NC	NC
ZN, TOTAL (UG/G)	0.097105	0.087625	0.069835	0.06304	743.415	113.32
TOTAL CARBON (%C)	19.605	14.755	16.99	16.595	22.235	19.45
N IN SEDIMENT (%N)	1.585	1.2	1.66	1.565	1.46	1.395

* Labeled 'Lake A' and 'Lake B' to protect site and client confidentiality. 'Lake A' is a legacy mining industry influenced lake at the further-more upstream position in a chain of lakes; 'Lake B' is a currently industry-influenced lake in a chain of lakes. Outflow from lakes in these two discreet systems terminate into Lake Superior.

** Not Calculable.

TABLE 3. CHARACTERISTICS OF SEDIMENT CORE SAMPLES FROM LITTLE SANDY LAKE (LSL), SANDY LAKE (SL) – THE CURRENT STUDY TWIN LAKES SYSTEM – AND TWO INDUSTRY-INFLUENCED LAKES IN ONTARIO. SEDIMENT CORES WERE OBTAINED NEAR AQUEOUS OUTFLOWS FROM EACH RESPECTIVE SYSTEM. CONCENTRATIONS ARE AVERAGES OF TWO SEPARATE CORE SECTIONS. TWIN LAKES CONCENTRATIONS ARE THE AVERAGE OF 0-5 AND 6-10 CM SECTIONS OF THE SAME CORE; 'LAKE A' AND 'LAKE B' CONCENTRATIONS ARE THE AVERAGE OF 0-4 AND 5-8 CM SECTIONS OF THE SAME CORE.

	SL OUTFLOW (S1; 0-10 CM AVG.)	SL OUTFLOW (S3; 0-10 CM AVG.)	LSL OUTFLOW (LSL1; 0-10 CM AVG.)	* 'LAKE A' OUTFLOW (0-8 CM AVG.)	* 'LAKE B' OUTFLOW (0-8 CM AVG.)
% MOISTURE	86.995	86.945	85.88	52.35	50.08
AVS (UMOL/G)	6.705	0.0225	79.601	1090.59	** NC
SEM [CD,CU,NI,PB,ZN] (UMOL/G)	1.6165	7.02	0.101	6.1745	0.7788
BULK DENSITY (G/CM^3)	0.075	1.9395	0.18	0.14	0.14
AS, TOTAL (UG/G)	0.014565	0.085	0.008235	NC	NC
CD, TOTAL (UG/G)	0.0004	0.00757	0.00038	3.87	0.79
CO, TOTAL (UG/G)	0.00979	0.01623	0.00628	29.89	14.83
CR, TOTAL (UG/G)	0.01517	0.00103	0.019105	27.745	22.225
CU, TOTAL (UG/G)	0.009745	0.00683	0.011555	90.235	38.53
FE, TOTAL (UG/G)	48.4	0.019455	71.6897	11745.25	9369.585
MN, TOTAL (UG/G)	0.58315	0.012835	0.70984	237.05	206.705
MO, TOTAL (UG/G)	NC	41.66965	NC	2.11	9.48
NI, TOTAL (UG/G)	0.012485	0.36301	0.009385	29.34	31.895
PB, TOTAL (UG/G)	0.02454	NC	0.042385	17.91	15.025
S, TOTAL (UG/G)	22.1156	0.01399	53.4509	5233.115	6468.965
SE, TOTAL (UG/G)	NC	0.0302	NC	NC	NC
ZN, TOTAL (UG/G)	0.09266	37.3131	0.066545	1019.205	104.09
TOTAL CARBON (%C)	34.555	NC	17.055	15.48	19.465
N IN SEDIMENT (%N)	2.155	0.10355	1.605	1.215	1.445

* Labeled 'Lake A' and 'Lake B' to protect site and client confidentiality. 'Lake A' is a legacy mining industry influenced lake at the further-more upstream position in a chain of lakes; 'Lake B' is a currently industry-influenced lake in a chain of lakes. Outflow from lakes in these two discreet systems terminate into Lake Superior.

** Not Calculable.

FIGURE 1. AUGUST 2018: WILD RICE PLANTS GROWING IN 'LAKE A' SEDIMENT.

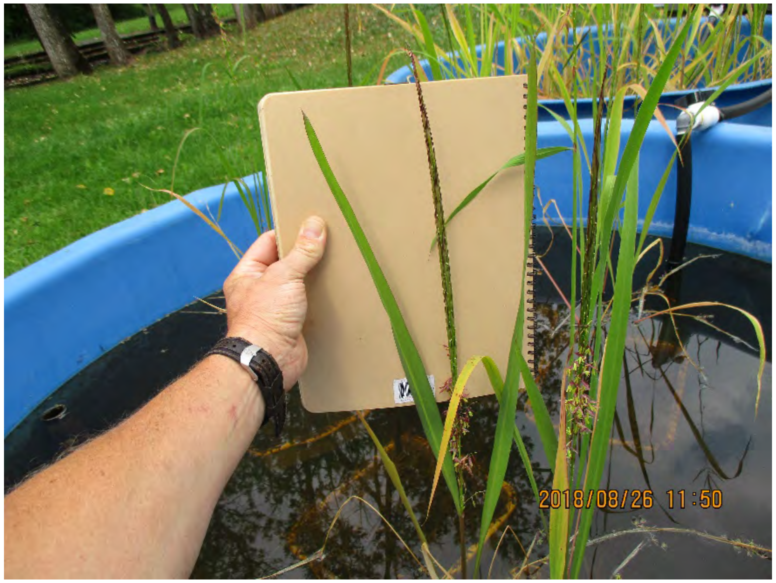

FIGURE 2. AUGUST 2018: WILD RICE PLANT PANICLE IN 'LAKE A' SEDIMENT_2.

FIGURE 3. AUGUST 2018: WILD RICE PLANT PANICLE IN 'LAKE A' SEDIMENT_1.

FIGURE 4. AUGUST 2018: WILD RICE PLANT PANICLE IN 'LAKE A' SEDIMENT_3.

FIGURE 5. AUGUST 2018: WILD RICE PLANTS GROWING IN 'LAKE B' SEDIMENT.

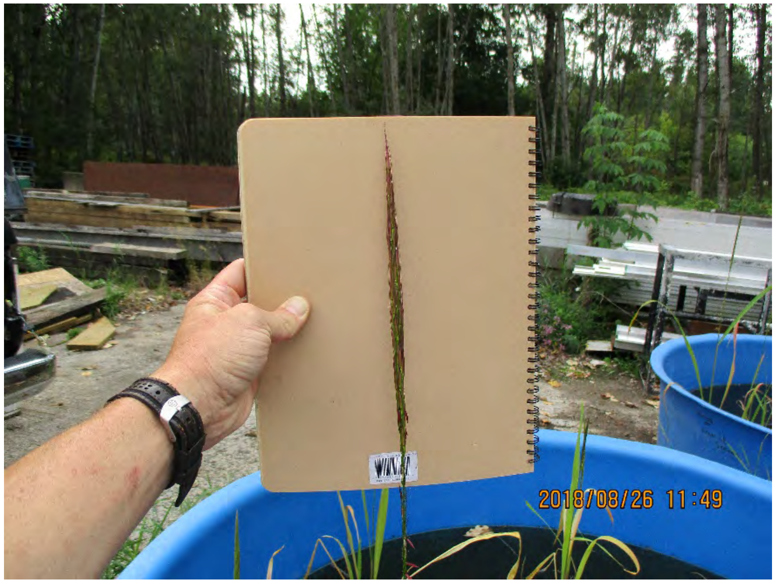

FIGURE 6. AUGUST 2018: WILD RICE PLANT PANICLE IN 'LAKE B' SEDIMENT_2.

FIGURE 7. AUGUST 2018: WILD RICE PLANT PANICLE IN 'LAKE B' SEDIMENT_1.

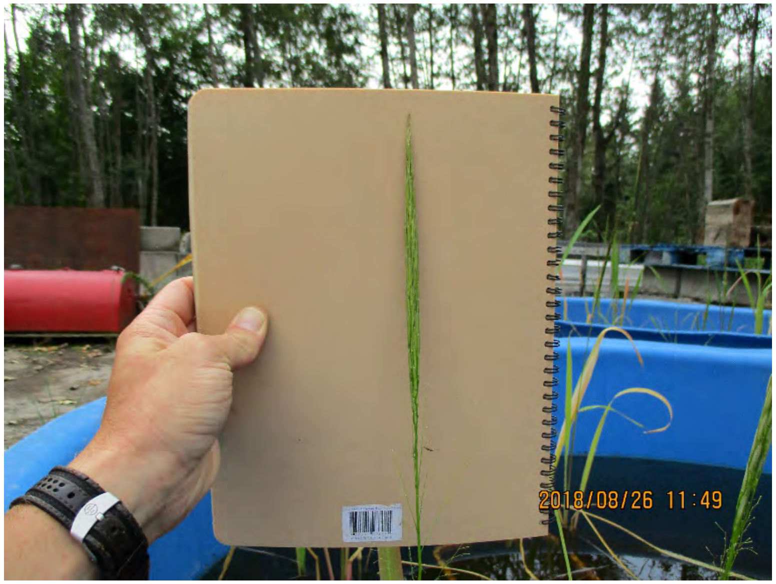

FIGURE 8. AUGUST 2018: WILD RICE PLANT PANICLE IN 'LAKE B' SEDIMENT_

APPENDIX C

TECHNICAL MEMORANDUM FROM DR. PETER LEE

Sediment Core Analysis / Evaluation. Dr. Peter Lee, Lakehead University, Thunder Bay, Ontario, CA.

Values for all sediment cores by 5 cm sections (top of sediment to 25 cm core depth) for Sandy and Little Sandy Lakes are contained in Appendix A. The results for both total and pore water values are summarized in Tables 1 and 2 and compared to data collected by the MPCA during 2011 (Myrbo et al, 2012) and other data from wild rice lakes in Ontario. Not all the same parameters as per the twin lakes were collected for the comparison data, but they do provide a useful comparison.

Comparing total values (Table 1) in the top 5 cm layer for Sandy versus Little Sandy, Little Sandy had noticeably higher values for AVS, Bo, Fe, Mn, and S and lower values for SEM. Other parameters were similar in values. Both lakes had values for Fe, S, AVS, Mn, and Pb decline considerably from the top 5 cm layer to the 6-10 cm layer. This declining trend continued to the 21-25 cm layer with S levels lower by a factor of 10 and Fe by a factor of 5 at these depths in the sediment. Presumably the concentrations for these chemical constituents at the lower depths were reflective of original background levels prior to mining operations.

Compared to values found by Myrbo et al. (2012) and the Ontario data, values in Sandy and Little Sandy sediment for Moisture, As, Cd, Co, Cu, Mn, Pb, and Zn were all within the ranges found elsewhere. AVS, Fe, and S were above the ranges.

Table 2 contains the pore water values for Sandy and Little Sandy Lakes in comparison to the MPCA data and that of Jorgenson (2013). Cl values were somewhat elevated in the Twin Lakes versus the comparison data but were in range for Ca, Fe, K, Mg, Na and Sr. Comparing the 21-25 cm layer in Sandy Lake (this layer was not available for Little Sandy Lake), there was a noticeable decline in values for K, Fe, Mn, Na, S, and SO_4 from the top layer. Although changes in Fe, Mn, S and SO_4 could be attributed to mining activities, the declines in K and Na were similarly found in natural sediment cores by Jorgenson (2013). Most of the values for sulfides (Appendix A) were below detection limits versus those found by Myrbo et al. (2012). This may reflect the fact that the MPCA collected sulfides *in situ* at their field sites. This same approach will be done at the Twin Lakes in 2015 to see if sulfide values differ when sampled directly.

In terms of whether or not the sediments in Sandy and Little Sandy will support wild rice growth, it will depend on the effects on growth of the elevated values of metals and sulfur compounds present versus normal concentrations in lake sediments. Ideally, a bioassay for wild rice growth that examined site specific effects could be used to test the wild rice response, but this is not available. MPCA (2014) in the draft analysis for scientific peer review suggested that sulfides were responsible for wild rice growth reduction. They further correlated the presence of sulfides to iron concentrations. If iron in pore water were sufficiently high, no sulfides would be expected. In both Sandy and Little Sandy Lakes, elevated sulfur levels in the sediment also correlated to elevated iron levels. The MPCA (2014) also determined there was a significantly positive correlation of AVS, standardized with total organic carbon, versus sulfate in surface waters. This relationship could potentially be used to determine if there was sufficient iron present to counter the increases in sulfides. Again, a bioassay of the response of wild rice in the twin lake sediments would be a true test of whether or not there was sufficient iron present to buffer the production of detrimental sulfides.

References:

Jorgenson, K. 2013. Northern wild rice (*Zizania palustris* L.) as a phytoremediation species in eutrophic wetlands – investigation of root-sediment interactions. M.Sc. Thesis, Lakehead University, Thunder Bay, ON. 270 pp.

Minnesota Pollution Control Agency, 2014. Analysis of the wild rice sulfate standard study: draft of scientific peer review. 91 pp.

Myrbo, A., Ramstack, J., and R. Thompson. 2012. Wild rice sulfate preliminary field survey 2011. University of Minnesota. Prepared for MPCA. 150 pp.

Table 1. Total values (digested) for parameters in sediment cores collected from Sandy and Little Sandy Lakes compared to other studies (Myrbo et al. 2012; Jorgenson, 2013; Whitefish, unpublished, LUEL).

Parameter			Sandy Lake			Little Sandy Lake			Mybro	Mybro	Mybro	Whitefish	Jorgenson
	MDL	UNITS	0 - 5 cm	6 - 10 cm	21 - 25 cm	0 - 5 cm	6 - 10 cm	21 - 25 cm	(mean)	(min)	(max)		
% Moisture Content	n / a	%	86.87	82.26	85.41	86.7	85.34	83.26	76.50	20.10	96.00		
Acid Volatile Sulfides	0.0001	%	0.034	0.024	0.005	0.192	0.083	0.0051					
Acid Volatile Sulfides	0.003	umole / g	10.71	7.53	1.64	60.0	25.93	1.60	0.72	0.00	6.25	1.90	
SEM [Cd,Cu,Ni,Pb,Zn]	0.002	umole / g	0.991	0.733	0.916	0.125	0.112	0.084				1.390	
Bulk Density	0.05	g / cm3	0.12	0.19	0.12	0.16	0.18	0.21					
Total Recoverable Arsenic in sediment	2	ug / g	9.63	6.99	5.01	9.6	8.79	4.02	2.64	0.44	11.92		1.00
Total Recoverable Boron in sediment	2	ug / g	28.7	17.71	20.37	61.58	45.12	44.63					
Total Recoverable Cadmium in sediment	0.25	ug / g	0.80	1.014	0.93	0.35	0.83	0.53	0.37	0.02	0.88	1.66	
Total Recoverable Cobalt in sediment	0.2	ug / g	8.04	6.10	5.14	5.83	6.09	5.75	2.11	0.19	10.26	0.71	
Total Recoverable Chromium in sediment	0.03	ug / g	19.62	19.76	21.07	17.76	21.76	24.30				7.07	
Total Recoverable Copper in sediment	0.05	ug / g	11.47	11.67	12.2	9.69	11.94	11.62	7.19	0.68	22.65	25.84	
Total Recoverable Iron in sediment	0.1	ug / g	59414.6	35683.6	15315.47	68833.9	39081.4	13125.70	8328.4	1298.4	50389.0	7852.65	1210.0
Total Recoverable Manganese in sediment	0.05	ug / g	436.62	298.25	259.38	624.39	267.45	181.91	608.60	45.52	3814.96	135.41	134.25
Total Recoverable Molybdenum in sediment	2	ug / g	< DL	< DL	< DL	< DL	< DL	< DL					
Total Recoverable Nickel in sediment	0.2	ug / g	12.55	13.04	14.86	8.44	11.4	14.30				8.43	
Total Recoverable Lead in sediment	1	ug / g	30.18	22.20	6.30	33.36	23.36	4.95	11.11	0.60	76.64	13.42	
Total Recoverable Sulfur in sediment	1	ug / g	47172.4	28590.4	6374.58	64517.3	32975.5	4071.13	3116.0	55.0	12515.0	247.19	4519.0
Total Recoverable Selenium in sediment	2	ug / g	< DL	< DL	< DL	< DL	< DL	< DL					
Total Recoverable Zinc in sediment	0.03	ug / g	98.36	92.20	75.23	68.16	82.90	61.61	38.05	4.92	103.98	49.70	75.14
Total Carbon in sediment	0.01	%	20.63	18.71	24.50	17.31	16.76	18.23					
N in sediment	0.01	%	1.72	1.47	1.69	1.7	1.43	1.32					

Table 2. Pore water values for parameters in sediment cores collected from Sandy and Little Sandy Lakes compared to other studies (Myrbo et al. 2012; Jorgenson, 2013).

Parameter	MDL	UNITS	Sandy Lake 0 - 5 cm	Sandy Lake 21 - 25 cm	L. Sandy 0 - 5 cm	Mybro (mean)	Mybro (min)	Mybro (max)	Jorgenson
Sulfide(S2-) in porewater	0.01	mg / L	<DL	<DL	0.223	0.305	0.01	14.84	
Chloride (IC) in porewater	0.05	mg / L	38.00	46.97	56.98	21.85	4.91	36.36	
Dissolved Arsenic in porewater	0.05	mg / L	<DL	<DL	<DL				
Dissolved Boron in porewater	0.05	mg / L	0.052	<DL	0.071				
Dissolved Calcium in porewater	0.01	mg / L	45.8	11.80	69.82	50.4	24.54	80.77	39.96
Dissolved Cadmium in porewater	0.002	mg / L	<DL	<DL	<DL				
Dissolved Cobalt in porewater	0.004	mg / L	<DL	<DL	<DL				
Dissolved Chromium in porewater	0.002	mg / L	<DL	<DL	<DL				
Dissolved Copper in porewater	0.004	mg / L	<DL	<DL	<DL				
Dissolved Iron in porewater	0.025	mg / L	1.642	0.997	0.552	10	0.012	35.59	1.735
Dissolved Potassium in porewater	0.1	mg / L	11.296	3.263	12.42	3.43	0.03	26.68	0.75
Dissolved Magnesium in porewater	0.01	mg / L	44.26	10.251	75.21	26.67	7.80	134.38	7.91
Dissolved Manganese in porewater	0.005	mg / L	0.539	0.211	0.334	1.97	0.025	16.72	0.313
Dissolved Molybdenum in porewater	0.05	mg / L	<DL	<DL	<DL				
Dissolved Sodium in porewater	0.05	mg / L	24.57	9.979	37.06	7.2	0.06	92	5.16
Dissolved Nickel in porewater	0.025	mg / L	<DL	<DL	<DL				
Dissolved Lead in porewater	0.025	mg / L	<DL	<DL	<DL				
Dissolved Sulfur in porewater	0.05	mg / L	23.639	5.00	51.19				0.4
Dissolved Selenium in porewater	0.05	mg / L	<DL	<DL	<DL				
Dissolved Strontium in porewater	0.01	mg / L	0.165	0.053	0.248	0.166	0.067	0.511	0.104
Dissolved Zinc in porewater	0.005	mg / L	0.019	0.016	0.007	0.061	0.01	0.275	0.005
Sulphate (SO4) [IC] in porewater	0.03	mg / L	69.19	42.04	145.39				

APPENDIX D

2013 SEDIMENT PORE WATER RESULTS

SANDY LAKE AND LITTLE SANDY LAKE SEDIMENT PORE WATER SAMPLE RESULTS

				Sandy Lake Core 1					Sandy Lake Core 2					Sandy Lake Core 3					Sandy Lake Core 4					Sandy Lake Core 5				
Parameter	Description	MDL	UNITS	Section 1	Section 2	Section 3	Section 4	Section 5	Section 1	Section 2	Section 3	Section 4	Section 5	Section 1	Section 2	Section 3	Section 4	Section 5	Section 1	Section 2	Section 3	Section 4	Section 5	Section 1	Section 2	Section 3	Section 4	Section 5
WH2S	Sulfide(S2-) in porewater	0.01	mg / L	<DL	IV	IV	IV	IV	<DL	IV	<DL	IV	IV	<DL	IV	IV	IV	IV	<DL	IV	<DL	IV	<DL	<DL	IV	<DL	IV	<DL
WICCL	Chloride (IC) in porewater	0.05	mg / L	24.18	IV	IV	IV	IV	33.73	IV	39	IV	IV	36.38	IV	IV	IV	IV	44.68	IV	47.32	IV	43.28	47.99	IV	52.81	IV	50.66
WICP4AS	Dissolved Arsenic in porewater	0.05	mg / L	<DL	IV	IV	IV	IV	<DL	IV	<DL	IV	IV	<DL	IV	IV	IV	IV	<DL	IV	<DL	IV	<DL	<DL	IV	<DL	IV	<DL
WICP4B	Dissolved Boron in porewater	0.05	mg / L	0.056	IV	IV	IV	IV	0.083	IV	<DL	IV	IV	0.073	IV	IV	IV	IV	0.082	IV	0.066	IV	<DL	0.078	IV	0.071	IV	<DL
WICP4CA	Dissolved Calcium in porewater	0.01	mg / L	31.64	IV	IV	IV	IV	56.44	IV	8.74	IV	IV	41.78	IV	IV	IV	IV	55.48	IV	43.53	IV	20.03	48.93	IV	36.92	IV	3.56
WICP4CD	Dissolved Cadmium in porewater	0.002	mg / L	<DL	IV	IV	IV	IV	<DL	IV	<DL	IV	IV	<DL	IV	IV	IV	IV	<DL	IV	<DL	IV	<DL	<DL	IV	<DL	IV	<DL
WICP4CO	Dissolved Cobalt in porewater	0.004	mg / L	<DL	IV	IV	IV	IV	<DL	IV	<DL	IV	IV	<DL	IV	IV	IV	IV	<DL	IV	<DL	IV	<DL	<DL	IV	<DL	IV	<DL
WICP4CR	Dissolved Chromium in porewater	0.002	mg / L	<DL	IV	IV	IV	IV	<DL	IV	<DL	IV	IV	<DL	IV	IV	IV	IV	<DL	IV	<DL	IV	<DL	<DL	IV	<DL	IV	<DL
WICP4CU	Dissolved Copper in porewater	0.004	mg / L	<DL	IV	IV	IV	IV	<DL	IV	<DL	IV	IV	<DL	IV	IV	IV	IV	<DL	IV	<DL	IV	<DL	<DL	IV	<DL	IV	<DL
WICP4FE	Dissolved Iron in porewater	0.025	mg / L	7.988	IV	IV	IV	IV	0.523	IV	0.326	IV	IV	1.591	IV	IV	IV	IV	0.604	IV	1.759	IV	1.698	0.82	IV	1.192	IV	0.296
WICP4K	Dissolved Potassium in porewater	0.1	mg / L	6.896	IV	IV	IV	IV	11.69	IV	2.174	IV	IV	11.04	IV	IV	IV	IV	19.41	IV	12.15	IV	4.984	13.56	IV	12.59	IV	1.541
WICP4MG	Dissolved Magnesium in porewater	0.01	mg / L	26.48	IV	IV	IV	IV	54.14	IV	9.279	IV	IV	33.52	IV	IV	IV	IV	50.21	IV	38.05	IV	17.14	51.57	IV	35.08	IV	3.361
WICP4MN	Dissolved Manganese in porewater	0.005	mg / L	0.844	IV	IV	IV	IV	0.588	IV	0.103	IV	IV	0.707	IV	IV	IV	IV	0.592	IV	0.545	IV	0.347	0.544	IV	0.597	IV	0.075
WICP4MO	Dissolved Molybdenum in porewater	0.05	mg / L	<DL	IV	IV	IV	IV	<DL	IV	<DL	IV	IV	<DL	IV	IV	IV	IV	<DL	IV	<DL	IV	<DL	<DL	IV	<DL	IV	<DL
WICP4NA	Dissolved Sodium in porewater	0.05	mg / L	13.463	IV	IV	IV	IV	22.643	IV	6.049	IV	IV	23.472	IV	IV	IV	IV	27.732	IV	27.962	IV	15.563	28.673	IV	30.303	IV	4.395
WICP4NI	Dissolved Nickel in porewater	0.025	mg / L	<DL	IV	IV	IV	IV	<DL	IV	<DL	IV	IV	<DL	IV	IV	IV	IV	<DL	IV	<DL	IV	<DL	<DL	IV	<DL	IV	<DL
WICP4PB	Dissolved Lead in porewater	0.025	mg / L	<DL	IV	IV	IV	IV	<DL	IV	<DL	IV	IV	<DL	IV	IV	IV	IV	<DL	IV	<DL	IV	<DL	<DL	IV	<DL	IV	<DL
WICP4S	Dissolved Sulfur in porewater	0.05	mg / L	13.761	IV	IV	IV	IV	11.711	IV	2.346	IV	IV	16.131	IV	IV	IV	IV	28.811	IV	17.951	IV	7.45	25.571	IV	20.011	IV	2.552
WICP4SE	Dissolved Selenium in porewater	0.05	mg / L	<DL	IV	IV	IV	IV	<DL	IV	<DL	IV	IV	<DL	IV	IV	IV	IV	<DL	IV	<DL	IV	<DL	<DL	IV	<DL	IV	<DL
WICP4SR	Dissolved Strontium in porewater	0.01	mg / L	0.119	IV	IV	IV	IV	0.2	IV	0.036	IV	IV	0.165	IV	IV	IV	IV	0.199	IV	0.176	IV	0.088	0.187	IV	0.16	IV	0.018
WICP4ZN	Dissolved Zinc in porewater	0.005	mg / L	0.006	IV	IV	IV	IV	<DL	IV	0.011	IV	IV	0.013	IV	IV	IV	IV	0.006	IV	0.015	IV	0.014	0.01	IV	0.007	IV	0.018
WICSO4	Sulphate (SO4) [IC] in porewater	0.03	mg / L	40.3	IV	IV	IV	IV	33.14	IV	26.7	IV	IV	46.58	IV	IV	IV	IV	86.58	IV	51.93	IV	35.23	75.77	IV	58.48	IV	48.84

				Sandy Lake Core 5					Sandy Lake Core 6					Sandy Lake Core 7					Sandy Lake Core 8				Sandy Lake Core 9				Sandy Lake Core 10	
Parameter	Description	MDL	UNITS	Section 1	Section 2	Section 3	Section 4	Section 5	Section 1	Section 2	Section 3	Section 4	Section 5	Section 1	Section 2	Section 3	Section 4	Section 5	Section 1	Section 2	Section 3	Section 4	Section 1	Section 2	Section 3	Section 4	Section 1	Section 2
WH2S	Sulfide(S2-) in porewater	0.01	mg / L	<DL	IV	<DL	IV	<DL	<DL	<DL	IV	IV	IV	<DL	<DL	IV	IV	IV	<DL	IV	IV	IV	<DL	<DL	IV	IV	IV	IV
WICCL	Chloride (IC) in porewater	0.05	mg / L	47.99	IV	52.81	IV	50.66	37.38	38.99	IV	IV	IV	37.24	48.74	IV	IV	IV	31.60	IV	IV	IV	48.85	46.59	IV	IV	IV	IV
WICP4AS	Dissolved Arsenic in porewater	0.05	mg / L	<DL	IV	<DL	IV	<DL	<DL	<DL	IV	IV	IV	<DL	<DL	IV	IV	IV	<DL	IV	IV	IV	<DL	<DL	IV	IV	IV	IV
WICP4B	Dissolved Boron in porewater	0.05	mg / L	0.078	IV	0.071	IV	<DL	<DL	<DL	IV	IV	IV	<DL	<DL	IV	IV	IV	<DL	IV	IV	IV	<DL	<DL	IV	IV	IV	IV
WICP4CA	Dissolved Calcium in porewater	0.01	mg / L	48.93	IV	36.92	IV	3.56	40.13	38.80	IV	IV	IV	47.57	47.04	IV	IV	IV	38.20	IV	IV	IV	52.03	54.55	IV	IV	IV	IV
WICP4CD	Dissolved Cadmium in porewater	0.002	mg / L	<DL	IV	<DL	IV	<DL	<DL	<DL	IV	IV	IV	<DL	<DL	IV	IV	IV	<DL	IV	IV	IV	<DL	<DL	IV	IV	IV	IV
WICP4CO	Dissolved Cobalt in porewater	0.004	mg / L	<DL	IV	<DL	IV	<DL	<DL	<DL	IV	IV	IV	<DL	<DL	IV	IV	IV	0.005	IV	IV	IV	<DL	<DL	IV	IV	IV	IV
WICP4CR	Dissolved Chromium in porewater	0.002	mg / L	<DL	IV	<DL	IV	<DL	<DL	<DL	IV	IV	IV	<DL	<DL	IV	IV	IV	<DL	IV	IV	IV	<DL	<DL	IV	IV	IV	IV
WICP4CU	Dissolved Copper in porewater	0.004	mg / L	<DL	IV	<DL	IV	<DL	0.013	<DL	IV	IV	IV	<DL	<DL	IV	IV	IV	0.010	IV	IV	IV	<DL	<DL	IV	IV	IV	IV
WICP4FE	Dissolved Iron in porewater	0.025	mg / L	0.82	IV	1.192	IV	0.296	0.523	0.921	IV	IV	IV	0.889	1.830	IV	IV	IV	0.511	IV	IV	IV	1.327	0.826	IV	IV	IV	IV
WICP4K	Dissolved Potassium in porewater	0.1	mg / L	13.56	IV	12.59	IV	1.541	10.160	7.644	IV	IV	IV	10.890	7.909	IV	IV	IV	10.463	IV	IV	IV	7.558	7.603	IV	IV	IV	IV
WICP4MG	Dissolved Magnesium in porewater	0.01	mg / L	51.57	IV	35.08	IV	3.361	37.000	31.987	IV	IV	IV	54.540	47.025	IV	IV	IV	38.961	IV	IV	IV	51.960	54.750	IV	IV	IV	IV
WICP4MN	Dissolved Manganese in porewater	0.005	mg / L	0.544	IV	0.597	IV	0.075	0.236	0.331	IV	IV	IV	0.413	0.314	IV	IV	IV	0.307	IV	IV	IV	0.624	0.504	IV	IV	IV	IV
WICP4MO	Dissolved Molybdenum in porewater	0.05	mg / L	<DL	IV	<DL	IV	<DL	<DL	<DL	IV	IV	IV	<DL	<DL	IV	IV	IV	<DL	IV	IV	IV	<DL	<DL	IV	IV	IV	IV
WICP4NA	Dissolved Sodium in porewater	0.05	mg / L	28.673	IV	30.303	IV	4.395	26.750	27.300	IV	IV	IV	27.190	32.025	IV	IV	IV	22.567	IV	IV	IV	28.680	30.580	IV	IV	IV	IV
WICP4NI	Dissolved Nickel in porewater	0.025	mg / L	<DL	IV	<DL	IV	<DL	<DL	<DL	IV	IV	IV	<DL	<DL	IV	IV	IV	<DL	IV	IV	IV	<DL	<DL	IV	IV	IV	IV
WICP4PB	Dissolved Lead in porewater	0.025	mg / L	<DL	IV	<DL	IV	<DL	<DL	<DL	IV	IV	IV	<DL	<DL	IV	IV	IV	0.041	IV	IV	IV	<DL	<DL	IV	IV	IV	IV
WICP4S	Dissolved Sulfur in porewater	0.05	mg / L	25.571	IV	20.011	IV	2.552	20.408	17.260	IV	IV	IV	34.598	41.397	IV	IV	IV	26.792	IV	IV	IV	34.968	33.218	IV	IV	IV	IV
WICP4SE	Dissolved Selenium in porewater	0.05	mg / L	<DL	IV	<DL	IV	<DL	<DL	<DL	IV	IV	IV	<DL	<DL	IV	IV	IV	<DL	IV	IV	IV	<DL	<DL	IV	IV	IV	IV
WICP4SR	Dissolved Strontium in porewater	0.01	mg / L	0.187	IV	0.16	IV	0.018	0.143	0.157	IV	IV	IV	0.163	0.189	IV	IV	IV	0.129	IV	IV	IV	0.183	0.185	IV	IV	IV	IV
WICP4ZN	Dissolved Zinc in porewater	0.005	mg / L	0.01	IV	0.007	IV	0.018	0.030	0.011	IV	IV	IV	0.021	0.012	IV	IV	IV	0.041	IV	IV	IV	0.023	0.011	IV	IV	IV	IV
WICSO4	Sulphate (SO4) [IC] in porewater	0.03	mg / L	75.77	IV	58.48	IV	48.84	53.16	47.50	IV	IV	IV	94.67	123.84	IV	IV	IV	80.53	IV	IV	IV	111.98	95.16	IV	IV	IV	IV

APPENDIX E

TWIN LAKES PEEPER PORE WATER RESULTS (2015-2018)

2015 Twin Lakes Peeper Pore Water Sample Results

PARAMETER	UNITS	DATE	Twin Lakes Outflow	Sandy Lake Mid	Little Sandy Lake Outlet	Little Sandy Lake Inflow 1	Little Sandy Lake Inflow 2	Little Sandy Lake Inflow 3	Field Blank	MDL
Sulfide	mg/L	8/5/2015	<DL	0.115	0.077	0.045	2.55	0.014		0.01
		9/3/2015	0.572	0.079	5.8	1.815	1.265	4.457	<DL	
		10/2/2015	0.44	0.871	3.23	3.18	7.7	7.12		
Chloride	mg/L	8/5/2015	6.46	23.73	50.37	41.56	58.97	28.25		0.05
		9/3/2015	6.28	29.82	44.94	42.91	62.22	27.23	0.51	
		10/2/2015	5.1	37.89	46.38	50.6	53.17	26.82		
Arsenic, Dissolved	mg/L	8/5/2015	<DL	<DL	<DL	<DL	<DL	<DL		0.03
		9/3/2015	<DL	<DL	0.033	<DL	<DL	<DL	<DL	
		10/2/2015	NM	NM	NM	NM	NM	NM		
Boron, Dissolved	mg/L	8/5/2015	<DL	<DL	0.061	0.049	0.101	<DL		0.025
		9/3/2015	<DL	<DL	0.051	<DL	0.101	<DL	<DL	
		10/2/2015	<DL	0.05	0.473	0.044	0.103	0.026		
Calcium, Dissolved	mg/L	8/5/2015	26.68	23.88	57.24	39.4	92.31	28.13		0.01
		9/3/2015	24.99	31.39	49.64	30.53	104.9	31.6	0.44	
		10/2/2015	34.91	45.41	47.7	44.41	109.92	39.98		
Cobalt, Dissolved	mg/L	8/5/2015	<DL	<DL	<DL	<DL	<DL	<DL		0.004
		9/3/2015	<DL	<DL	<DL	<DL	<DL	<DL	<DL	
		10/2/2015	<DL	<DL	<DL	<DL	<DL	<DL		
Copper, Dissolved	mg/L	8/5/2015	<DL	<DL	<DL	<DL	<DL	<DL		0.004
		9/3/2015	<DL	<DL	<DL	<DL	<DL	<DL	<DL	
		10/2/2015	<DL	<DL	<DL	<DL	<DL	<DL		
Iron, Dissolved	mg/L	8/5/2015	3.243	8.72	0.78	5.586	0.174	1.763		0.025
		9/3/2015	0.892	0.15	0.205	1.049	<DL	0.814	<DL	
		10/2/2015	1.18	0.027	1.212	0.198	0.026	0.317		
Potassium, Dissolved	mg/L	8/5/2015	4.813	5.904	8.683	6.762	7.453	4.602		0.1
		9/3/2015	4.431	5.137	8.104	6.223	7.277	4.508	<DL	
		10/2/2015	5.863	4.627	8.029	7.243	7.217	5.42		
Magnesium, Dissolved	mg/L	8/5/2015	10.85	17.72	45.78	33.07	107.3	25.49		0.01
		9/3/2015	9.249	32.89	39.63	23.86	122.1	23.43	0.124	
		10/2/2015	13.45	59.34	42.53	45.07	124.2	41.46		
Manganese, Dissolved	mg/L	8/5/2015	0.384	1.621	0.266	0.468	0.037	0.304		0.005
		9/3/2015	0.398	0.031	0.214	0.392	0.006	0.377	<DL	
		10/2/2015	0.98	<DL	0.427	0.222	0.018	0.799		
Sodium, Dissolved	mg/L	8/5/2015	5.325	13.79	28.91	23.83	35.42	13.66		0.05
		9/3/2015	4.576	16.97	26.27	21	37.92	15.42	0.196	
		10/2/2015	4.972	25.76	27.4	28.02	39.64	20.13		
Lead, Dissolved	mg/L	8/5/2015	<DL	<DL	<DL	<DL	<DL	<DL		0.025
		9/3/2015	<DL	<DL	<DL	<DL	<DL	<DL	<DL	
		10/2/2015	<DL	<DL	<DL	<DL	<DL	<DL		
Sulfur, Dissolved	mg/L	8/5/2015	3.235	4.711	17.39	22.37	116.6	5.583		0.05
		9/3/2015	3.882	18.6	6.722	7.026	84.52	2.986	0.167	
		10/2/2015	2.122	71.35	2.474	7.199	52.3	5.546		
Strontium, Dissolved	mg/L	8/5/2015	0.085	0.081	0.19	0.15	0.287	0.114		0.01
		9/3/2015	0.078	0.112	0.17	0.123	0.328	0.139	<DL	
		10/2/2015	0.115	0.171	0.171	0.158	0.334	0.147		
Zinc, Dissolved	mg/L	8/5/2015	<DL	0.01	<DL	<DL	<DL	<DL		0.005
		9/3/2015	0.021	0.074	0.116	0.03	0.025	0.03	0.032	
		10/2/2015	0.011	0.008	0.013	0.009	<DL	<DL		
Sulfate	mg/L	8/5/2015	5.05	8.02	41.28	51.37	174.17	12.24		0.03
		9/3/2015	12.94	59.59	19.45	25.53	294.34	14.01	1.98	
		10/2/2015								

MDL = Method Detection Limit
<DL - Below lab detection limit
NM - Not measured

2016 Twin Lakes Peeper Pore Water Sample Results

PARAMETER	UNITS	DATE	Twin Lakes Outflow	Sandy Lake Mid	Little Sandy Lake Outlet	Little Sandy Lake Inflow 1	Little Sandy Lake Inflow 2	Little Sandy Lake Inflow 3	MDL
Sulfide	mg/L	5/26/2016	**0.23**	**0.25**	**3.5**	**1.4**	**11.8**	**0.61**	Varies
		6/24/2016	**0.11**	**0.13**	**0.28**	**0.63**	**11.3**	**2.4**	
		7/22/2016	**0.34**	**0.18**	**0.37**	**1.5**	**41.9**	**0.97**	
		8/25/2016	**0.18**	**0.17**	**0.77**	**0.37**	**20.8**	**2.3**	
Iron, Dissolved	ug/L	5/26/2016	**2100**	**8550**	**870**	**2600**	**57.9**	**2700**	50.0
		6/24/2016	**14000**	**6240**	**12700**	**3620**	**176**	**4800**	
		7/22/2016	**13200**	**989**	**3350**	**855**	**73.8**	**1360**	
		8/25/2016	**15600**	**729**	**4110**	**4840**	**124**	**377**	
Sulfate	mg/L	5/26/2016	**39.7**	**105**	**18.2**	**81.3**	**82.8**	**3.0**	2.0
		6/24/2016	**2.3**	**16.1**	<2.0	**2.0**	**24.3**	**14.1**	
		7/22/2016	**2.1**	**27.3**	**2.1**	**3.0**	**17.0**	**2.6**	
		8/25/2016	<2.0	<2.0	<2.0	<2.0	**8.2**	<2.0	
Chloride	mg/L	5/26/2016	**23.1**	**21.0**	**39.3**	**31.6**	**26.2**	**12.0**	1.0
		6/24/2016	**32.6**	**29.0**	**37.3**	**40.6**	**52.9**	**18.6**	
		7/22/2016	**33.0**	**31.3**	**40.7**	**43.7**	**40.4**	**15.3**	
		8/25/2016	**19.1**	**24.4**	**41.5**	**44.7**	**47.4**	**20.7**	
Sodium, Dissolved	ug/L	5/26/2016	**13100**	**12600**	**20000**	**21400**	**15400**	**9010**	1000
		6/24/2016	**20200**	**16800**	**18400**	**21800**	**29400**	**11400**	
		7/22/2016	**18800**	**16500**	**19300**	**24000**	**24500**	**10600**	
		8/25/2016	**13600**	**14400**	**24800**	**27600**	**34400**	**16700**	
Calcium, Dissolved	ug/L	5/26/2016	**28800**	**31800**	**34400**	**46900**	**49200**	**18400**	500
		6/24/2016	**50600**	**25900**	**37500**	**33200**	**53700**	**22900**	
		7/22/2016	**50400**	**30100**	**45200**	**37600**	**73700**	**25200**	
		8/25/2016	**40100**	**26600**	**45500**	**40100**	**82700**	**36700**	
Potassium, Dissolved	ug/L	5/26/2016	**4530**	**4260**	**5770**	**7590**	**3460**	**3190**	2500
		6/24/2016	**7130**	**5290**	**5550**	**7150**	**5450**	**4080**	
		7/22/2016	**6950**	**4920**	**5460**	**7530**	**6750**	**4010**	
		8/25/2016	**8910**	**4720**	**7810**	**8800**	**8800**	**4970**	
Magnesium, Dissolved	ug/L	5/26/2016	**28700**	**35400**	**30400**	**53700**	**42300**	**19600**	500
		6/24/2016	**49100**	**25200**	**23000**	**31900**	**63300**	**23200**	
		7/22/2016	**46200**	**30100**	**29800**	**38700**	**69500**	**25600**	
		8/25/2016	**34800**	**28000**	**39400**	**38400**	**93900**	**42700**	
Manganese, Dissolved	ug/L	5/26/2016	**604**	**720**	**302**	**633**	**63.9**	**231**	5.0
		6/24/2016	**1270**	**1370**	**720**	**502**	**257**	**355**	
		7/22/2016	**958**	**287**	**522**	**366**	**341**	**247**	
		8/25/2016	**1260**	**376**	**604**	**664**	**121**	**281**	

MDL - Method Detection Limit

Vaires - MDL changes based on result's concentration.

2017 Twin Lakes Peeper Pore Water Sample Results

PARAMETER	UNITS	DATE	Twin Lakes Outflow	Sandy Lake Mid	Sandy Lake South Inflow	Little Sandy Lake Inflow 1	Little Sandy Lake Inflow 2	Little Sandy Lake Outlet	MDL
Sulfide	mg/L	5/25/2017	**0.73**	**0.23**	**0.10**	<0.10	**30.3**	**0.12**	Varies
		6/22/2017	**0.41**	**0.35**	**0.10**	**<0.10**	**41.9**	**1.3**	"
		7/27/2017	**0.39**	**0.11**	**0.17**	**<0.10**	**71.0**	**4.4**	"
		8/24/2017	**0.22**	**0.36**	<0.10	**0.31**	**34.2**	**NS**	"
		9/25/2017	**0.422**	<0.078	**0.095**	**0.42**	**29.6**	<0.078	"
		10/26/2017	**0.650**	<0.078	<0.078	<0.078	**52.6**	**0.65**	"
Iron, Dissolved	ug/L	5/25/2017	**7020**	**9870**	**429**	**778**	**139**	**4760**	50.0
		6/22/2017	**5590**	**3160**	**1430**	**9490**	**592**	**2800**	"
		7/27/2017	**8810**	**5060**	**20200**	**467**	**55.8**	**62.8**	"
		8/24/2017	**5130**	**3520**	**15600**	**2050**	**81.3**	**NS**	"
		9/25/2017	**5020**	**279**	**5250**	**873**	**<50.0**	**1170**	"
		10/26/2016	**1990**	**729**	**881**	**1820**	**215**	**316**	"
Sulfate	mg/L	5/25/2017	**3.6**	**6.1**	**51.3**	**215**	**82.8**	**10.8**	Varies
		6/22/2017	**19.7**	**9.1**	39.1	**227**	**19.0**	**6.7**	"
		7/27/2017	**<2.0**	**<2.0**	**<2.0**	**345**	**11.2**	**5.2**	"
		8/24/2017	<2.0	<2.0	**17.8**	**3.5**	**12.7**	**NS**	"
		9/25/2017	<2.0	<2.0	**48.0**	<2.0	**6.5**	**64.3**	"
		10/26/2017	<2.0	<2.0	**107**	**225**	**22.8**	**6.0**	"
Manganese, Dissolved	ug/L	5/25/2017	**828**	**287**	**38.1**	**108**	**87.5**	**525**	10.0
		6/22/2017	**942**	**298**	**58.0**	**336**	**59.7**	**348**	"
		7/27/2017	**1200**	**268**	**420**	**<10.0**	**53.8**	**241**	"
		8/24/2017	**627**	**283**	**281**	**293**	**73.5**	**NS**	"
		9/25/2017	**1160**	**220**	**146**	**293**	**307**	**399**	"
		10/26/2017	**655**	**217**	**18.9**	**199**	**158**	**346**	"

MDL - Method Detection Limit

Varies - MDL changes based on result's concentration.

2018 Twin Lakes Peeper Pore Water Sample Results - Phase 1

PARAMETER	UNITS	DATE	Inflow 2	Phase 1 - A	Phase 1 - B	Phase 1 - C	Phase 1 - D	Phase 1 - E	Phase 1 - F	MDL
Sulfide	mg/L	6/18/2018	**44.4**	**9.13**	**11.7**	**14.3**	**12.1**	**3.75**	**2.49**	Varies
Sulfide	mg/L	7/20/2018	**46.7**	**10.10**	**2.83***	**16.8**	**18.9**	**11.4**	**8.62**	"
Average	mg/L		**45.6**	**9.6**	**11.7**	**15.6**	**15.5**	**7.6**	**5.6**	"
Iron, Dissolved	ug/L	6/18/2018	**65.2**	**292**	**212**	**86.5**	**96.1**	**381**	**397**	50.0
Iron, Dissolved	ug/L	7/20/2018	**50**	**146.00**	**50**	**73.1**	**50**	**328**	**164**	"
Average	ug/L		**57.6**	**219.0**	**131.0**	**79.8**	**73.1**	**354.5**	**280.5**	"
Sulfate	mg/L	6/8/2018	**15.7**	**5.8**	**2.1**	**17.3**	**30.6**	**72.5**	**73.3**	Varies
Sulfate	mg/L	7/20/2018	**15.1**	**4.70**	**25.1**	**10.8**	**8.1**	**37.5**	**25.2**	"
Average	mg/L		**15.4**	**5.3**	**13.6**	**14.1**	**19.4**	**55.0**	**49.3**	"
Manganese, Dissolved	ug/L	6/18/2018	**40.0**	**342**	**407**	**183**	**221**	**289**	**387**	10.0
Manganese, Dissolved	ug/L	7/20/2018	**41.7**	**143.00**	**197**	**168**	**242**	**222**	**215**	"
Average	ug/L		**40.9**	**242.5**	**302.0**	**175.5**	**231.5**	**255.5**	**301.0**	"

MDL - Method Detection Limit

Varies - MDL changes based on result's concentration.

* Broken peeper. This data point is not valid.

2018 Twin Lakes Peeper Pore Water Sample Results - Phase 2

PARAMETER	UNITS	DATE	Inflow 2	Phase 2 - A	Phase 2 - B	Phase 2 - C	Phase 2 - D	Phase 2 - E	Phase 2 - F	Phase 2 - G	Phase 2 - H	MDL
Sulfide	mg/L	8/20/2018	**74.2**	**15.6**	**11.7**	**3.43**	**1.38**	**8.91**	**18.6**	**8.3**	**1.42**	Varies
Sulfide	mg/L	9/20/2018	**72.9**	**14.3**	**9.53**	**0.52**	**0.778**	**4.55**	< 7.79	**9.88**	**0.216**	
Average	mg/L		**73.6**	**15.0**	**10.6**	**2.0**	**1.1**	**6.7**	**13.2**	**9.1**	**0.8**	"
Iron, Dissolved	ug/L	8/20/2018	**972**	**197**	**215**	**170**	**1160**	**404**	**107**	**631**		50.0
Iron, Dissolved	ug/L	9/20/2018	< 50.0	**265**	< 50.0	**1440**	**2860**	**259**	**536**	**509**	**701**	"
Average	ug/L		**511.0**	**231.0**	**132.5**	**805.0**	**2010.0**	**331.5**	**321.5**	**570.0**	**701.0**	"
Sulfate	mg/L	8/20/2018	**14.1**	**5**	**3.8**	< 2.0	< 2.0	**3.3**	**5.7**	< 2.0	< 2.0	Varies
Sulfate	mg/L	9/20/2018	**14.9**	**6.4**	**17**	**5.1**	< 2.0	**3.8**	**2.8**	**3.2**	**2.3**	"
Average	mg/L		**14.5**	**5.7**	**10.4**	**3.6**	**2.0**	**3.6**	**4.3**	**2.6**	**2.2**	"
Manganese, Dissolved	ug/L	8/20/2018		**124**	**162**	**166**	**326**	**76**	**84.7**	**3430**		10.0
Manganese, Dissolved	ug/L	9/20/2018	**3.5**	**125**	**150**	**247**	**341**	**80.3**	**248**	**173**	301	"
Average	ug/L		**3.5**	**124.5**	**156.0**	**206.5**	**333.5**	**78.3**	**166.4**	**1801.5**	**301.0**	"
Manganese, Dissolved	ug/L	9/20/2018	**3.5**	**125**	**150**	**247**	**341**	**80.3**	**248**			"
Average	ug/L		**3.5**	**124.8**	**153.0**	**226.8**	**337.3**	**79.3**	**207.2**	**1801.5**	**301.0**	"

MDL - Method Detection Limit

Varies - MDL changes based on result's concentration.

APPENDIX F

COMMENTS FROM MIKE MADDEN ON BOIS FORTE SANDY AND LITTLE SANDY LAKES ANNUAL MONITORING REPORT (2018)

Tracy Muck

From: Moe, Tom A <tmoe@uss.com>
Sent: Friday, January 18, 2019 9:48 AM
To: Mike and Mary
Cc: Tracy Muck
Subject: RE: [External]-Re: Sandy Lake and Little Sandy Lake monitoring report - 2018

Mike,

Thanks for including me on your distribution list. Very interesting observations. I would like your permission to use your comments in our final report currently in preparation. Do you have any problem with that?

Thanks again.

Tom Moe
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U. S. Steel Minnesota Ore Operations
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218-248-0028 (cell)
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From: Mike and Mary [mailto:mikeandmary@mikeandmaryrange.com]
Sent: Friday, January 18, 2019 9:44 AM
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pierard.kevin@epa.gov; haugland.john@epa.gov; holst.linda@epa.gov
Subject: [External]-Re: Sandy Lake and Little Sandy Lake monitoring report - 2018

Darren,

Thank You for including me with this.

Two things stand out to me after reading the report(skimming) that are probably not relevant but I thought I would pass on. In the vegetation study there is no mention of cattails. Back in the 70's there were no cattails. The entire shore around the lake where cattails grow now was spruce bog or as we called it cranberry bog. The cattails started showing up around the same time the rice started to disappear, which is also when the water levels started to rise. Even the creek to Admiral lake was completely open and passable by small boat. Now its completely choked off.

Secondly and less important, looking at the water level chart many of the drops in water level over the years can be attributed to myself and other locals attempting to remove beavers and dams. We have spent countless hours removing dams and beavers but it's a losing battle for us. Former CO Gerry McHugh was convinced high water levels were the problem with the rice and he encouraged us in our efforts to lower the levels. Even with US Steels recent efforts at controlling the water level during their recent permit time we never had a full growing season free of high water.

Thank you all for your efforts. Feel free to contact me if you have any questions.

Mike Madden

218 780 3993

From: Darren Vogt <Dvogt@1854treatyauthority.org>
Sent: Thursday, January 17, 2019 8:09 AM
To: 'Tom Rusch'; 'Ann Geisen'; 'Daniel C Ryan'; 'Melissa Thompson'; 'Rod Ustipak'; 'Seth Moore'; 'Wayne DuPuis'; 'Nancy Schuldt'; 'Bill Latady'; 'Gerald Blaha'; 'Ed Swain'; Tyler Kaspar; 'amyrbo@umn.edu'; Thomas Howes; Edie Evarts; Esteban

Chiriboga; John Coleman; 'Tara Geschick'; Krista McKim; John Thomas; Smith, Erik (MPCA); Suzanne Baumann; Nathan Johnson; John Pastor; 'Chrissy Bartovich'; Tom Moe; Margaret Watkins; Brad Johnson; Jeremy Maslowski; steve.sommer@state.mn.us; phil.monson@state.mn.us; pmaccabee@justchangelaw.com; khoffman@mncenter.org; Ralph.J.Augustin@usace.army.mil; jtbutcher@fs.fed.us; emilybcreighton@fs.fed.us; Mike and Mary; Jeff Udd; Jessica Holmes; Lee Johnson; Tony Swader; gcng@umn.edu; Curt Goodsky (cgoodsky@boisforte-nsn.gov); marko.katharine@epa.gov; Jill.C.Bathke@usace.army.mil; jillhoppe@fdlrez.com; Spading, Kenton E CIV USARMY CEMVP (US); Morningstar, Desiree L CIV USARMY CEHQ (US); Marty Rye; Bev Miller; sarah.beimers@mnhs.org; Rick Gitar; Mary Ann Gagnon; Robin, Jim (MPCA); Patrick O'Hara; Laura Matson; Mae Davenport; Lotthammer, Shannon (MPCA); Wester, Barbara; moody.jonathan@epa.gov; pierard.kevin@epa.gov; haugland.john@epa.gov; holst.linda@epa.gov
Subject: Sandy Lake and Little Sandy Lake monitoring report - 2018

Hi all,
I have attached a report summarizing information from monitoring activities completed at Sandy and Little Sandy lakes in 2010-2018.

Thank you, and please let me know any questions on things.

Darren Vogt
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APPENDIX G

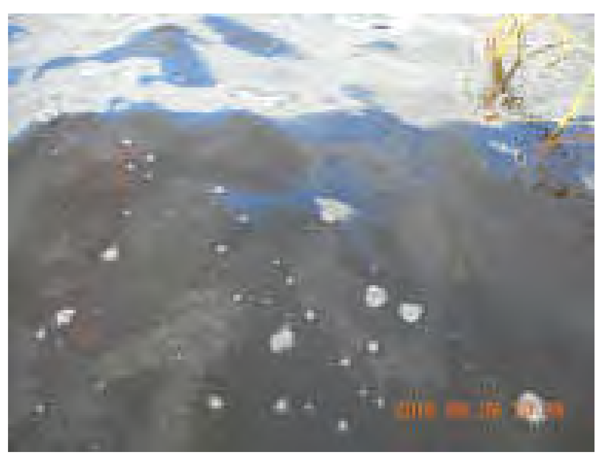
PHOTOS OF WILD RICE SEED PLOT GROWTH

Twin Lakes Wild Rice Growth in Seeded Areas

August 9, 2016

Sandy Lake Northwest

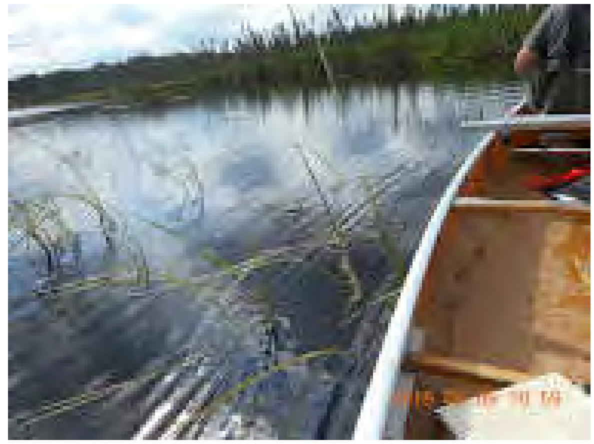
Sandy Lake East



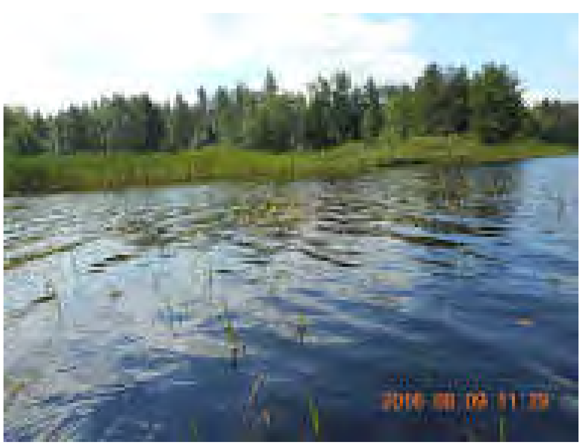
Sandy Lake East (Con't)

Sandy Lake Southwest

Sandy Lake Southwest (Con't)

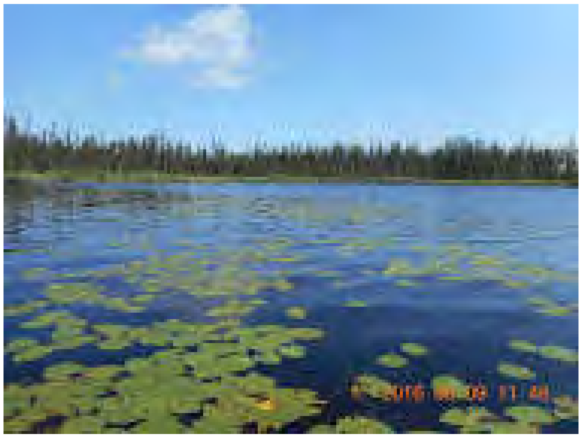


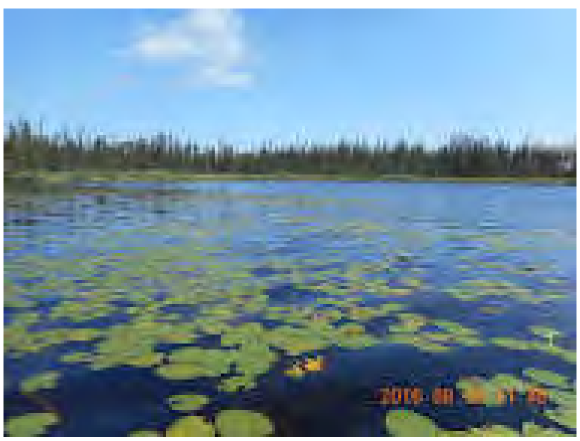
Little Sandy South



Little Sandy Northwest

Little Sandy Northeast





Appendix H

Wild Rice Seed Plot Densities

Wild Rice Densities 2016-2018

	2016	2017	2018
Sandy Lake North	31 plants at 2.7-2.9 ft. depth	4 Plants at 3.0 ft. depth	8 plants at 0.75 ft. depth
Sandy Lake Southeast	> 200 plants at 3.8-4.0 ft. depth	3 plants at 3.25 ft. depth	1 plant at 2.25 ft. depth
Sandy Lake West	> 200 plants at 3.5 ft. depth	50-60 plants at 3.25-3.75 ft. de	20 plants at 2.25 ft. depth
Sandy Lake South Inflow	15-20 plants at 2.7 ft. depth	18-20 plants at 1.25 ft. depth	15 plants at 2 ft.
Little Sandy Lake Northeast	10 plants at 3.2-3.9 ft. depth	60 plants at 3.0 ft. depth	8 plants at 1.75 ft. depth
Little Sandy Lake Northwest	None	2 plants at 1.25 ft. depth	12 plants at 2.5 ft. depth
Little Sandy Lake South	>200 plants at 3.75-4.0 ft.depth	50 plants at 3.5 ft. depth	50 plants at 1.75 ft. depth

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Research article

A comparison of results from a hydrologic transport model (HSPF) with distributions of sulfate and mercury in a mine-impacted watershed in northeastern Minnesota

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A R T I C L E I N F O

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A B S T R A C T

The St. Louis River watershed in northeast Minnesota hosts a major iron mining district that has operated continuously since the 1890s. Concern exists that chemical reduction of sulfate that is released from mines enhances the methylation of mercury in the watershed, leading to increased mercury concentrations in St. Louis River fish. This study tests this idea by simulating the behavior of chemical tracers using a hydrologic flow model (Hydrologic Simulation Program FORTRAN; HSPF) and comparing the results with measured chemistry from several key sites located both upstream and downstream from the mining region. It was found that peaks in measured methylmercury (MeHg), total mercury (THg), dissolved organic carbon (DOC), and dissolved iron (Fe) concentrations correspond to periods in time when modeled recharge was dominated by active groundwater throughout the watershed. This helps explain why the timing and size of the MeHg peaks was nearly the same at sites located just upstream and downstream from the mining region. Both the modeled percentages of mine water and the measured sulfate concentrations were low and computed transit times were short for sites downstream from the mining region at times when measured MeHg reached its peak. Taken together, the data and flow model imply that MeHg is released into groundwater that recharges the river through riparian sediments following periods of elevated summer rainfall. The measured sulfate concentrations at the upstream site reached minimum concentrations of approximately 1 mg/L just as MeHg reached its peak, suggesting that reduction of sulfate from non-point sources exerts an important influence on MeHg concentrations at this site. While mines are the dominant source of sulfate to sites downstream from them, it appears that the background sulfate which is present at only 1–6 mg/L, has the largest influence on MeHg concentrations. This is because point sourced sulfate is transported generally under oxidized conditions and is not flushed through riparian sediments in a gaining stream watershed system.

1. Introduction

When a river is legally classified as *impaired* with respect to a constituent, the causes of the impairment need to be studied to determine what corrective steps may be needed to bring the river back to an unimpaired state. This can become a time consuming, high-stakes process, especially when considering changes to a watershed that contains streams and rivers of high scenic and recreational value and a major industry that impacts flow and water chemistry. Such is the case for the St. Louis River in northeastern Minnesota (Fig. 1) which contains a richly forested land dotted with wetlands and lakes, but hosts world-class iron deposits that have been mined for more than a century and extensive, undeveloped, copper-nickel deposits that may be mined in the future. This river, like many others in Minnesota, is considered impaired with respect to mercury concentration in fish (Anderson et al., 2013).

The primary method Minnesota has chosen to address fish mercury impairments is to decrease mercury emissions in the state by 93 percent from 1990 levels and by active and aggressive participation in national and worldwide efforts to cut anthropogenic Hg emissions (MPCA, 2009). This should, in time, lead to a 65

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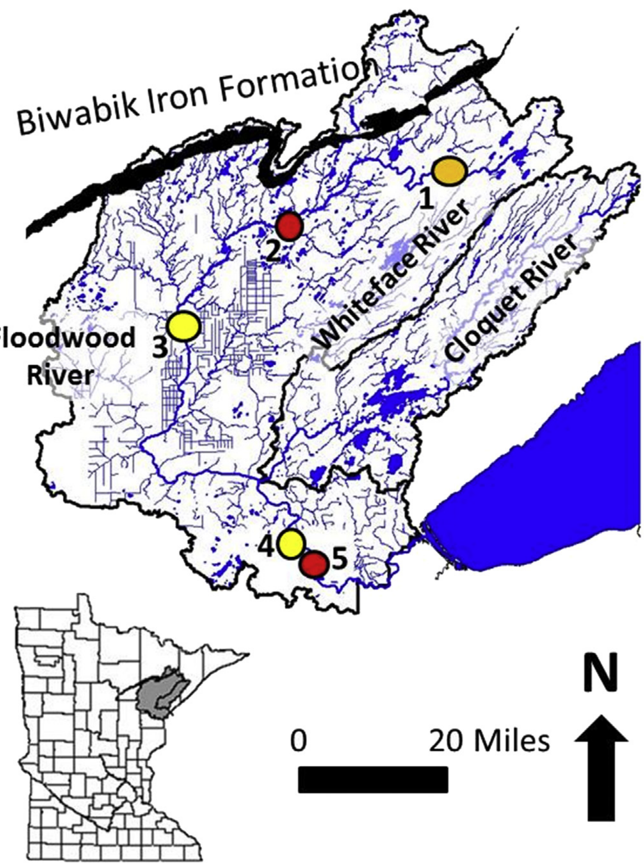

Fig. 1. Location Map showing the St. Louis River watershed and major points of interest to this study. Site 1 is Mile 179 near Skibo, MN, where both flow and chemistry were monitored upstream from the mining region (Biwabik Iron Formation in black). Sites 3 and 4 refer to Miles 94 and 36, respectively, where chemistry was sampled progressively downstream from the mining region. Sites 2 and 5 refer to the Forbes and Scanlon flow monitoring stations.

percent decrease in the amount of mercury in fish throughout the state. However, several rivers, including the St. Louis River, are expected to remain impaired even if these reduction goals are achieved (MPCA, 2014). Thus, the state is interested in determining what other measures might be useful in bringing this and other rivers that will remain impaired into eventual compliance.

One possible management strategy under consideration for such rivers involves decreasing the amount of sulfate released from the mining industry. Sulfate reducing bacteria (SRB) have long been known to participate in mercury methylation processes (Benoit et al., 1999; Gilmour et al., 1992). Sulfate added to water from the agricultural industry is widely debated, for example, as a primary cause for elevated methylmercury levels in certain fish in the Florida Everglades region (Gabriel et al., 2014; Julian et al., 2015). Debate over a possible connection between mining-related sulfate and methylmercury has also ensued for the St. Louis River, and so the State of Minnesota has been urged by environmental and mining advocates alike to study this issue.

Sulfate in Minnesota's mining region is produced when small amounts of pyrite and other less abundant iron sulfide minerals are exposed to air during the mining of taconite iron ore. This sulfate is rinsed into surface and groundwaters when precipitation infiltrates the oxidized portions of rock stockpiles and tailings. The majority of the sulfate currently released from mine wastes in the St. Louis River watershed eventually reaches the bottoms of still active mine pits and is discharged with mine water into nearby surface streams (Berndt and Bavin, 2012a,b). Additionally, some abandoned pits have become filled with high sulfate water (e.g., typically 100–1000 mg/L) that can overflow into nearby streams. The iron mining region, active since the 1890s, also contains other rock stockpiles and tailings piles that can promote oxidation of sulfide minerals that seep into the subsurface and emerge nearby, but this is a much smaller source than the sumps or pits that feed directly into streams in the St. Louis River's northern headwater regions.

Significant chemical and biological sampling efforts were made in this region in 2012 to identify linkages between sulfate release from the mining region and possible influence on MeHg production, transport, and bioaccumulation in the watershed (Berndt et al., 2014; Jeremiason et al., 2016; Johnson et al., in press). The watershed often experiences wet conditions in the spring and early summer that transitions to drier periods in late autumn and this also happened in 2012 (Fig. 2). Comparison of water chemistry for sites located both upstream and downstream from the mining region for this period indicated that sulfate was strongly correlated to magnesium, but not to dissolved organic carbon (DOC) or to methylmercury (MeHg), total mercury (THg), or dissolved iron (Fe) (Berndt et al., 2014). The latter components were, however, strongly correlated to each other. Although sulfate in reduced settings influenced mercury and methylmercury dynamics in sediments, the results suggested that the sulfate from mines may have had relatively little opportunity to interact with reduced sediments in a manner conducive for production and transport of MeHg. This study tests and expands this interpretation by comparing chemical results from the 2012 sampling study to seasonally varying differences in hydrologic flow components as modeled using an HSPF watershed model (Tetratech, 2015).

The HSPF model was selected for this study because it has the ability to provide an independent method to quantify and track the relative amounts of water delivered to the river specifically via surface runoff, interflow, and groundwater recharge. Recharge mechanisms that force hillslope flow paths through riparian zones have received recent attention for use in quantifying DOC, THg, and MeHg delivery to watersheds from similarly forested boreal catchments in Sweden (Bishop et al., 2004; Eklof et al., 2015; Seibert et al., 2009; Winterdahl et al., 2011). According to these models, groundwater that enters a river in its headwater regions attains much of its chemistry by reaction with riparian sediments, the last substrate with which it is in contact prior to becoming part of the surface water flowage. Thus, a comparison of measured chemistry to HSPF modeling results can help to determine the degree to which similar processes might help to account for the chemistry of water in mine-impacted portions of the St. Louis River.

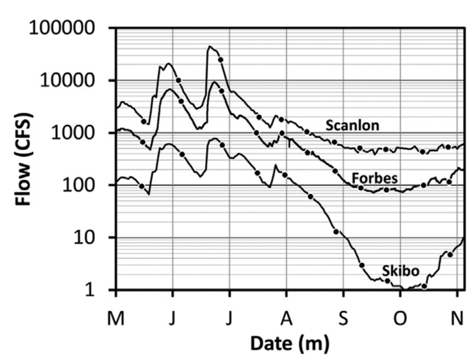

Fig. 2. Measured flow volumes in the St. Louis River during the study period (lines). Solid dots refer to dates when chemical samples were collected at Miles 36, 94, and 179.

2. Methods

HSPF modeling tools provide a well-established means to numerically characterize water recharge and routing in a watershed (Bicknell et al., 2001; Ouyang et al., 2012; Rolle et al., 2012). This model is part of the United States Environment Protection Agency's US-EPA's Better Assessment Science Integrating point and Nonpoint Sources (BASINS) software package (US-EPA, 2013). To the extent possible, HSPF models take into account all available climatological information, land use, topography, and surficial geology. Records from point sources, dams, and gaging stations located along the river or its tributaries are also considered directly in the final hydrologic calibration. The state of Minnesota has invested heavily in the development of HSPF watershed models as a means to improve its understanding of nutrient, sediment, and contaminant loading to rivers and lakes throughout the state. In 2015, a calibrated HSPF model became available for the St. Louis River watershed, with hydrologic calibration extending through the end of 2012 (Tetratech, 2015).

Flow measurements from 11 gaged stations located throughout the watershed were used in the calibration. This included sites at Scanlon (2005–2012 data set, $R^2 = 0.9293$ for monthly average flows), Forbes (2010–2012; $R^2 = 0.8561$), and Skibo (2011–2012, $R^2 = 0.8756$) (Fig. 1). Part of the calibration involved distributing non-point recharge to rivers along three primary flow paths that depend on land characteristics and the intensity and duration of storm events. The HSPF model was used to calculate the percentages of water at each of our sampling locations derived from different recharge sources. Five simulated tracers were defined (n with concentration C_n) each unique to water source types. These tracers were then introduced independently to each water source type as they entered the surface water flow environment as follows:

1. $C_{SR} = 1.0$ mg/L added only to water that enters the surface waters as surface runoff,
2. $C_{IF} = 1.0$ mg/L added only to water that enters the surface waters as interflow,
3. $C_{AG} = 1.0$ mg/L added only to water that enters the surface waters as active groundwater,
4. $C_{P1} = 1.0$ mg/L added only to water that enters the surface waters from mining point sources.
5. $C_{P2} = 1.0$ mg/L added only to water that enters the surface waters from non-mining point sources.

Direct precipitation onto open water was also modeled with a tracer, but its percentage was generally small compared to the others and its contribution is ignored here. The other tracer concentrations were used as proxies for the relative amounts of water derived as a function of time from individual source types.

A second calculation was also conducted for groundwater that involved additional input of a decaying tracer, $^{*}C_{AG}$, also at 1 mg/L concentration to all water entering the watershed as groundwater. This tracer was allowed to decay by a small fraction, k, each day. An indication of actual and relative transit time for dissolved components entering the stream from groundwater could then be computed using $^{*}C_{AG}/C_{AG}$ ratios as follows:

$$\text{Transit time (days)} = -\ln(^{*}C_{AG}/C_{AG})/k \quad (1)$$

where k is a decay rate in units of days^{-1} (e.g., $dC_{AG}/dt = -kC_{AG}$). In reality, some molecules in a watershed could take years to move from source region to sampling site while other molecules sourced nearby a can make the transit in seconds. Thus, transit times defined in this way are not singular or statistically defined values (McDonnell et al., 2010). The transit time in this application is operationally defined by Equation (1). It is used more appropriately in a semiquantitative sense to systematically compare the time that the majority of molecules transported in a stream have spent in the water column since entering the river.

3. Results

Simulated C_{SR}, C_{IF}, C_{AG}, C_{P1}, and C_{P2} concentrations varied by site and by season (Fig. 3). Relative tracer concentrations at all three sites summed very closely to unity in all cases, so the concentration of a particular constituent represents the fraction of water that originated from the tracer's designated source type. C_{AG} values close to 1.0 throughout the region indicate that active groundwater was the overwhelmingly dominant source of water input during most periods from April through July. Overland surface runoff and interflow waters were common immediately following large rain events, but these were flushed quickly downstream by more persistent, longer lasting recharge from active groundwater flow. The simulated tracer concentrations suggest that groundwater also dominated through the winter and dry autumn months at Mile 179, where no significant point sources were present upstream. Modeled mining point sources accounted for over 40 percent of the flow at Mile 94 during winter and at the height of the autumn dry period. Point sources accounted for less than 20 percent of flow in winter at Mile 36 but reached approximately 30 percent in the autumn, 20 percent of which was from the mining industry.

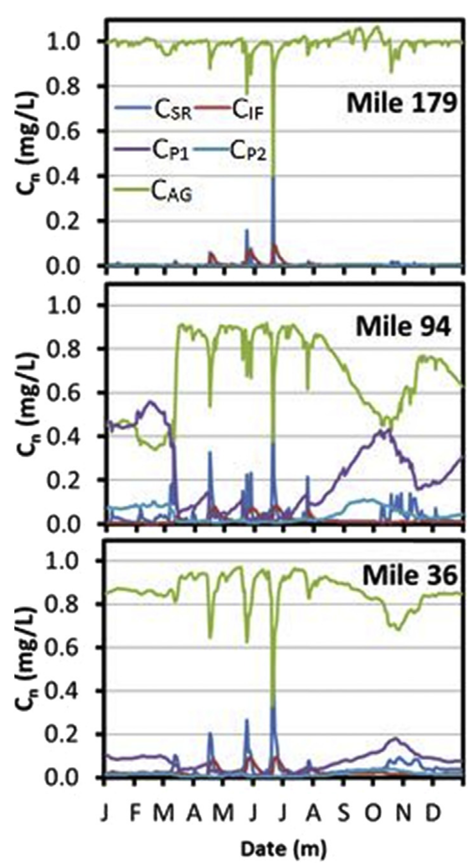

Fig. 3. Computed source type tracer concentrations (C_n) for the three sites sampled in 2012. The model indicates that May through July were dominated by discharge from active groundwater sources (C_{AG}). Mining (C_{P1}) and other (C_{P2}) point sources became progressively more important from August through October downstream from the mining region (Miles 94 and 36) as flow rates declined throughout the watershed.

Sulfate, DOC, THg, MeHg, and Fe concentrations measured at the three sites can be compared with computed mining point source tracer concentrations (Fig. 4) to provide insight on the potential for mine waters to impact these constituents. Dissolved sulfate measured in the water column increased when modeled mine tracer concentrations also increased at Mile 94, but the arrival of the measured sulfate peak at Mile 36 was somewhat delayed compared to that predicted by the minewater tracer. The source of this offset is part of an ongoing investigation to improve the HSPF model's accuracy.

Measured DOC, THg, MeHg, and Fe concentrations declined rapidly as the modeled mine water fraction increased. However, the fraction of mine water present in the watershed at the sampling sites was far too small to explain the declines by simple dilution. While there were peaks for DOC, THg, MeHg, and Fe at all sites, a second large peak in measured concentrations at Mile 179 occurred in August for DOC, THg, Fe, but not MeHg. This later peak followed a relatively small precipitation event near the end of July. The second peak in measured concentrations at Mile 179 was more pronounced for DOC and Fe than for THg and not observed at the downstream sites.

Calculated transit times for groundwater-derived components were generally 10 days or less at all sites from April through July (Fig. 5) but increased significantly, especially at Miles 36 and 94 in the fall and winter months. Transit times were never greater than 8 days at Mile 179, where there must be limited in stream storage between sources and the sampling site. The short computed transit times at Mile 179 suggest that water column demethylation processes were likely not important and, thus, the lack of high MeHg in the autumn is indicative of processes occurring in the source regions. Computed transit times for Mile 94 and Mile 36 increased, respectively, to approximately 25 and 40 days by early October suggesting there was greater opportunity for instream reactions such as DOC photodegration and mercury demethylation during these periods.

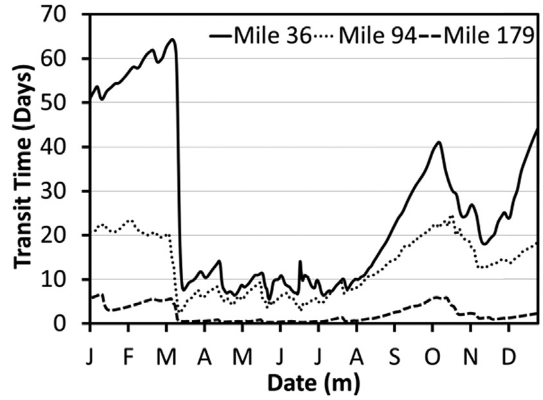

Fig. 5. Calculated transit times at the three sampling sites for components that enter the watershed from active groundwater sources. Transit times become short when flow rates become elevated.

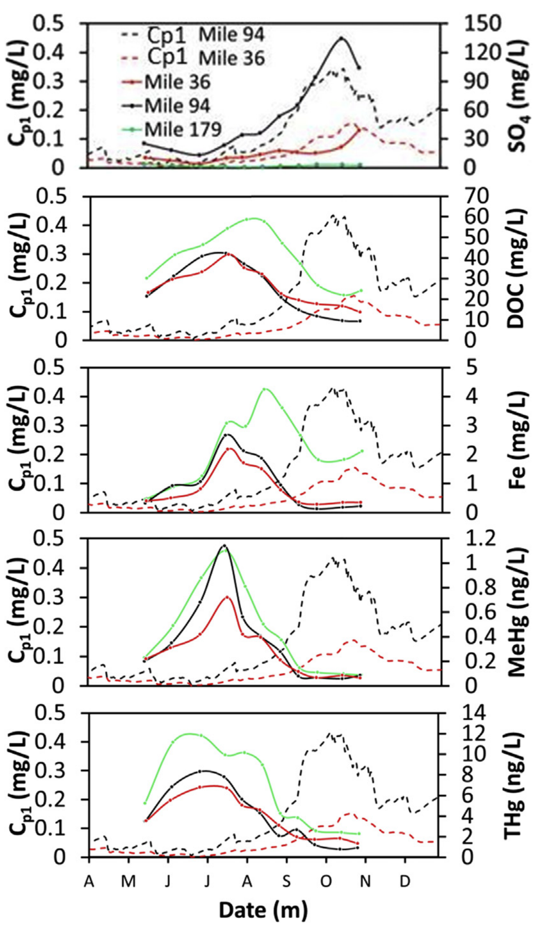

Fig. 4. Relationship between modeled mine water tracer concentration (C_{p1}, dashed lines) and dissolved concentrations of a variety of dissolved constituents (Sulfate, DOC, THg, MeHg, and Fe; solid lines) at Miles 36, 94, and 179.

4. Discussion

Landscapes and climate create complicated variables that result in many possible dynamically changing flow paths and mixtures of water in a river. Water from precipitation is added to streams via surface runoff or may be progressively delayed as it flows through and reacts with sediments along interflow and groundwater flow paths. Owing to this complexity, contextual information needed to interpret the chemistry of water draining a large river system can probably best be provided by computer watershed models like HSPF. The model developed here used simulated tracers to provide a mechanism to independently distinguish and track the source and fate of water entering the St. Louis River watershed for a year characterized by periodic sampling at sites located upstream and downstream from the mining region.

Active groundwater tracer concentrations calculated for each of the sampling points approached unity during periods when elevated methylmercury concentrations were found, signifying the importance of groundwater recharge in the MeHg generating process in this river. Although three major rain events early in the growing season led to pronounced but briefly elevated simulated tracer concentrations for interflow and surface water runoff, these components were diluted and washed quickly downstream by groundwater recharge when elevated MeHg concentrations were found in the river (Figs. 3 and 4).

It has long been known that riparian sediments can exert an important influence on the chemistry of stream waters recharged by groundwater (Bishop et al., 2004; Brigham et al., 2009; Vidon et al., 2010). Stream waters in several heavily studied forested boreal watersheds in Sweden, with composition similar to the St. Louis River, are thought to take their chemistry directly from riparian pore waters that obtained their chemistry during reaction with riparian sediments (Eklof et al., 2015; Seibert et al., 2009; Winterdahl et al., 2011). Under conditions of high flow the stream chemistry more closely mimics pore water chemistry that evolves in upper riparian soils. Conversely, stream chemistry under lower flow conditions mimics that of pore fluids that evolve in deeper sediments underlying the riparian soils. The Riparian Profile Flow-Concentration Model (RIM) describes changes in stream chemistry by integrating groundwater flux and concentration profiles for water moving laterally across riparian soils and sediments (Seibert et al., 2009). Based on the above theory, we hypothesize that stream chemistry reflects riparian pore fluid processes during periods of high groundwater input in our region, and use measured stream chemistry (Fig. 6) to infer processes occurring in riparian sediments upstream from the Mile 179 site. This HSPF model indicates water sampled at this site was almost totally from groundwater and had relatively short flow path from stream recharge to the sampling site (Fig. 6).

Sulfate concentration was initially above 5 mg/L when methylmercury and DOC concentrations were low, indicating that constituents in groundwater passing into the stream were not being rapidly metabolized and DOC was not being as actively produced as later in the season. By late July, the growing season was near its peak and sulfate concentrations dropped to approximately 1 mg/L while dissolved MeHg concentration reached its peak. As the summer continued, sulfate continued to remain close to 1 mg/L while iron began to climb to values eventually reaching 4 mg/L. This suggests that iron and sulfate reduction were both occurring within the pore fluid environment in the groundwater source region during these periods. The fact that MeHg concentrations were in decline as iron concentrations began to increase implies that iron reduction may not be the primary process associated with MeHg production and transport during the late summer months. Near the end of August, sulfate levels again began to climb, eventually to approximately 3 mg/L, just as MeHg reached stable low values (e.g., approximately 0.1 ng/L) and iron concentrations declined to approximately 2 mg/L. The gain in sulfate and loss of iron signals the slowing of both iron and sulfate reduction processes and corresponds to a decrease in DOC from almost 60 mg/L to values near 25 mg/L. Water levels in the watershed had declined greatly by this time, meaning that most water entering the streams may have been occurring through long-lasting springs and seeps, involving less contact with labile organic matter or at colder temperatures. For this part of the watershed, however, the attainment of minimum sulfate concentrations coincided with the methylmercury maximum, suggesting a strong role for sulfate reduction in the process that methylates mercury. It is reasonable to expect a similar reaction sequence in the nonmining portions of the mining watersheds where water filters through the landscape and riparian soils.

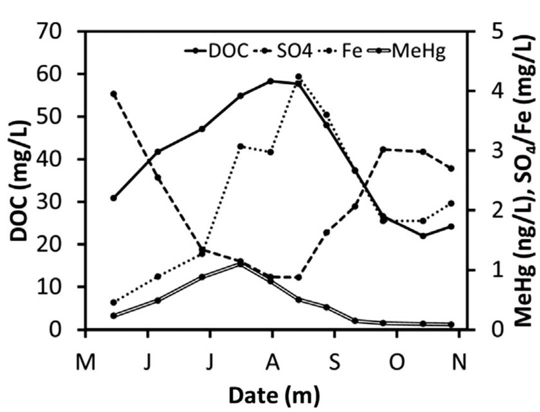

Fig. 6. Dissolved DOC, sulfate, Fe, and MeHg at Mile 179 in 2012. The MeHg peak occurred and Fe concentration quickly increased when sulfate dipped to approximately 1 mg/L. This suggests that DOC, MeHg, and Fe are generated by reactions involving sulfate and iron reduction as groundwater passes through riparian sediments on its way to recharging the river.

The climate impacting the different parts of the watershed appears to be similar based on the similarity of hydrographs for different parts of the river (Fig. 2). The geography and geology of the regions is variable and some differences in chemistry can be expected even without the presence of any mine influences. There are also more lakes and reservoirs that can enhance the importance of in-lake reactions for water collected at Miles 36 and 94, as compared to Mile 179. Despite these differences, the MeHg peaks occurred at the same time in all parts of the watershed, specifically when HSPF modeling suggests there was a very small fraction of mine water flowing in the river at the sampling sites. There was also an extended Fe and DOC peak in the area upstream from Mile 179 compared to at the sites downstream (Fig. 4). Flows at Mile 179 during the late summer become exceedingly small compared to earlier in the summer (Fig. 2). It is possible that a similar high-Fe peak was delivered to the other parts of the watershed, too, but in volumes so small that they were masked by iron-poor water already stored in the watershed. Modeled transit times for components of groundwater recharge increased during this time much more at Mile 36 and Mile 94 than at Mile 179 (Fig. 5), supporting this interpretation.

Two factors make it difficult for sulfate from the mines to impact MeHg in the rivers. First, the sulfate from mines is introduced largely as point sources at the ends of a relatively few tributaries and, thus, is limited geographically from interacting with riparian sediments in the great majority of the region. Second, even in the streams it flows through, it may be hydrologically excluded from reacting with riparian sediments that have the reduced conditions needed to promote methylation. The St. Louis River watershed receives, on average, approximately 8 inches more precipitation than is evaporated or transpired, and thus stream segments along the flow path mostly gain water from the surrounding landscape. The hydraulic gradient, is therefore, well poised to produce and transport chemicals like DOC and MeHg to the river, but water derived from mines is not well poised hydrologically to interact with riparian sediments where DOC and MeHg are likely to be produced.

This does not mean that sulfate introduced as point sources from mines or municipalities will never impact zones of active mercury methylation, but it does imply that instances may be rare in a mining region that receives more rainfall than can evaporate or transpire from the landscape. For example, a wetland rich area may become flooded with mine water containing sulfate during periods of increased pumping rate or from formation of temporary dams (e.g., beavers). Riverine sulfate may also react with materials in its streambed through diffusional exchange and hyporheic flow. Several studies have been conducted in the St. Louis River's mining region to evaluate stream and lake bed processes (Bailey et al., 2014a, 2014b; Berndt and Bavin, 2011). In general, MeHg production was found to be suppressed in sediments when overlying sulfate levels were high, owing likely to the binding of Hg with dissolved sulfide (Johnson et al., in press). This is consistent with findings from other studies which indicate that sulfate availability can lead to reduced sulfur species that can bind with Hg(II), reducing bioavailability (Benoit et al., 1999). A hypereutrophic lake (Lake Manganika) that receives mine water and municipal waste water has also been studied during several seasons. In the first season, when only the outflow for the lake was studied, large amounts of MeHg were found and it was proposed that the lake was producing MeHg in its water column or sediments and mixing on a relatively frequent basis (Berndt and Bavin, 2011). Subsequent years with intensified efforts found that the lake remained stratified during the summer months and while dissolved MeHg concentrations were elevated in the hypolimnion, they remained low in the epilimnion and Lake's outlet (Bailey et al., 2014b).

Instances like these should still be avoided or controlled to limit potential local impacts to MeHg inventories in local streams. However, the great majority of the mining sulfate added to streams apparently has little measureable impact on stream chemistry because opportunities are rare for the sulfate added as a point source to flow onto landscapes, through reduced soils, and back out into openly flowing waters. Elevated MeHg levels at sites located upstream and downstream from the mining region appear linked in time to periods of high summer groundwater recharge and not to periods of elevated minewater influence. Thus, it appears that limiting sulfate from point discharges would be an ineffective strategy for lowering MeHg levels in the St. Louis River.

5. Conclusions

Comparison of measured chemical trends to an HSPF source tracer model for the St. Louis River suggests that MeHg production and transport is associated primarily with the reduction of nonpoint sourced sulfate in groundwater that recharges the river through riparian sediments throughout the watershed. While abundant point sourced sulfate is delivered to the watershed from mines, this type of sulfate is typically delivered to the river in a manner that is isolated geographically and hydrologically from impacting the river's primary MeHg production and transport process. Thus, controlling mine derived sulfate would likely serve as an ineffective means for decreasing MeHg levels in the St. Louis River.

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GREAT LAKES Wild Rice INITIATIVE

Lake Superior Manoomin Cultural and Ecosystem Characterization Study

Final Report
May 29, 2020

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Table of Contents

1. Introduction

Manoomin (wild rice) is integral to the culture, livelihood, and identity of the Anishinaabe, a group of Indigenous peoples within Canada and the United States. Manoomin grows only in the clean waters of the Gichi-manidoo gitigaan (The Great Spirits Garden). The arrival of the Anishinaabe to the Great Lakes Basin was in fulfillment of the prophecy that guided their migration from the Atlantic Northeast westward toward the Great Lakes to where "food grows on the water." In addition to the vital role of Manoomin in the lives of the Anishinaabe, it is also recognized as being ecologically important. Migrating and resident wildlife feed on Manoomin seeds in wild rice beds, which provide a nursery for many species of fish and serve as nesting and breeding habitats for many waterfowl and muskrat. Many species feed on the plant. Wild rice plants can also help stabilize shorelines (Tribal Wild Rice Task Force, 2018; David et al., 2019).

In this project we aim to describe the importance of Manoomin to help foster community stewardship and education; and to inform Manoomin management, protection, and policy in the Lake Superior Basin and throughout the Great Lakes. Specifically, our objectives were to document and characterize (1) the importance of Manoomin habitat to cultural perspectives and identity, community connections, and cultural and spiritual practices of the Anishinaabe people; and (2) the ecological importance of Manoomin habitat as indicators *of* a high-quality, high-functioning, and biodiverse ecosystem around the Lake Superior Basin.

In this report we provide a brief background on the cultural and ecological importance of Manoomin, and describe current threats (Chapter 2). We then describe the methodology undertaken to characterize the importance of Manoomin in this study (Chapter 3); and provide the study's results, including cultural and ecological metrics developed to characterize cultural (Chapter 4) and ecological functionality of Manoomin and seven case studies (Chapter 5). Based on these results, we offer cross-case findings and lessons learned over the course of this study (Chapter 6), and provide conclusions and discuss potential next steps (Chapter 7).

Project Team members and audience

We, the Project Team members of this study, are a diverse group of Lake Superior Basin Anishinaabe communities, and federal and state agencies (Exhibit 1.1), supported by Abt Associates (Abt). We are self-identified participants in the study, which originated from annual Lake Superior Manoomin Restoration Workshops. The workshops were held in April 2017, April 2018, and December 2019 to discuss the complexity of Manoomin management, its cultural significance, and the challenges and need for coastal wetland restoration where Manoomin is currently and historically harvested (NOAA, 2017, 2018, 2019a). As an outcome of these workshops, the National Oceanic and Atmospheric Administration (NOAA) applied for and received a Great Lakes Restoration Initiative (GLRI) grant, which provided funding to support this current study. A larger group was involved in the initial 2017 and 2018 workshop discussions; the

Exhibit 1.1. Project Team

The Project Team consists of the following entities:

- Fond du Lac Band of Lake Superior Chippewa
- Keweenaw Bay Indian Community
- Lac du Flambeau Band of Lake Superior Chippewa
- Lac Vieux Desert Band of Lake Superior Chippewa
- Grand Portage Band of Lake Superior Chippewa
- 1854 Treaty Authority
- Great Lakes Indian Fish and Wildlife Commission
- Lake Superior National Estuarine Research Reserve
- National Oceanic and Atmospheric Administration
- National Sea Grant College Program
- U.S. Bureau of Indian Affairs
- Wisconsin Department of Administration.

list in Exhibit 1.1 reflects the entities who continued to be engaged in the GLRI-funded project implementation. As Project Team members, we decided upon the design and study methodology on a consensus basis, which Abt, our contractor providing technical support, then applied. We then reviewed and approved all reports and materials developed during this study.

The primary audiences for this report are Indigenous communities, tribal and non-tribal governments, and organizations who are working to actively manage and restore Manoomin across the Great Lakes.

2. Importance of Manoomin

Manoomin is central to the Anishinaabe cultural identity, traditions, and livelihood. It is an important species to the ecology of waters within the Great Lakes region, proving food and habitat to endemic and migratory species. This chapter first provides a brief overview of the cultural and ecological importance of Manoomin, and then describes some of the threats to Manoomin and its associated habitat. For a more detailed understanding of the relationship Manoomin holds with other beings, see Barton (2018) and David et al. (2019).

Cultural importance

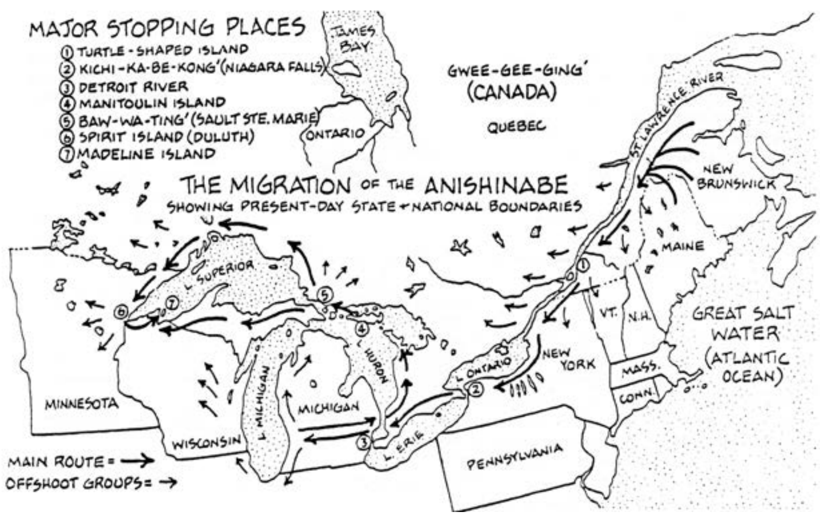
Photo of Kathleen Smith, Habitat Specialist/Plants Program, Keweenaw Bay Indian Community
Photo credit: Todd Marsee, Michigan Sea Grant.

Manoomin is a central part of the Anishinaabe migration story: the Anishinaabe people were told to head West to their chosen land by the third of seven prophets, and they would know they were home when they found “the food that grows out of the water” (Exhibit 2.1; Benton-Banai, 1985; David et al., 2019). This food would sustain their families’ bodies and souls for generations. As a result, Manoomin holds a critically important place in Anishinaabe culture.

Manoomin is a sacred symbol – it represents the Anishinaabe people’s journey, their relationship to the land, and their identity as a culture (Tribal Wild Rice Task Force, 2018). For the Anishinaabe people, Manoomin is considered a sacred, animate, more-than-human being and not an inanimate resource. Manoomin accompanies all ceremonies, celebrations, feasts, funerals, and initiations as a food source and a spiritual presence (David et al., 2019).

The Manoomin harvest is critical to Anishinaabe culture and is part of long-standing traditions. The harvest is a major community activity

Exhibit 2.1. The migration story



Source of map: Benton-Banai, 1985.

Ongow Anishinaabeg ogii-piminizha’aawaan iniw miigisan. Mii iw gaa-izhi-dagoshinowaad eteg wiisiniwin imaa nibiikaang.

The Anishinaabe people were to follow the direction of the Miigis Shell and by doing so would find their final destination; a place identifiable because it was where “food grows on water” [The Migration Story: In Search of Wild Rice. *Ayanjigozing, Manoomin Nandawaabanjigaadeg.* As translated and transcribed by Gimiwan (Dustin Burnette)].

Source of text: David et al., 2019.

that strengthens bonds within the community and within families. Families and friends work together, and children and elders come together to harvest. This tradition is passed down through generations and links the past to the present, providing intergenerational connections and allowing young people to participate in their heritage and history (Kjerland, 2015b). An essential part of harvesting Manoomin is the renewal of ties to the land and spirits (Raster and Hill, 2017). Harvesting by hand reaffirms the nature of Manoomin as a gift from the Creator and that Manoomin should be treated with respect and gratitude (Tribal Wild Rice Task Force, 2018).

Wild rice harvesting

Mii izhichigewaad ingiw Anishinaabeg dibwaa bawa`amowaad akawe asemaakewag biindaakoojigewag. Mii aw asemaa ayaabadizid biindaakoonind a`aw Manidoo. Geget apiitendaagozi asemaa. Mii akina ge izhichigeyangiban gegoo mamooyan imaa zayaaga`kiigin, gidaa-biindaakoojigemin.

The first thing Anishinaabe do is make an offering of tobacco before they harvest wild rice. Tobacco is used when making an offering to the spirit. Tobacco is highly valued. When we take from nature, we should make an offering of tobacco.

Source: GLIFWC, 2010.

Manoomin is a healthy, traditional food source for the Anishinaabe. It remains a dietary staple, nourishing the Anishinaabe and providing spiritual and cultural sustenance. Manoomin is highly nutritious, with a low-glycemic index, and provides benefits in preventing chronic diseases. It is a source of vitamins, minerals, fiber, and protein. Manoomin harvesting can also provide cardiovascular benefits from the physical activity associated with traditional food-gathering (Fond du Lac Band, 2018; David et al., 2019). It provides food sovereignty for the Anishinaabe as well, as it can be stored and consumed year-round (David et al., 2019). Hand-harvested Manoomin is often given as a gift or used for trade. This barter-and-trade system surrounding Manoomin also contributes to Anishinaabe food sovereignty by reducing food costs and improving food security (Tribal Wild Rice Task Force, 2018).

Manoomin is so fundamental to the Anishinaabe identity and culture that Anishinaabe treaties with the U.S. government guarantee access to Manoomin. The Treaties of 1837, 1842, and 1854 reserve gathering rights for Manoomin (among other rights) in lands ceded to the United States. In the Treaty of 1837, Manoomin is the only more-than-human being (i.e., the only biological resource) specifically mentioned. The rights to rice waters explicitly reserved in these treaties have been fundamental to Anishinaabe life historically and currently; and ensure Manoomin's central place in Anishinaabe culture through religious, ceremonial, medicinal, subsistence, and economic uses (David et al., 2019).

Ecological importance


Photo credit: Todd Marsee, Michigan Sea Grant

Manoomin is an essential part of the Great Lakes ecosystem and environment. Natural Manoomin beds are part of complex aquatic ecosystems that support wildlife and waterfowl. Over 17 species of wildlife that use Manoomin habitat for reproduction or foraging are listed in the Minnesota Department of Natural Resources' Comprehensive Wildlife Conservation Strategy as "species of greatest conservation need" (Fond du Lac Band, 2018). Ducks, geese, swans, muskrat, deer, and moose all feed on wild rice. Additionally, insect larvae feed on Manoomin and, in turn, birds feed on these insects.

Decaying Manoomin supports invertebrates that support birds, fish, and amphibians (Raster and Hill, 2017; Tribal Wild Rice Task Force, 2018). Manoomin beds provide breeding and resting grounds for migratory birds, rearing habitat for resident bird species (Raster and Hill, 2017), and nursery areas for young fish and amphibians (Fletcher and Christin, 2015).

Manoomin also plays an important role in maintaining ecosystem quality by sequestering nutrients, enriching soils, and countering nutrient loading and its negative impacts such as algal growth and turbidity (Tribal Wild Rice Task Force, 2018). Manoomin binds loose soils, which slows sedimentation. Additionally, through binding loose soils and acting as a windbreak, Manoomin limits the mixing of soil nutrients into waters, thus improving water clarity and reducing algal blooms (Loew and Thannum, 2011; Fletcher and Christin, 2015; Tribal Wild Rice Task Force, 2018). Manoomin is also an indicator of overall water quality and ecosystem health because it is highly sensitive to changes in water quality (David et al., 2019).

Threats to Manoomin

Manoomin and its associated habitat face many threats, some of which are highlighted below; for a more comprehensive list of threats, see David et al. (2019).

Hydrologic changes. Manoomin depends on shallow waters and both natural and human-based causes can alter lakes and rivers to make them inhospitable to this plant. Manoomin also depends on occasional hydrological disturbances, as long-term stability allows perennial plants to outcompete Manoomin, which is an annual plant. Therefore, occasional high or low water years allow Manoomin to flourish in the long-term. Damming and releasing water can degrade Manoomin habitat. Dams and ditching – created by humans or through natural causes, such as beavers or vegetation – can result in water-level regimes that are not conducive to Manoomin. Manmade dams on some reservoirs impose a large annual variability in water levels that do not allow Manoomin to flourish, while others that control water levels on lakes with lakefront property often impose highly consistent annual water levels that are also unsuitable for Manoomin growth. These managed water-level regimes can further allow other plant species to outcompete Manoomin for habitat. Other human activities that can lead to hydrologic changes that are detrimental to Manoomin include industrial resource extraction, such as mining. Industrial water appropriations and discharges can change water levels in Manoomin waters, preventing Manoomin from growing (David et al., 2019).

Pollution. Manoomin is highly sensitive to changes in water quality and requires unpolluted water to flourish. Sulfate pollution is particularly notable for its harm to Manoomin. Research dating back to the first half of the 20th century demonstrated that wild rice growth is impaired by elevated sulfate in water, but the specific mechanisms were unknown (Plain, 2017). Several recently published studies provide insight into how sulfate in water impairs wild rice: sulfate, which is converted to sulfide by microorganisms in the soil, becomes directly toxic to wild rice (e.g., Myrbo et al., 2017a, 2017b; Pastor et al., 2017; Pollman et al., 2017). Field research and controlled experiments have shown that waters with sulfate levels over 10 parts per million (ppm) are detrimental to Manoomin (Moyle, 1944; Pastor et al., 2017; David et al., 2019; Vogt, 2020b). Sulfate is commonly discharged in wastewater from mining activities, both from tailings basin discharges and process wastewater from ore processing plants (David et al., 2019).

Invasive and native competitive species. Several aquatic invasive species have locally threatened the survival of Manoomin, including milfoil, pondweed, cattail, common reed, flowering rush, and common carp. Plant species such as milfoil, cattail, and pondweed can directly compete with Manoomin for

space, nutrients, and habitat. Other species such as purple loosestrife can indirectly compete with Manoomin by reducing suitable habitat if the loosestrife extent expands down-elevation under drought conditions. Common carp can significantly diminish Manoomin survival by feeding on rice seeds and by uprooting plants (David et al., 2019). Some native plants such as ginoozhegoons (or pickerelweed or moose ear) also directly compete with Manoomin for habitat (see Exhibit 2.1).

Exhibit 2.1. Native plant competition

Ginoozhegoons is a native species that occupies the same habitat as Manoomin. As a perennial species, ginoozhegoons continues to grow each year, whereas Manoomin, an annual species, grows from an individual seed each year (Howes, 2010). Although ginoozhegoons is often considered a competitor, in some instances it appears to protect Manoomin beds by absorbing wind and wave action (David et al., 2019).

Photo credit: www.freepik.com.

Land use impacts. Manoomin is sensitive to changes in land use patterns, such as residential development. Lakeside residential development is often associated with motorized boating activity, which can increase wave damage and chop up rice mats. Channel dredging is also more likely to occur in areas with high boating activity, which can lead to changes in hydrology that negatively impact Manoomin. Residential development is also associated with higher levels of ammonium in wetlands, which can limit Manoomin stands (Pillsbury and McGuire, 2009). Shoreline development can also lead to wide-scale vegetation removal, including Manoomin, from property owners desiring an open view (David et al., 2019).

Herbivory. Large populations of birds, especially resident geese and trumpeter swans, can threaten Manoomin. Geese feed on Manoomin, and can have large impacts on small or sparse stands. These populations have been increasing on treaty territories over the past two decades and can have pronounced impacts on smaller rice lakes (Nichols, 2014; David et al., 2019). Other species such as wazhashk (muskrats) and red-winged blackbirds can also heavily utilize or feed on Manoomin, sometimes causing significant impact. However, wazhashk – often classified as “cleaners” or “gardeners” – are also thought to be beneficial to Manoomin, and may play a role in controlling competing vegetation or stirring sediment to the benefit of Manoomin (David et al., 2019).

Climate change. Climate change has begun to negatively impact Manoomin and is projected to have negative impacts on Manoomin in the future. Climate change is expected to lead to more frequent heavy rainfall events, which will lead to flooding that uproots or drowns Manoomin beds. Warmer temperatures resulting from climate change will also negatively impact Manoomin abundancy by favoring outcompeting plants that are better adapted for warmer climates; and being conducive to brown spot disease, which destroys photosynthetic tissues, reduces seed production, and favors high temperature and humidity (Barton et al., 2013; Cozzetto et al., 2013; Grand Portage Band of Lake Superior Chippewa, 2016; David et al., 2019). Warmer temperatures can also change the range of Manoomin and reduce germination. Projections of future climate in the 1854 Ceded Territory indicate substantial warming over the historical baseline that could lead to a shifting of wild rice outside the Great Lakes region and the 1854 Ceded Territory due to the location of Manoomin at the southern edge of its range. These increased temperatures could also lead to decreased germination of Manoomin if the temperatures are too warm for the dormant hardening-off period that northern wild rice requires (Stults et al., 2016). In a climate change vulnerability assessment conducted by the Great Lakes Indian Fish and Wildlife Commission (GLIFWC), Manoomin was found to be the species most vulnerable to the impacts of climate change out of all the species assessed, both because of the numerous climate-related threats and because it is sensitive to different climate effects at all stages of its life cycle (GLIFWC, 2018).

3. Methodology selected to characterize the importance of Manoomin

We evaluated several methodologies for characterizing the cultural and ecological importance of Manoomin and its associated habitat, and ultimately selected an innovative combined Habitat Equivalency Analysis (HEA) approach. This chapter describes how we selected and then applied this combined HEA approach.

Selecting a method

As a team, we identified several methods to characterize the cultural and ecological importance of Manoomin and its associated habitat. We reviewed the cultural and ecological literature, and used our collective knowledge of cultural and ecological characterization methodologies to develop the following list of possible methods:

- **In-person interviews or listening sessions** with tribal community members to gather qualitative information about perspectives, cultural identify, and value systems.
- **A case study analysis** to conduct a systematic and in-depth examination of the cultural and ecological importance of Manoomin across the Lake Superior region.
- **Indigenous metrics** to evaluate Indigenous priorities for cultural, social, and ecological aspects of the community that are understandable to both Indigenous and non-Indigenous ways of thinking (Donatuto et al., 2016), including themes developed by the community (Fond du Lac Band, 2018).
- **An ecosystem service conceptual model** to link changes caused by external stressors or interventions to Manoomin through the ecological system to socioeconomic and well-being outcomes (Olander et al., 2018).
- **A social-ecological keystone concept** to quantify biocultural elements of Manoomin as a keystone species (Winter et al., 2018).
- **An HEA** to determine the amount of restoration needed as a counter-balance for habitat that has lost cultural and ecological functionality (NOAA, 2000, 2019b).
- **A combined HEA approach** to combine several methodologies that overcome individual shortcomings to develop a strong framework to characterize Manoomin and its associated habitat.

We developed and applied a set of criteria to evaluate possible methods for characterizing the cultural and ecological importance of Manoomin (Exhibit 3.1). Using these criteria, we narrowed the possible methodologies to three options – a case study analysis, Indigenous metrics, and an HEA – and a fourth approach that combined these three methods. Ultimately, we selected the combined HEA approach by consensus.

Exhibit 3.1. Criteria for selecting a characterization method

Methods should be:

1. Non-monetary
2. Capable of combining ecological and cultural characterization into a single analysis
3. Implementable using mainly existing data and information (i.e., study should not involve extensive primary data collection efforts)
4. Based, at least in part, on Indigenous methodologies, or research for and by Indigenous people using techniques and methods drawn from their traditions and knowledge.

Applying the combined HEA approach

We applied the combined HEA approach to determine or "scale" the amount of restoration needed to counter-balance habitat with cultural and ecological functionality losses over time. We developed and applied a set of cultural and ecological metrics to characterize (1) the degree of lost functionality at a given location, and (2) the increased functionality provided by restoration actions at that location. We then "scaled" the restoration gains to the losses to quantify the equivalent amount of that same restoration that would be needed to balance the losses. The case studies describe specific locations with degraded Manoomin habitat with reduced cultural and ecological functionality, and actions undertaken in attempts to restore or improve the cultural and ecological functionality. We applied the combined HEA approach to these locations.

The combined HEA approach included (1) identifying case study sites as examples of degraded and restored Manoomin habitat, (2) refining and applying cultural and ecological metrics to characterize the degraded and restored Manoomin and its associated habitat at the case study sites, and (3) using HEA to quantify the amount of restoration need to counter-balance the lost Manoomin habitat functionality (Exhibit 3.2). We describe these steps in more detail below.

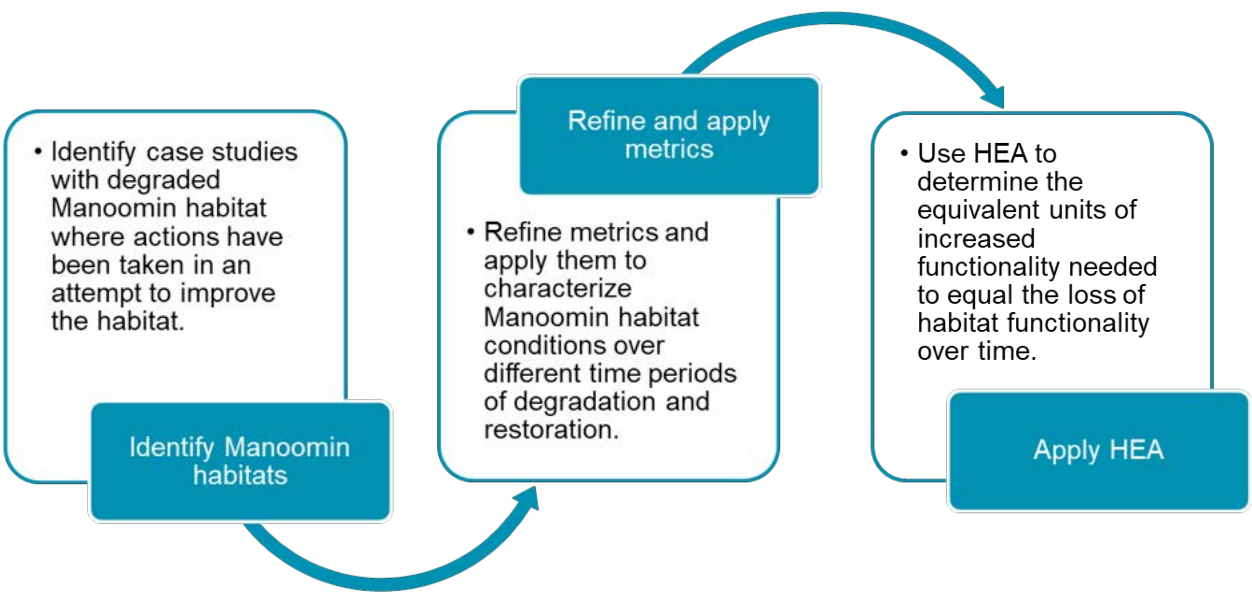


Exhibit 3.2. Steps in the combined HEA approach

Identify Manoomin habitats

We identified areas across the Lake Superior region with current or former Manoomin habitat. Our goal was to identify places that experienced a decline in Manoomin over time, and places where restoration actions have attempted to address the decline. At each site, we aimed to understand:

- The ecological conditions at the site, such as the hydrology, water quality and land use, and climatic conditions
- The cultural and ecological importance of Manoomin at the site, including Manoomin harvest and wildlife dependence on Manoomin
- The cause of Manoomin decline, such as hydrologic changes, invasive species, climate change events, or other threats
- The types of restoration actions undertaken, such as seeding efforts or management of invasive or competitive species
- The success or failure of those restoration actions, including cultural and ecological effects
- The timeline of degradation and restoration actions.

We first selected two pilot case studies to test and refine the approach: Big Rice Lake and Twin Lakes. Once we refined the cultural and ecological metrics and the combined HEA approach, as described below, we then selected five additional case studies. Each Band on our Project Team selected a case study, focusing on places of particular importance to their Band. Case studies could be on reservation lands, in ceded territory, or elsewhere. For each case study, we gathered information about the extent and timeframe of the degradation and restoration. This resulted in a range of types of Manoomin habitat degradation and restoration approaches represented in our case studies, dispersed over a broad geographical area. For each site (or case study), we formed a case study team that assessed the Manoomin habitat degradation and restoration, using cultural and ecological metrics (described below). The case study team included members of our Project Team and other tribal, federal, or state partners with experience managing Manoomin at each case study site.

Refine and apply cultural and ecological metrics

We developed a set of metrics to broadly measure all aspects of community health, with health defined as a coexistence among human beings, nature and natural resources, and spiritual beings (Donatuto et al., 2016). We started with Donatuto et al.'s (2016) indicators of Indigenous health, as well as Fond du Lac Band's (2018) health impact assessment themes and Winter et al.'s (2018) biocultural functional groups; and then adjusted and added to them, to develop a set of cultural and ecological metrics focused on Manoomin and the Great Lakes coastal wetlands.

We refined the descriptive scales used by Donatuto et al. (2016) to rank the relative status of each metric at a specific time period. These rankings provided a baseline from which to compare future rankings of the same metric, and ultimately illustrated health trend data over time. We used the following five-point descriptive scale:

- We're doing great
- We're looking pretty good
- Things are not very good
- Things are very bad
- No use of Manoomin.

We later added numeric scores to the descriptive scales as a scalar for our HEA; our numeric scores ranged from 0% (No use) to 100% (Doing great).

We applied draft metrics to our pilot case study during a workshop in August 2019. We subsequently refined the metrics to incorporate additional considerations, such as incorporating health into the *food sovereignty* metric because eating good foods relates to the mind, body, and spirit. Once we finalized the metrics and agreed to them on a consensus basis, we applied them to our case study sites.

Apply HEA to characterize Manoomin

The HEA tool was developed to determine or "scale" the amount of restoration needed as a counter-balance for habitat that has lost cultural and ecological functionality.

We held a series of webinars for each case study. During these webinars, the case study team defined the case study time periods, and then ranked each metric for each time period. The case study team first identified time periods with distinct or changing Manoomin habitat conditions. This process relied on reviewing historical documents and records, as well as case study team member's specific knowledge of the place. We then stepped through each time period, and formally ranked each metric according to the scale given above. For the Anishinaabe metric, for example, we asked each case study team:

> How would you rank [insert place name] in terms of providing Manoomin, which is sacred to the Anishinaabe and central to the foundations of their culture, sovereignty, and treaty rights? Would you say (a) we're doing great, (b) looking pretty good, (c) not very good, (d) things are bad, or (e) no use?

The case study team members individually ranked each metric, and we took an average of these rankings.

Finally, we used our HEA model to calculate the amount of restoration needed to balance the reduced or lost functions. In other words, given that restoration is challenging and rarely achieves full functionality, and the degradation has often spanned prolonged periods of time, we use the HEA to quantify the additional amount of equivalent restoration that would be needed to counter-balance the lost functionality.

The HEA model includes:

- **Base year** for this economic analysis; we set the base year to the current year, 2020.
- **Intergenerational balancing factor** to account for time preference, where degradation and restoration are put in present-value terms (NOAA, 1999). Because not all communities share this same time preference, we discussed the appropriate factor for this study and decided to apply a constant factor of 3% across all case studies, where things in the past are more valuable than they are today and things in the future are less valuable than they are today. A 3% factor is typical for ecological projects (OMB, 2003).
- **Acres** of Manoomin or Manoomin habitat characterized by the case study team. In some cases, acres included the full area of Manoomin waters and in other cases it was a portion of Manoomin waters.
- **Rankings** of Manoomin habitat over degraded and restored time periods using cultural and ecological metrics.

The amount of restoration in acres needed to counter-balance losses may be significantly larger than the acres of degraded habitat. This may be true because of practical limitations in our ability to produce fully functioning restored habitat. For example, if one acre of restored Manoomin wetland only reaches 50% functionality, then two acres of restored habitat are needed to counter-balance the one acre of lost Manoomin habitat. In addition, the amount of time that the habitat was degraded is counter-balanced with the time the restored habitat takes to reach its maximum functionality. Thus, we can account for habitat degraded for longer periods of time, and restoration actions that take longer to mature.

4. Cultural and ecological metrics

We developed 12 metrics that characterize the cultural and ecological functions of Manoomin and its associated habitat. These metrics describe how Manoomin contributes to maintaining connections with the Anishinaabe culture, how ecological functionality is supported and resilient to changing conditions, and how continued learning and sharing of Anishinaabe values are promoted.

Exhibit 4.1 displays the metrics graphically in the form of a dream catcher. Although many Tribes have adopted dream catchers over time, the Anishinaabe may have originated this tradition. There are many legends and stories behind the origins of dream catchers; in most legends, a dream catcher serves to filter out bad bawedjigewin (dreams) and allow only the good ones to enter (We R Native, 2020). Many indicate that dream catchers were also intended to teach natural wisdom (We R Native, 2020). In this graphical display of the metrics, we group cultural and ecological metrics inside the dream catcher hoop, with the Anishinaabe metric centered as it is critical for all other metrics. The three cultural and ecological education metrics are displayed below the dream catcher, as these educational metrics aim to generate and transmit the cultural and ecological knowledge between generations and communities.

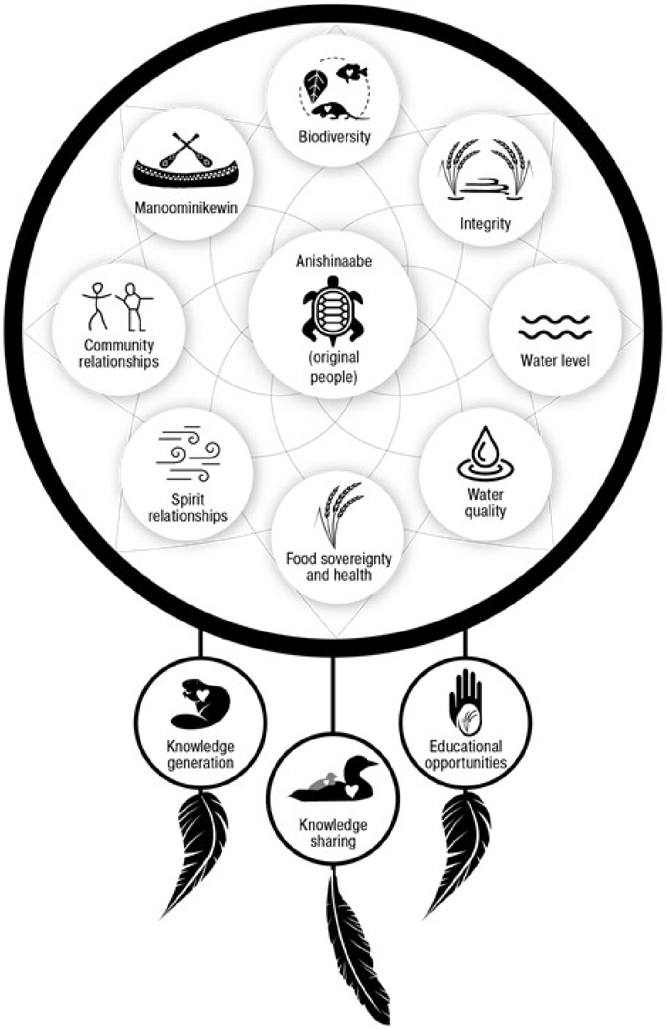


Exhibit 4.1. Dream catcher displaying the 12 metrics developed for this study

Below, we define the cultural, ecological, and cultural and ecological education metrics.

Cultural Metrics

Anishinaabe (original people) – The place provides manoomin, which is sacred to the Anishinaabe and central to the foundations of their culture, sovereignty, and treaty rights.

Community relationships – Manoomin at this place contributes to bonding, traditions, and strengthening family and community connections.

Spirit relationships – Manoomin at this place enables the Anishinaabe to maintain connections and balance with spirit beings (or relatives) from all other orders of creation (first order: rock, water, fire and wind; second order: other plant beings; third order: animal beings; fourth order: human beings).

Manoominikewin – This place allows for the Anishinaabe to harvest, prepare, and share (gifting, healing, and eating) manoomin in the ways practiced by their ancestors for centuries.

Food sovereignty and health – This place provides the capacity to provide for the sustenance, health, and independence of the Anishinaabe.

Ecological Metrics

Biodiversity – Healthy manoomin and appropriate habitat at this place supports diverse biological communities (e.g., free of invasive species) that indicate the capacity of the place to support abundant associated plant and animal species (e.g., other native aquatic vegetation, fish, waterfowl, muskrat), providing for spiritual and subsistence needs.

Integrity – Physical habitat and hydrology, water and sediment chemistry support stands of manoomin that exhibit natural annual variability; viable seed bank ensures that sustainable manoomin populations will persist even after occasional poor production years. Natural genetic diversity is maintained without impact from cultivated strains, or reduced gene flow from the loss of nearby manoomin populations.

Water quality – This place has clean water (e.g., sulfate levels below 10 ppm) and sediments that can support robust stand density and wildlife diversity; is free of contamination or impacts from industrial, agricultural, recreational, or residential influence; and is of sufficient areal extent to sustain a manoomin population.

Water level – This place has a natural or managed hydrologic regime that can maximize resilience under variable or extreme climatic conditions across the growing season (maintaining optimal depth range and flow).

Cultural and Ecological Education Metrics

Knowledge generation – This place allows for continued learning and generation of the Anishinaabe practices, values, beliefs, and language through experience.

Knowledge sharing – This place allows for the continued sharing and transmittal of the Anishinaabe practices, values, beliefs, and language among family members and community.

Educational opportunities – This place provides opportunities for language, land stewardship, and other educational programs, such as educational rice camps.

5. Cultural and ecological characterization case study results

The seven case studies, each of which profiles a story of changes in Manoomin cultural and ecological functionality over time, form the heart of this project. The case studies, grouped around the Lake Superior region, are located in the 1854 Ceded Territory and the 1842 Ceded Territory (Exhibit 5.1). Three of the seven case studies are located on reservation lands.

As described in Chapter 3, these case studies are primarily located in places with current or former Manoomin habitat that have experienced a decline in Manoomin over time, and where restoration actions have been undertaken in an effort to restore Manoomin habitat over different time periods. In a few case studies, documentation of Manoomin presence is not available from historical records; however, their physical or hydrologic features make them conducive to growing Manoomin.

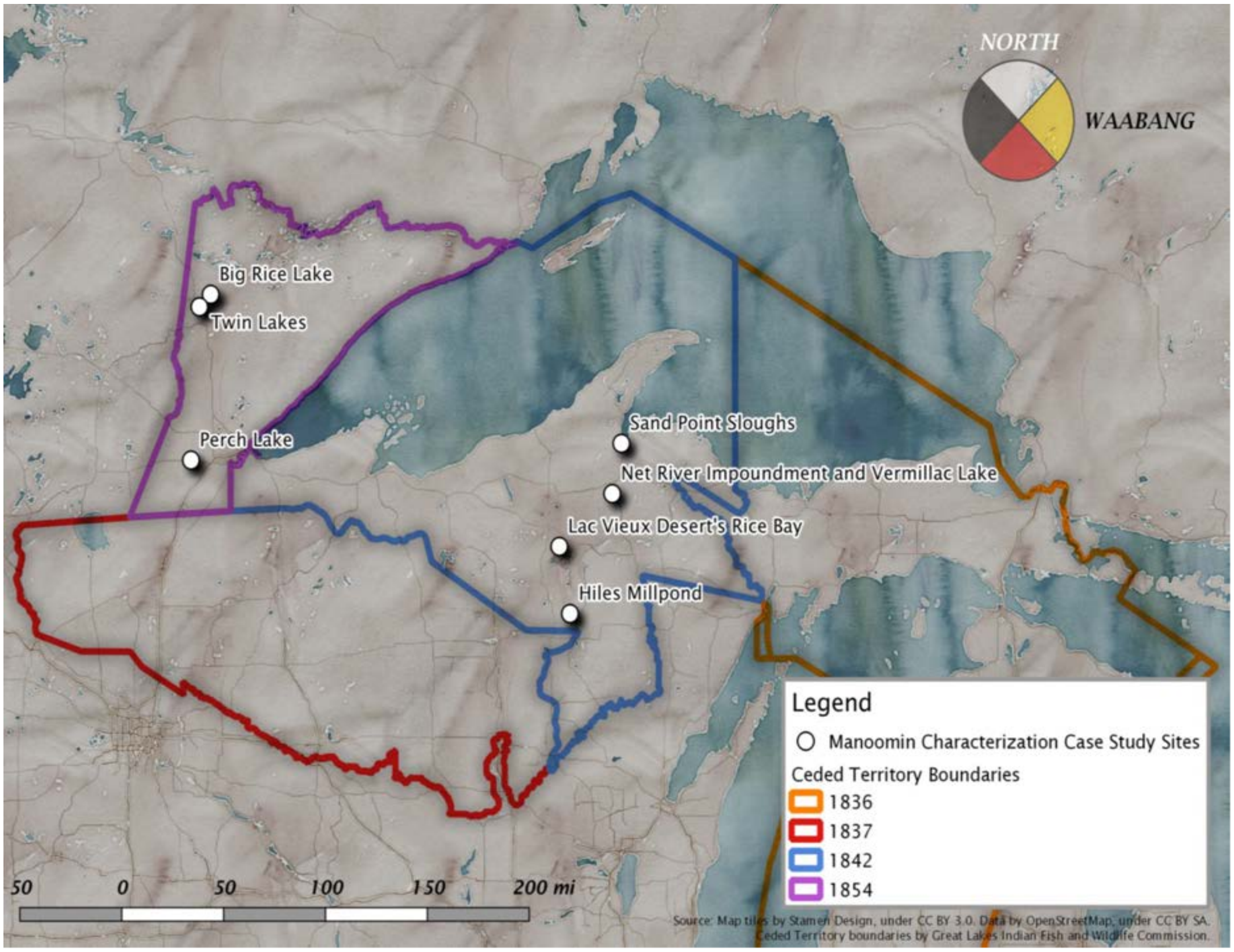


Exhibit 5.1. Map displaying the seven case study locations. The compass is in the form of a medicine wheel, an indigenous symbol used to denote the four directions.

Exhibit 5.2 provides a brief overview of the case studies, including the key threats to Manoomin at these places, some of the actions taken to improve Manoomin habitat, and, if available, the HEA results that indicate how many acres of similar Manoomin restoration habitat are needed to balance lost habitat functionality over time.

Exhibit 5.2. Case study summaries

Case study	Threats to Manoomin	Restoration actions to improve Manoomin	Additional restoration needed
Lac Vieux Desert's Rice Bay *Characterization focused on 243 restoration acres*	• High water levels caused by a concrete and steel dam at the outlet of the lake in the 1930s • High water levels caused by above-average precipitation in the 2010s	• Water level management • Manoomin seeding	**3,034 acres of similar Manoomin restoration** needed to balance the lost habitat functionality over time or **12 equivalent restoration efforts**.
Perch Lake *Characterization focused on 400 restoration acres*	• High water levels caused by agricultural ditching in the 1920s • Competitive vegetation caused by a non-functional dam in the 1960s	• Water level management • Removal of competitive vegetation	**5,204 acres of similar Manoomin restoration** needed to balance the lost habitat functionality over time or **13 equivalent restoration efforts**.
Sand Point Sloughs *Characterization focused on 8 restoration acres*	• Deposited mine tailings from a copper ore processing plant that operated north of the sloughs in the 1920s • High water levels and invasive species after 2005	• Manoomin seeding • Remediation efforts to stabilize the tailings	**175 acres of similar Manoomin restoration** needed to balance the lost habitat functionality over time or **22 equivalent restoration efforts**.
Net River Impoundment and Vermillac Lake *Characterization focused on 97 restoration acres*	Unclear if Manoomin historically grew at site; if it was, land use change likely responsible for Manoomin's depletion	• Manoomin seeding	**1,129 acres of similar Manoomin restoration** needed to balance the lost habitat functionality over time or nearly **12 equivalent restoration efforts**.
Hiles Millpond *Characterization focused on 300 restoration acres*	Unclear if Manoomin historically grew at site; if it was, high water levels caused by dam construction likely responsible for Manoomin's depletion	• Water level management • Manoomin seeding	**864 acres of similar Manoomin restoration** needed to balance the lost habitat functionality over time or **3 equivalent restoration efforts**.
Big Rice Lake *Characterization focused on 1,870 restoration acres*	• Hydrological changes • Competing vegetation	• Water level management • Removal of competitive vegetation	Varies depending on hypothetical improvement scenario.
Twin Lakes *Characterization focused on 210 acres*	• Discharge of mine tailings from an iron ore processing plant upstream of the lakes since the 1960s, which has *increased sulfate levels* and *increased water volume*	• Seepage collection system to collect some of the mine tailings discharge • Manoomin seeding (limited) • Water level management (limited)	Varies depending on hypothetical improvement scenario.

These seven case studies are described in more detail below. For each case study, we briefly describe the cultural and ecological importance of the place, and provide an overview of the threats to Manoomin and the actions taken to restore Manoomin. We then summarize how each case study team characterized the place over time using ecological and cultural metrics; and describe the additional restoration needed, as calculated with the HEA tool.

Lac Vieux Desert's Rice Bay

Lac Vieux Desert, located in Vilas County, Wisconsin, and Gogebic County, Michigan, is over 4,000 acres (Exhibit 5.3). Historically, Manoomin covered many parts of Lac Vieux Desert, including Rice Bay, Thunder Bay, Slaughters Bay, Misery Bay, and along the northwestern shore to the Wisconsin River and parts of the south shore.

Exhibit 5.3. Map of Lac Vieux Desert

Rice Bay is a 243-acre bay on the northeastern portion of Lac Vieux Desert, which historically contained a significant stand of Manoomin that was traditionally managed and harvested by the Lac Vieux Desert Band of Lake Superior Chippewa (LVD Band). West of Rice Bay is Ketegitigaaning, a ricing village used intermittently in the early 18th century by the LVD Band, followed by continuous habitation by 1900. In 2015, Rice Bay was registered as a Traditional Cultural Property on the National Register of Historic Places.

Threats to Manoomin at Rice Bay

Lac Vieux Desert was dammed around 1870 for logging operations. By 1907 the Wisconsin Valley Improvement Company (WVIC) began operating the lake as a storage reservoir and used the dam to create uniform stream flow down the Wisconsin River to reduce flooding events, facilitate hydroelectric power generation, and regulate effluent discharge downstream. In 1937, WVIC replaced the wooden dam with a reinforced concrete and steel structure. The high water levels caused by the dam initiated a decline in Manoomin (Labine, 2017). From 1938 to 1952, Manoomin declined steadily and community members stopped harvesting it during this period (Barton, 2018). During this time period, lakeside property owners became concerned about the erosion caused by rising lake levels.

More recently, heavy rainfall events have negatively affected Manoomin in Lac Vieux Desert (Roger Labine, LVD Band, personal communication, February 15, 2020). In the spring Manoomin is in the floating leaf stage, and can be uprooted by heavy rainfall that raises water levels and uproots Manoomin. In the summer, when Manoomin is in the flowering stage, heavy rainfall can knock Manoomin pollen down from the flower to the water's surface, which prevents pollination and results in "ghost rice" or empty seed hulls that never fill. In addition, the combination of heavy rainfall events and higher air temperatures may also increase the amount of brown spot – a destructive wild rice fungal disease – in Manoomin beds.

Actions taken to improve the abundance of Manoomin at Rice Bay

In 1991, a coalition of tribal, state, and federal governments and governmental agencies determined the operating regime of the dam on Lac Vieux Desert had been detrimental to Manoomin and its associated habitat (Onterra, 2012). By 2001, following a decade of negotiation and litigation, WVIC lowered the maximum operating level by about nine inches and provided financial contribution toward a Manoomin seeding and monitoring program (Barton, 2018). From 2002 to 2005, Lac Vieux Desert was seeded with 14,000 pounds of Manoomin, most of which occurred in Rice Bay (Labine, 2017). From 2007 through 2012, as Manoomin became reestablished on Rice Bay, the LVD Band held traditional ricing camps and workshops, which included traditional practices and activities (Barton et al., 2013).

Exhibit 5.4. Photograph of Lac Vieux Desert Lake's Rice Bay in 2003 (above) and 2010 (below)

Credit: Peter David, Great Lakes Indian Fish & Wildlife Commission (GLIFWC).

From 2000 to 2010, the acreage of Manoomin on Rice Bay significantly increased. In 2000, Rice Bay had just 11 acres of Manoomin coverage (or 5% of Rice Bay). After the first year of seeding, Manoomin coverage increased to over 25 acres (or 10% of Rice Bay). With below-average rainfall conditions in 2010, the extent of Manoomin increased to over 92 acres (or 38% of Rice Bay; Exhibit 5.4). While the extent of Manoomin on Rice Bay was less than its historical coverage, it was considered an improvement over conditions caused by the operating regime of the concrete dam (Barton, 2018).

Since 2011, the acreage of Manoomin on Rice Bay has been declining, with 34 acres in 2019 (GLIFWC, 2019; Exhibit 5.5). Because Manoomin abundance on Rice Bay is generally greatest during low-water years, natural resource managers believe this may be due to above-average precipitation over the past seven years (Peter David, GLIFWC, personal communication, November 12, 2019).

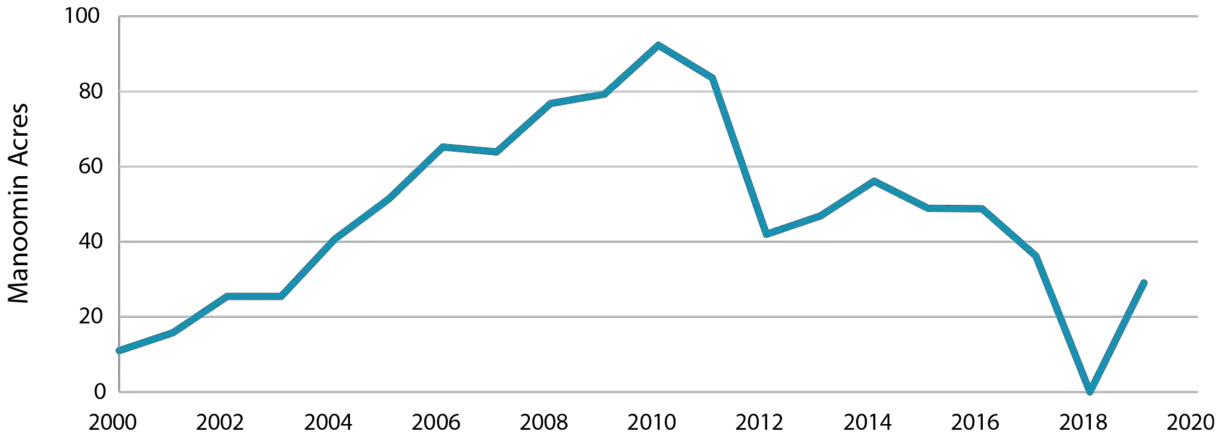


Exhibit 5.5. Manoomin acreage on Rice Bay, 2000 to 2019

Source: GLIFWC, 2019.

Cultural and ecological characterization at Rice Bay

Rice Bay's Manoomin and its associated habitat were characterized over four time periods.

1900 to 1936: With a wooden dam

Based on the combined ranking of cultural and ecological metrics, Rice Bay was characterized as "doing great" during this period. In the early 1900s, Ketegitigaaning was inhabited and the community harvested Manoomin in Rice Bay for gifting, healing, and consumption. The area also boasted a rich biodiversity; and hunting, trapping, fishing, and gathering local resources were common.

1937 to 1990: With a concrete and steel dam

After the replacement of the wooden dam with a concrete and steel structure, Manoomin declined steadily until the mid-1950s to the point that it was no longer harvestable by community members. During this time period, community members moved away from the lake and into surrounding towns, and stopped harvesting Manoomin in Rice Bay. The "disappearance of Manoomin started the deterioration of the Lac Vieux Desert community," where bonding, traditions, and community connections ceased (Roger Labine, LVD Band, personal communication, November 12, 2019). There was a steady decline in cultural and ecological functionality provided by Manoomin from 1937 to the mid-1950s, when Rice Bay was characterized as "very bad" based on the combined ranking of cultural and ecological metrics.

1991 to 2012: With restoration actions

Once restoration actions began in the 1990s, cultural and ecological functionality provided by Manoomin improved. By 2008, the LVD Band opened Rice Bay for Manoomin harvest and began hosting rice camps in the area for the first time since 1940. Although the community began knowledge sharing and knowledge generation, and educational opportunities increased, it remained difficult to get many community members interested in Manoomin because of its absence over the last 50 years. Even so, restoration actions led to an increase in cultural and ecological functionality. By 2012, Rice Bay ranked as "pretty good" based on the combined ranking of cultural and ecological metrics.

2013 to 2019: With restoration actions and above-average precipitation

With heavy rainfall events negatively affecting Manoomin beds during the growing season, cultural and ecological functionality at Rice Bay have declined. Currently, Rice Bay is ranked as "not very good" based on the combined ranking of cultural and ecological metrics. The decrease in ecological and cultural functionality provided by Manoomin in recent years suggests the need for adaptive management of Manoomin. Actions taken that may have been successful in restoring Manoomin in the past may need to be adjusted to respond to additional threats, such as climate change, to be successful in the future.

Cultural and ecological functionality provided by Manoomin and its associated habitat at Rice Bay have changed over time, both in total and for individual metrics (Exhibit 5.6).

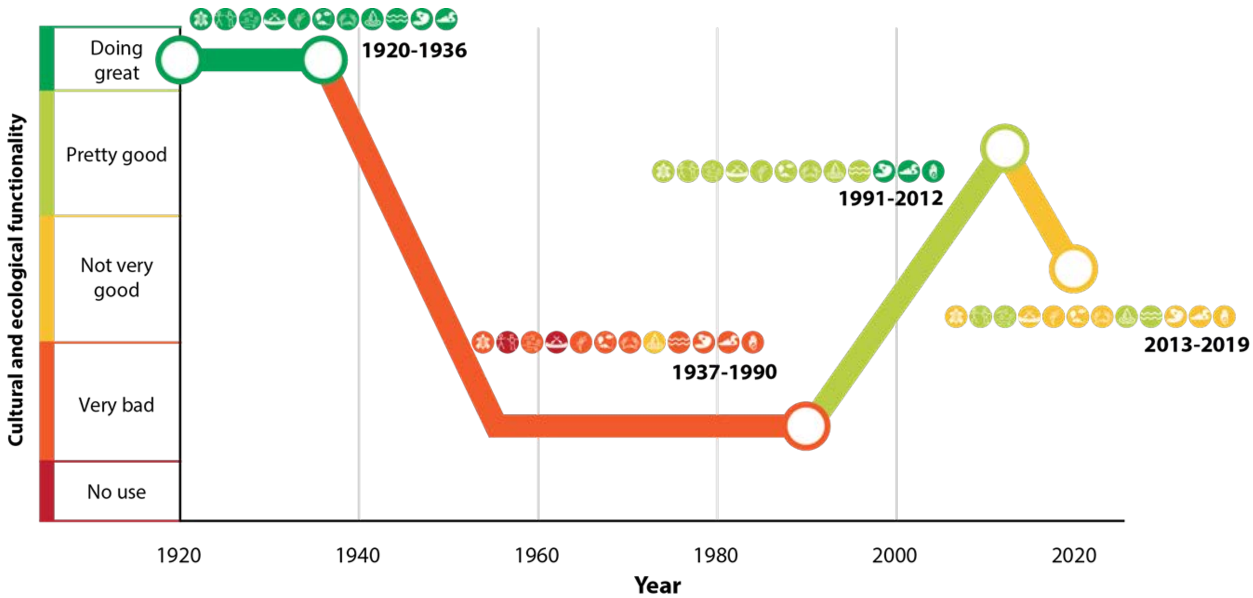


Exhibit 5.6. Characterization of cultural and ecological functionality provided by Manoomin and its associated habitat at Rice Bay

Additional restoration needed

Based on the characterization of the degree of cultural and ecological function over the four time periods, the HEA calculations demonstrate the additional equivalent units of restoration needed to counter-balance the severity and timespan of degradation. Given the success of restoration at the 243-acre Rice Bay, approximately 3,034 acres of similar Manoomin restoration is needed to counter-balance the lost habitat functionality that has occurred over time (Exhibit 5.7). In other words, 12 equivalent restoration efforts at Rice Bay (from 1991 to 2019) are needed to counter-balance the lost cultural and ecological habitat functionality (from 1937 to 1990).

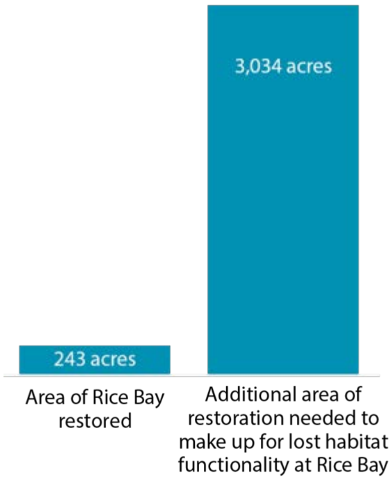


Exhibit 5.7. Additional restoration needed for Lac Vieux Desert Lake's Rice Bay

Case study acknowledgments

The Project Team would like to acknowledge Roger Labine (LVD) and Peter David (GLIFWC) for their valuable input and feedback in the development of this case study, and for participating in the cultural and ecological characterization of Lac Vieux Desert's Rice Bay.

Perch Lake

Perch Lake is located on the Fond du Lac Band of Lake Superior Chippewa Reservation in Minnesota (Exhibit 5.8). It is an approximately 650-acre, double-basin lake. The shallow, southern portion of the lake is approximately 400 acres, and it is the largest Manoomin-containing habitat on the Reservation (Fond du Lac Band, 2008). The northern basin also supports some Manoomin along its fringes.

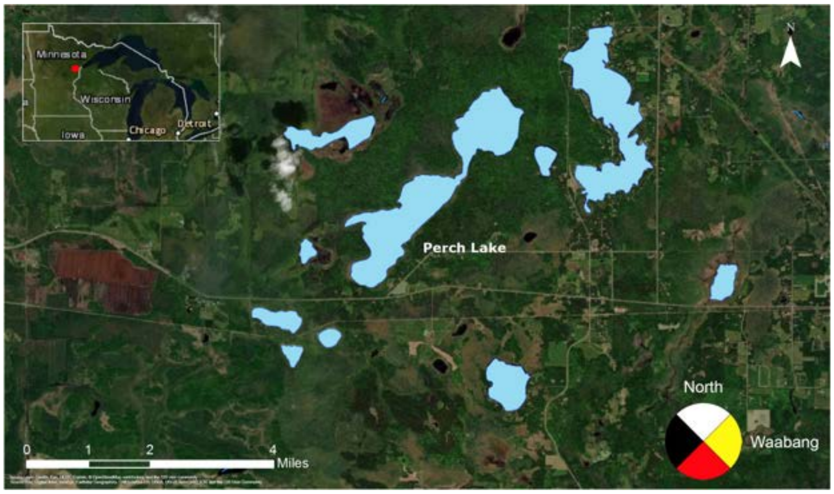


Exhibit 5.8. Map of Perch Lake

Perch Lake is an important traditional cultural property, used as a wild rice lake, a fisheries/spearing and netting site, and hunting grounds (Fond du Lac Band, 2018). Historical evidence suggests that Manoomin has been present at Perch Lake for over 2,000 years, with historical stands on approximately 392 acres (Fond du Lac Band, 2018).

Threats to Manoomin at Perch Lake

Historically, Perch Lake had abundant Manoomin habitat. In the early 1900s, many streams and wetland areas were ditched and drained to accommodate farming. After Perch Lake was ditched for agriculture around 1918 to 1921, the lake experienced a decline in Manoomin (Nancy Schuldt, personal communication, October 7, 2019).

To try to minimize the impacts of ditching, a concrete dam was installed at the lake outlet in 1936. The dam was managed to mimic the natural fluctuation of the water to benefit Manoomin. By the 1960s, the dam fell into disrepair and was non-functional. For the following several decades, lake levels were lower and stagnant, which allowed ginoozhegoons (pickerelweed) to displace Manoomin and become the dominant vegetation in the lake’s rice waters (Fond du Lac Band, 2018, 2019).

Actions taken to improve the abundance of Manoomin at Perch Lake

In 1998, a new water control structure was built at the outlet of Perch Lake to manage water levels for Manoomin and improve hydrologic function throughout the watershed (Fond du Lac Band, 2018). In 2001, the Fond du Lac Band began intensive mechanical vegetation removal of ginoozhegoons, a native perennial species that occupies the same habitat as Manoomin and often outcompetes Manoomin (Fond du Lac Band, 2018). Using a sedge mat cutter and aquatic harvesters, the Fond du Lac Band removed ginoozhegoons vegetation at least twice yearly (Exhibit 5.9). This process led to high Manoomin density in restored areas initially. However, three to five years after each removal, ginoozhegoons became dominant again, which called for a rotating schedule for removing this competing plant.

In 2012, Perch Lake experienced a 500-year flood in mid-summer, and the Fond du Lac Band used the water control structure to keep water levels high and eliminate as much ginoozhegoons as possible. The following year, Manoomin stands were so thick that it was difficult to travel through the lake. Learning from the natural flood event, the Fond du Lac Band then developed a management strategy to bring lake levels to flood stage every four years to stress perennial species, such as ginoozhegoons, which compete with Manoomin for habitat. Although this strategy also limits Manoomin production in flood years, it provides Manoomin with a competitive advantage in the years following a flood stage year (Fond du Lac Band, 2018).

With water level management and mechanical removal of competitive vegetation, the Fond du Lac Band has successfully restored Manoomin to over 200 acres on Perch Lake (Fond du Lac Band, 2019).

Exhibit 5.9. Photograph of Sedge mat cutter (above) and aquatic harvester (below)

Credit: Fond du Lac Band, 2018.

Cultural and ecological characterization at Perch Lake

Manoomin and its associated habitat at Perch Lake were characterized over four time periods.

1900 to 1920: Before agricultural ditching

Before it was ditched for agriculture, Perch Lake historically had abundant Manoomin stands. Fond du Lac resource managers estimate that nearly 60% of the lake had extensive Manoomin stands during this time, and it was harvested by the community. Based on the combined ranking of cultural and ecological metrics, Perch Lake was characterized as “doing great” during this first time period.

1921 to 1970: With agricultural ditching

After agricultural ditching of Perch Lake, Manoomin and its associated habitat declined abruptly. Lower and stagnant water levels allowed ginoozhegoons to become the dominant vegetation in the lake, displacing Manoomin, which resulted in a decline in use of the lake by waterfowl and other wildlife. Band members were unable to harvest Manoomin in the ways they did historically, which limited the generation and sharing of Anishinaabe practices, values, and beliefs. During this period of time, Perch Lake was characterized as “not very good” based on the combined ranking of cultural and ecological metrics.

1971 to 1997: Before the new water control structure and restoration actions

During this period, Perch Lake had a significant decline in Manoomin abundance and functionality; approximately 75% of the lake was covered with plant species that occupy the same habitat as and compete with Manoomin. Although Perch Lake's ecological and cultural functionality remained low, Band members continued to try to harvest at the lake; therefore, the lake provided some cultural services during this period. Many elders and wild rice chiefs believe Manoomin is a blessing and is seen as a golden age of their youth. For these reasons, Perch Lake ranked as "pretty good," which was slightly higher than the previous time period.

1998 to 2019: With the new water control structure and restoration actions

The water control structure built at the outlet of Perch Lake in 1998 helped restore the hydrologic conditions of the lake and improve Manoomin and its associated habitat. Active management of the lake started in 2001 and accelerated in 2012, which further restored hydrologic conditions of the lake and removed competing vegetation, all benefiting Manoomin. During this time period, the Fond du Lac Band was fairly successful at restoring Manoomin on Perch Lake. Manoomin covers over 200 acres of Perch Lake, which is about 30% of its historical coverage. Currently, Perch Lake is ranked as "pretty good" based on the combined ranking of cultural and ecological metrics.

The cultural and ecological functionality provided by the Manoomin and its associated habitat at Perch Lake varied over time, both in aggregate and for individual metrics (Exhibit 5.10).

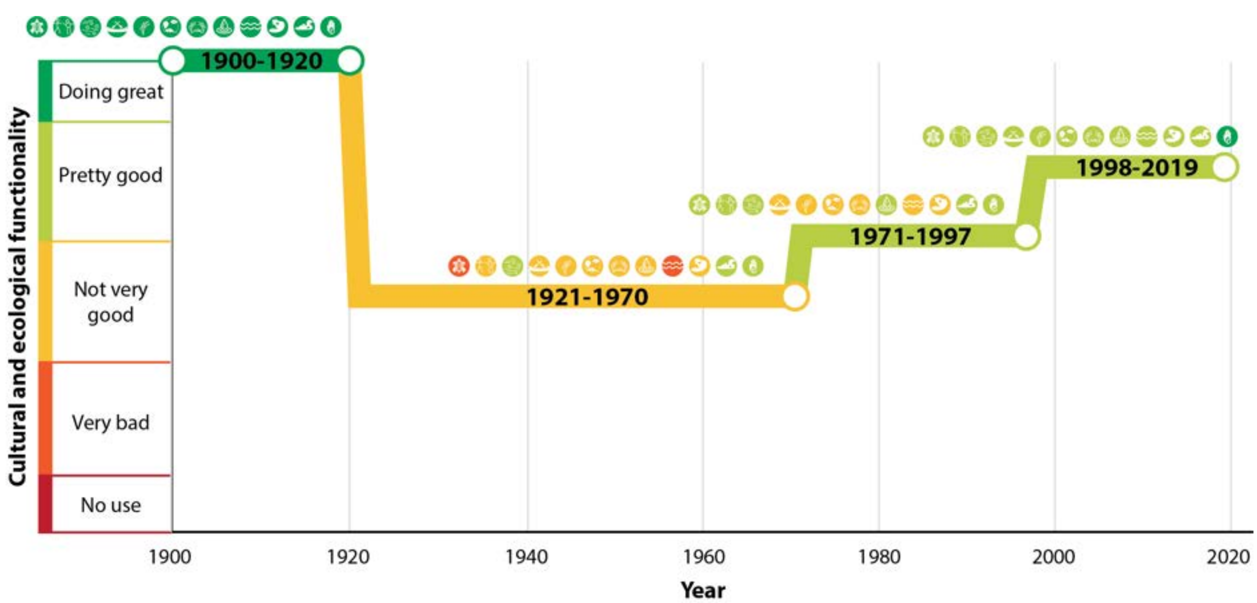


Exhibit 5.10. Characterization of cultural and ecological functionality provided by Manoomin and its associated habitat at Perch Lake

Additional restoration needed

Using the characterization of Perch Lake over the four time periods, an HEA demonstrates the additional equivalent units of restoration needed to counter-balance the severity and timespan of degradation. Given the success of restoration over the shallow, southern 400 acres of Perch Lake, approximately 5,204 acres of similar Manoomin restoration are needed to counter-balance the lost habitat functionality that has occurred over time (Exhibit 5.11). In other words, 13 equivalent restoration efforts at Perch Lake (from 1971 to 2019) are needed to counter-balance the lost cultural and ecological habitat functionality (from 1921 to 1970).

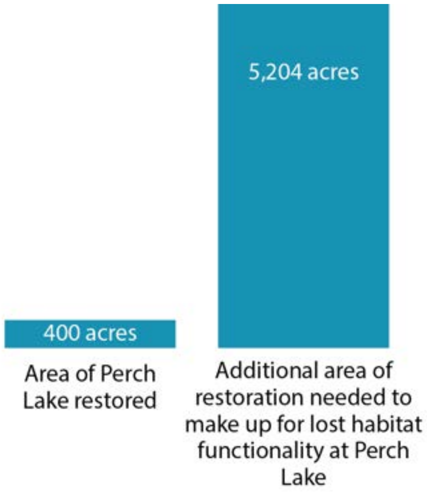


Exhibit 5.11. Additional restoration needed for Perch Lake

Case study acknowledgments

The Project Team would like to acknowledge Nancy Schuldt and Thomas Howes (Fond du Lac Band) for their valuable input and feedback in the development of this case study, and for participating in the cultural and ecological characterization of Perch Lake. We would also like to acknowledge the Fond du Lac Band elders and the wild rice chief who helped us characterize Perch Lake.

Sand Point Sloughs

Sand Point Sloughs are relatively shallow backwater sloughs connected to Lake Superior that are culturally important to the Keweenaw Bay Indian Community (KBIC). Native people used this area for hundreds of years, as indicated by the existence of ancient burial grounds and stories that have been passed on through oral tradition (KBIC, 2003). Manoomin is believed to have been present in Sand Point Sloughs prior to the 1900s (Ravindran et al., 2014). Today, the site contains the KBIC Pow Wow grounds, a traditional healing clinic, extensive wetlands, and Manoomin beds (Exhibit 5.12). A marina, campground, lighthouse, and recreational beaches signify the community's appreciation of this area. This area also holds ecological value as habitat. It provides for a number of species including medicinal plants, insects, fish, and other non-human relatives.

Exhibit 5.12. Map of Sand Point Sloughs

Threats to Manoomin at Sand Point Sloughs

Connected to Lake Superior, Sand Point Sloughs are part of a dynamic coastal system. In the early 20th century, a copper ore processing plant, Mass Mill, operated on the west side of Keweenaw Bay on the south shore of Lake Superior. During the copper ore processing, approximately six billion pounds of mine tailings, locally known as stamp sands, were disposed into Keweenaw Bay. Lake currents continue to carry these tailings southward and redeposit them onto Sand Point, located just four miles south of the Mass Mill. Sand Point has an extensive beach area with approximately 2.5 miles of lake front and is connected to the sloughs. These tailings contain high concentrations of heavy metals that have the potential to cause environmental harm.

More recently, Sand Point Sloughs have been affected by regional hydrologic conditions – including higher water levels – that are occurring at a regional scale and are beyond local control. As a plant species sensitive to changes in water level, higher water levels have negatively affected the establishment and abundance of Manoomin in Sand Point Sloughs. The sloughs' connection to Lake Superior also opens the pathway to aquatic invasive species, such as carp and reed canary grass. Carp, for example, are bottom feeders that uproot Manoomin (Premo et al., 2014). Manoomin abundance may also be impeded by competing native vegetation, such as ginoozhegoons (pickerelweed); and by excessive browsing by wildlife on new stands, such as waterfowl.

Actions taken to improve the abundance of Manoomin at Sand Point Sloughs

Sand Point Sloughs are a KBIC Tribal Trust property, wholly owned by KBIC and located entirely within KBIC L'Anse Reservation boundaries. KBIC took over management of the sloughs in the early 1990s, and shortly after began efforts to reintroduce Manoomin. Between 1991 and 1997, KBIC seeded nearly 1,800 pounds of Manoomin across 8 acres of Sand Point Sloughs. By 1999, Manoomin density was sufficient for KBIC to engage in the tradition of ricing. Between 1999 and 2002, community members harvested an estimated 60 to 150 pounds per year (Ravindran et al., 2014). Since 2013, KBIC has seeded Manoomin annually at Sand Point Sloughs (Exhibit 5.13). KBIC continues to tend to this site in an effort to keep Manoomin teachings and traditions vital. However, since 2002, community members have not been able to harvest Manoomin at Sand Point Sloughs, due to decreased abundance of Manoomin related to regional hydrologic conditions.

In addition to seeding efforts, KBIC and partners have undertaken remediation along the Sand Point shoreline, which was listed as a brownfield site. Remediation efforts included capping stamp sands to stabilize the tailings; planting native plants, trees, and shrubs to increase habitat for birds and other wildlife; and installing mounds and boulders to provide relief in the topography, reduce erosion, and protect valuable coastal wetlands, including Manoomin beds (Ravindran et al., 2014).

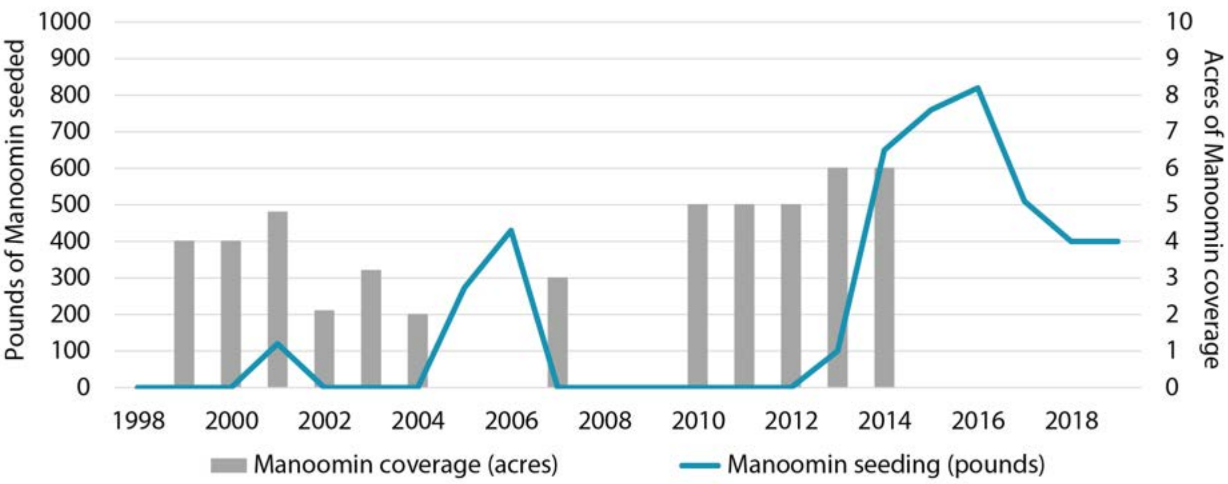


Exhibit 5.13. Manoomin seeding and acres of Manoomin coverage at the Sand Point Sloughs, 1999 to 2019 (data were not collected before 1999, and Manoomin coverage data were not recorded after 2014)

Sources: Ravindran et al., 2014; Karena Schmidt, personal communication, October 31, 2019.

Cultural and ecological characterization at Sand Point Sloughs

Sand Point Sloughs' Manoomin and its associated habitat were characterized over four time periods. This characterization begins after the copper ore processing plant ceased operations around the 1920s.

1920 to 1990: Before KBIC ownership

Based on the combined ranking of cultural and ecological metrics, Sand Point Sloughs was characterized as "not very good" during this period. This ranking reflects the absence of Manoomin from the sloughs and the deposition of mine tailings onto Sand Point. Although Manoomin was absent, the sloughs were still a place of cultural and ecological importance: waterfowl and other wildlife foraged at the sloughs; and community members fished, hunted, and gathered there and held Pow Wows on the grounds. Given the intrinsic cultural and ecological values of the sloughs, some cultural metrics – including spirit relationships, knowledge sharing, and food sovereignty – were characterized with a higher ranking.


Water level

For each of the four time periods, the water level metric was ranked as "not very good." Due to their location, the Sand Point Sloughs are influenced by regional factors such as Lake Superior water levels, which are beyond local control.

1991 to 1998: With active management of Manoomin

Once KBIC took over management of Sand Point Sloughs in the early 1990s and began seeding activities, Manoomin grew modestly. Although community members could not yet harvest Manoomin, the presence of Manoomin significantly improved the ranking of most cultural and ecological metrics. During this period, Sand Point Sloughs ranked as "pretty good" based on the combined ranking of cultural and ecological metrics.

1999 to 2005: With active management and harvesting of Manoomin

Once Manoomin was adequately established at Sand Point Sloughs, KBIC was able to open Sand Point Sloughs to their community members for harvesting. Harvesting allowed the recovery and sharing of Anishinaabe practices, values, beliefs, and language at the sloughs in ways that had not been practiced for years. During this period, Sand Point Sloughs ranked as "doing great" based on the combined ranking of improved cultural and ecological metrics.

2006 to 2019: With higher water levels

Sand Point Sloughs is connected to Lake Superior, and is affected by changes in the lake's water level and invasive and competitive species. Invasive species and competing vegetation that have been documented at Sand Point Sloughs may be impacting Manoomin abundance. Water levels have also fluctuated in Sand Point Sloughs, with lower water levels recorded in 2006 and 2007, and higher water levels in recent years (Ravindran et al., 2014). During this period, Sand Point Sloughs' functionality decreased to "pretty good" based on the combined ranking of cultural and ecological metrics. The decrease in ecological and cultural functionality provided by Manoomin in recent years suggests the need for adaptive management of Manoomin. Actions taken that may have been successful in restoring Manoomin in the past may need to be adjusted to respond to additional threats, such as climate change, to be successful in the future.

The cultural and ecological functionality provided by the Manoomin and its associated habitat at Sand Point Sloughs varied over time, both in aggregate and for individual metrics (Exhibit 5.14).

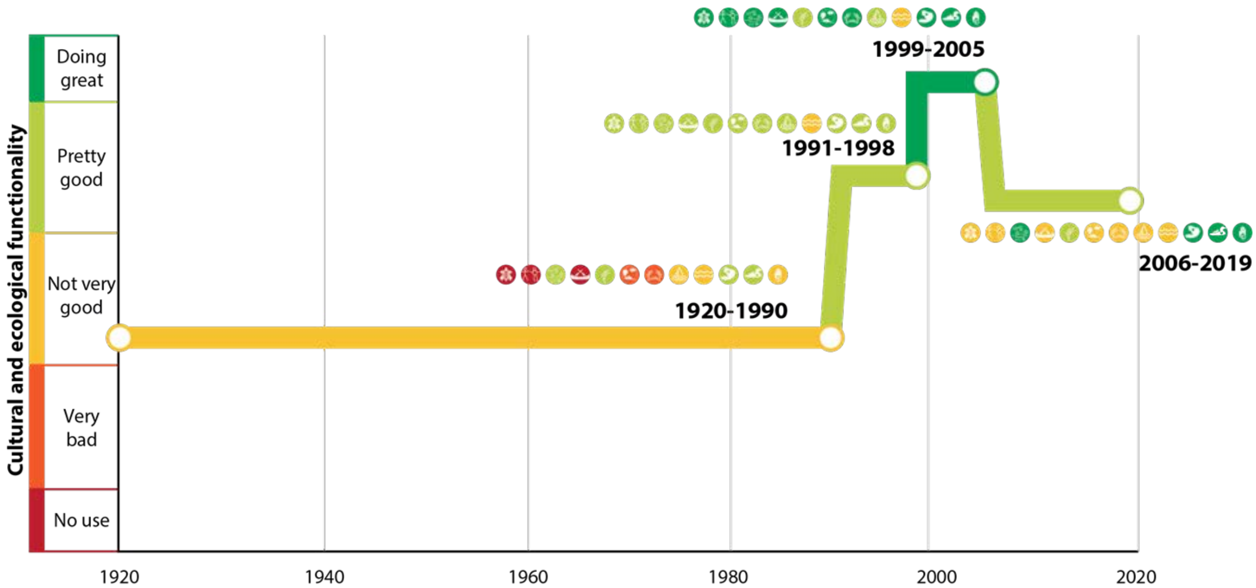


Exhibit 5.14. Characterization of cultural and ecological functionality provided by Manoomin and its associated habitat at Sand Point Sloughs

Additional restoration needed

Based on the characterization of the degree of cultural and ecological function over the four time periods, the HEA calculations demonstrate the additional equivalent units of restoration needed to counter-balance the severity and timespan of degradation. Given the success of restoration on 8 acres of Sand Point Sloughs, 175 acres of similar Manoomin restoration is needed to counter-balance the lost habitat functionality that has occurred over time (Exhibit 5.15). In other words, 22 equivalent restoration efforts at Sand Point Sloughs (from 1991 to 2019) are needed to counter-balance lost cultural and ecological habitat functionality (from 1920 to 1990).

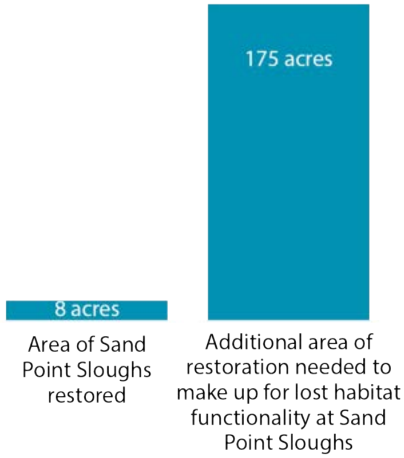


Exhibit 5.15. Additional restoration needed for Sand Point Sloughs

Case study acknowledgments

The Project Team would like to acknowledge Evelyn Ravindran, Karena Schmidt, and Erin Johnston (KBIC) for their valuable input and feedback in the development of this case study, and for participating in the cultural and ecological characterization of KBIC's Sand Point Sloughs.

Net River Impoundment and Vermillac Lake

The Net River is nearly 15 miles long and flows from Baraga County to Iron County, Michigan. Impounded in 1990 as a wetland mitigation site to provide waterfowl benefits, the Net River Impoundment is now 35 acres in size. Vermillac (or Worm) Lake is a 423-acre lake in Baraga County. Both the Net River Impoundment and Vermillac Lake are located outside the L'Anse Indian Reservation, but within Ceded Territory (Exhibit 5.16).

Exhibit 5.16. Map of Net River Impoundment and Vermillac Lake

Threats to Manoomin at Net River Impoundment and Vermillac Lake

Both the Net River Impoundment and Vermillac Lake possibly had Manoomin beds in the past. Many believe that historical trails around the Net River Impoundment indicate traditional use of these places for cultural practices (Evelyn Ravindran, KBIC personal communication, August 20, 2019). Land use changes have altered the local landscape, which may have contributed to the presence or absence of Manoomin at these places.

Actions taken to improve Manoomin at Net River Impoundment and Vermillac Lake

KBIC is receiving more and more teachings from Manoomin and is working to understand which locations on the L'Anse Indian Reservation and within Ceded Territory have conditions that are conducive to grow and sustain Manoomin (BIA, 2019). KBIC is interested in having local sources of Manoomin as seed banks for future restoration activities; as well as places where community members can harvest, prepare, and gift Manoomin. KBIC is currently assessing suitable Manoomin habitat across their territory, and focusing restoration in lakes with the most favorable conditions for Manoomin.

In the early 2010s, KBIC worked with the Michigan Department of Natural Resources to identify additional areas for Manoomin restoration. The Net River Impoundment and Vermillac Lake were selected as lakes with potential for Manoomin beds, and KBIC seeded test plots at both lakes. Given their success, KBIC then seeded the Net River Impoundment and Vermillac Lake with nearly 2,000 pounds of Manoomin seed. Cultural teachings and practices related to Manoomin are beginning to occur at the Net River Impoundment. KBIC continues to seed 97 acres across both lakes with nearly 2,000 pounds of Manoomin each year.

The ultimate goal of the seeding efforts at Net River Impoundment is to produce a Manoomin seed source for Vermillac Lake and other KBIC restoration sites. In keeping with the principles of the honorable harvest, KBIC aims to achieve conditions that will allow the rice to reseed itself to feed wildlife and nourish the people.

Cultural and ecological characterization at Net River Impoundment and Vermillac Lake

Manoomin and its associated habitat at the Net River Impoundment and Vermillac Lake were characterized over two time periods. This characterization begins after the Net River was impounded as a wetland mitigation bank in 1990.

1990 to 2013: Before Manoomin seeding

Based on the combined ranking of cultural and ecological metrics, conditions at the Net River Impoundment and Vermillac Lake were characterized as “not very good” during this period. This ranking reflects the absence of Manoomin from the Net River Impoundment and Vermillac Lake before 2013. Although Manoomin was absent, these areas were culturally and ecological important. Community members used these sites for gathering, fishing, and hunting activities; during these activities, families passed down knowledge to their children or grandchildren about traditional practices and resources. Given the intrinsic cultural and ecological value of these places, some metrics – including spirit relationships, food sovereignty, knowledge generation and sharing, and water level and quality – ranked higher in cultural and ecological characterization.

2014 to 2019: After Manoomin seeding

Once KBIC began seeding the Net River Impoundment and Vermillac Lake, Manoomin grew at these places. Currently, Manoomin supports wildlife and other ecosystem functions. These places have the potential for Manoomin harvesting in the future, although they cannot yet support it. The presence of Manoomin significantly improved the ranking of most of the cultural and ecological metrics. During this period, conditions at the Net River Impoundment and Vermillac Lake ranked as “pretty good” based on cultural and ecological metrics. Although Manoomin provides cultural and ecological functionality, additional management of water levels at the Net River Impoundment could continue to improve the abundance of Manoomin and the long-term sustainability of healthy Manoomin beds.

Cultural and ecological functionality provided by Manoomin and its associated habitat at the Net River Impoundment and Vermillac Lake have increased over time, both in aggregate and for the individual metrics (Exhibit 5.17).

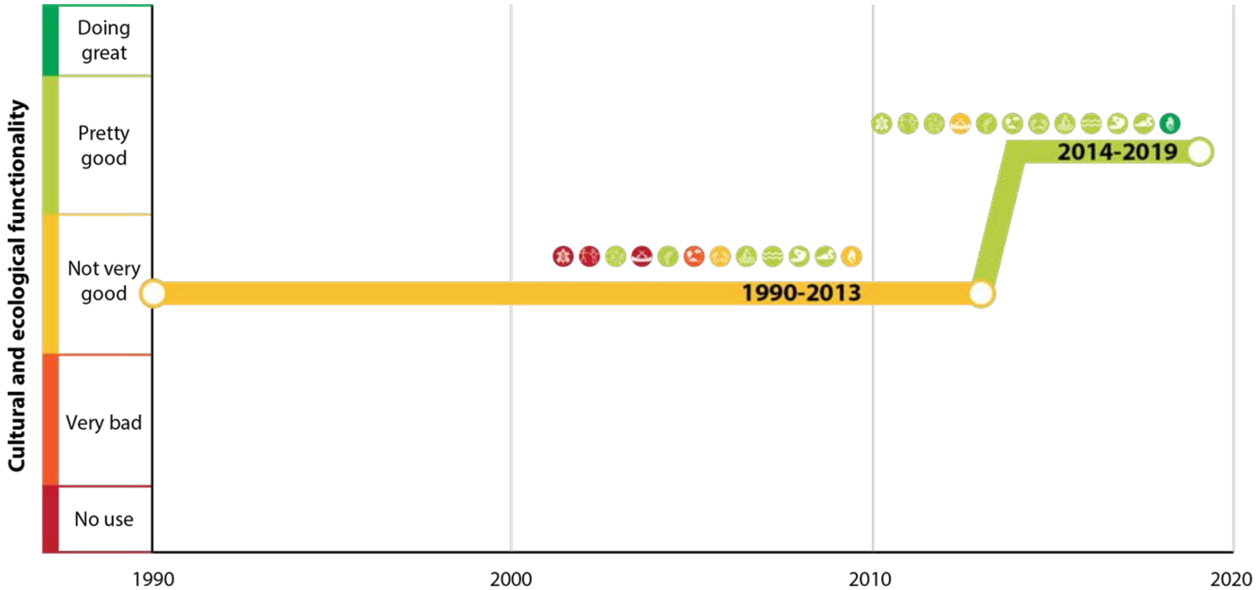


Exhibit 5.17. Characterization of cultural and ecological functionality provided by Manoomin and its associated habitat at Net River Impoundment and Vermillac Lake

Additional restoration needed

Based on the characterization of the degree of cultural and ecological function over the four time periods, the HEA calculations demonstrate the additional equivalent units of restoration needed to counter-balance the severity and timespan of degradation. With seeding, resource managers successfully established Manoomin across the Net River Impoundment and Vermillac Lake. However, given that the period of degradation is much larger (over 20 years) than the period of restoration (around 5 years), an additional 1,129 acres of similar Manoomin restoration is needed to counter-balance the lost habitat functionality that has occurred over time (Exhibit 5.18). In other words, nearly 12 equivalent restoration efforts at the Net River Impoundment and Vermillac Lake (from 2014 to 2019) are needed to counter-balance the lost cultural and ecological habitat functionality (from 1990 to 2013).

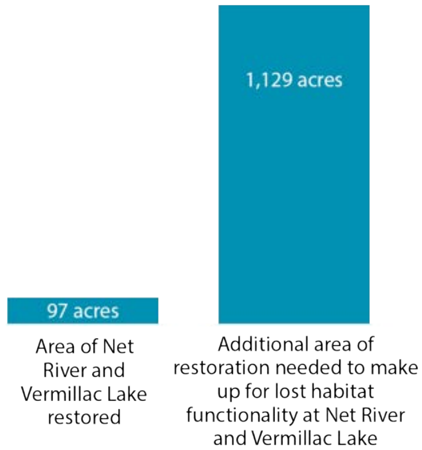


Exhibit 5.18. Additional restoration needed for Net River Impoundment and Vermillac Lake

Case study acknowledgments

The Project Team would like to acknowledge Evelyn Ravindran, Karena Schmidt, and Erin Johnston (KBIC) for their valuable input and feedback in the development of this case study; and for participating in the cultural and ecological characterization of KBIC's Net River Impoundment and Vermillac Lake.

Hiles Millpond

Hiles Millpond is an approximately 300-acre lake located in Forest County, Wisconsin, an 1842 Ceded Territory (Exhibit 5.19).

The millpond provides excellent wildlife habitat, especially for waterfowl, furbearers, eagles, and other wetland-dependent species. The lake also supports a northern pike and panfish fishery.

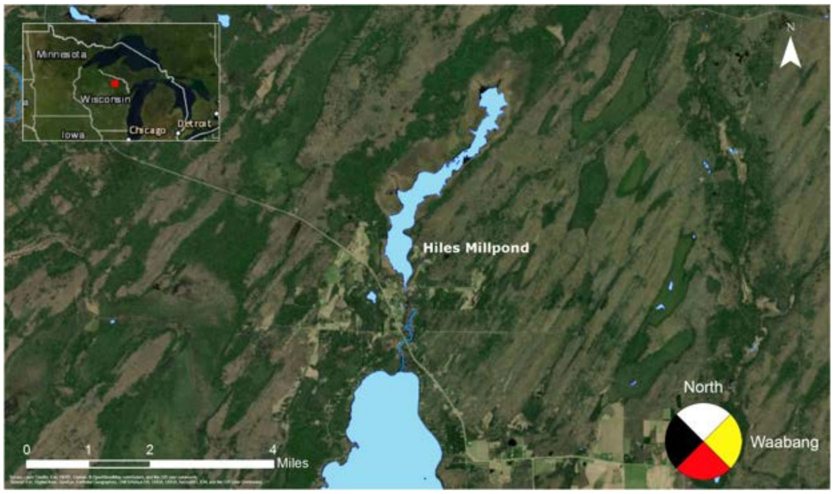


Exhibit 5.19. Map of Hiles Millpond

Threats to Manoomin at Hiles Millpond

Water ponded at Hiles Millpond in the late 1880s, when the Hiles Lumber Company built a dam for logging purposes. Although there is no record of the presence of Manoomin at Hiles Millpond, it may have been there at some point prior to dam construction, since Manoomin is in nearby waters. If Manoomin was present at Hiles Millpond historically, it could have been negatively affected by changes in water levels associated with construction of the dam.

The area and waters around the Town of Hiles were traditionally used by the Lac du Flambeau Band of Lake Superior Chippewa Indians (LDF Band), the Sokaogon Chippewa Community, and other Ojibwe Bands and their ancestors. However, use of the area by Bands for hunting, gathering, fishing, and trapping was limited during much of the last century up until the 1980s. Use of this area increased after this time when relations with the local community in the Town of Hiles improved.

Actions taken to improve the abundance of Manoomin at Hiles Millpond

In 1992, safety inspections found several problems with the dam structure at Hiles Millpond. To meet contemporary safety standards, the Town of Hiles needed to replace the dam structure. Since the town lacked adequate funds, federal, state, tribal, and nongovernmental organizations entered into a cooperative effort. A Memorandum of Understanding included a provision for the town to cooperate with the Forest Service to manage the millpond for productive wildlife and fish habitats, including possible manipulation of water levels, following completion of the project. The dam and water control structure were rebuilt in fall 1993.

Shortly after, biologists realized that the ecological benefits of Hiles Millpond could be significantly enhanced by establishing Manoomin on the millpond. Establishing Manoomin could also help to make up for the loss of Manoomin on other waters in the region, many of which were difficult or impossible to recover due to excessive development, conflicting uses, or other threats to Manoomin (Peter David, GLIFWC, personal communication, November 27, 2019).

In 1998, GLIFWC and the Forest Service cooperatively seeded the Hiles Millpond flowage with a relatively modest amount of Manoomin (329 pounds). Small patches of Manoomin then expanded modestly over the next several years. In 2011, Manoomin expanded significantly under natural drought conditions, which led biologists to believe that Manoomin might increase if the typical summer water level was lowered slightly.-

Although the Town of Hiles was initially concerned that lower water levels might negatively affect the northern pike fishery, it ultimately agreed to manage the water level for Manoomin. Once lowered, Manoomin showed an immediate response. Manoomin abundance increased significantly from 2013, before water levels were lowered, to 2014, following a lowering of water levels (Exhibit 5.20). In recent years, over 125 acres of Manoomin can be found growing across the lake (Peter David, GLIFWC, personal communication, November 27, 2019).

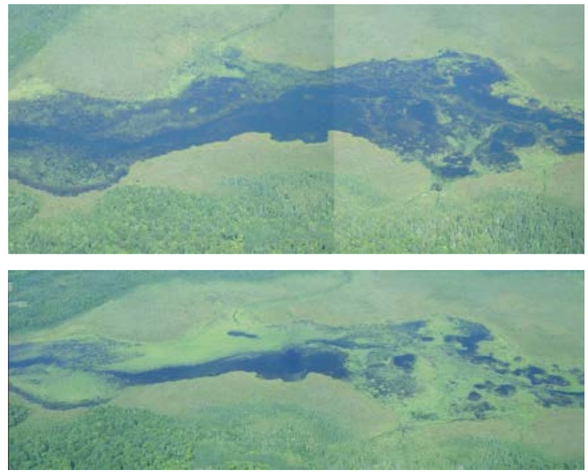


Exhibit 5.20. Manoomin abundance on a portion of the Hiles Millpond in 2013 (above), and in 2014 (below) following a lowering of water levels

Credit: Peter David, GLIFWC.

Cultural and ecological characterization at Hiles Millpond

Manoomin and its associated habitat at Hiles Millpond were characterized over three time periods. The characterization starts in 1980 because prior to that time community members were less likely to travel to Hiles Millpond to harvest Manoomin, and undertake other traditional hunting and gathering practices.

1980 to 1997: Before Manoomin seeding

Based on the combined ranking of cultural and ecological metrics, Hiles Millpond was characterized as “very bad” during this period. Because of the absence of Manoomin in the millpond, most of the metrics – particularly cultural metrics – ranked low on the score range.

1998 to 2013: After Manoomin seeding

Once seeding activities began in 1998, Manoomin began to grow at the millpond. The presence of Manoomin improved the rankings for most cultural and ecological metrics. In particular, the presence of Manoomin at Hiles Millpond allowed for some harvesting, preparation, and sharing of Manoomin by the community. It also improved the Anishinaabe’s connections and balance with spirit beings and relatives, and it supported diverse biological communities. During this period, Hiles Millpond ranked as “not very good” based on the combined ranking of cultural and ecological metrics.

2014 to 2019: With water level management

After resource managers adjusted water levels for Manoomin in 2014, its coverage continued to expand. More Manoomin allowed for harvesting, preparation, and sharing of Manoomin in ways practiced by ancestors. It also allowed for knowledge generation and sharing of Anishinaabe practices, values, beliefs, and language. Although Manoomin provides many cultural and ecological functionality, additional management of water levels could continue to improve Manoomin and its associated habitat at Hiles Millpond. During this period, Hiles Millpond ranked as “pretty good” based on the combined ranking of cultural and ecological metrics.

Cultural and ecological functionality provided by Manoomin and its associated habitat at Hiles Millpond have increased over time, both in aggregate and for individual metrics (Exhibit 5.21).

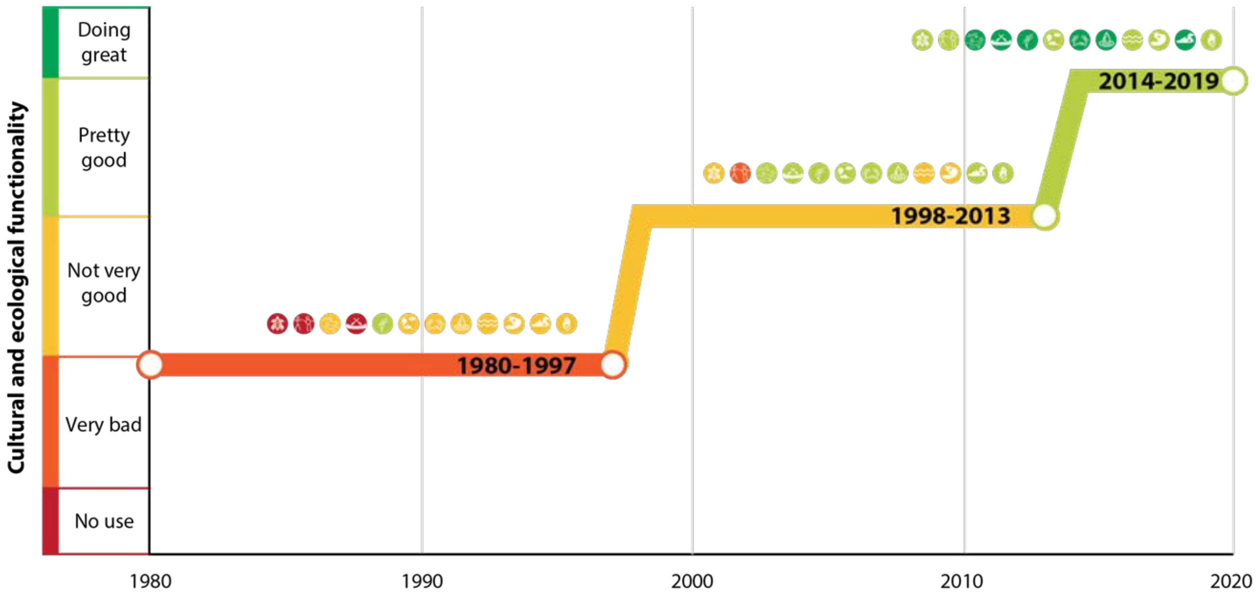


Exhibit 5.21. Characterization of cultural and ecological functionality provided by Manoomin and its associated habitat at Hiles Millpond

Additional restoration needed

Based on the characterization of the degree of cultural and ecological function over the four time periods, the HEA calculations demonstrate the additional equivalent units of restoration needed to counter-balance the severity and timespan of degradation. With modest seeding and slight modifications in water-level management, resource managers successfully established Manoomin across the Hiles Millpond. The analysis indicates that an additional 864 acres of similar Manoomin restoration is needed to counter-balance the lost habitat functionality that has occurred over time (Exhibit 5.22). In other words, nearly three equivalent restoration efforts at Hiles Millpond (from 1998 to 2019) are needed to counter-balance the lost cultural and ecological habitat functionality (from 1980 to 1997).

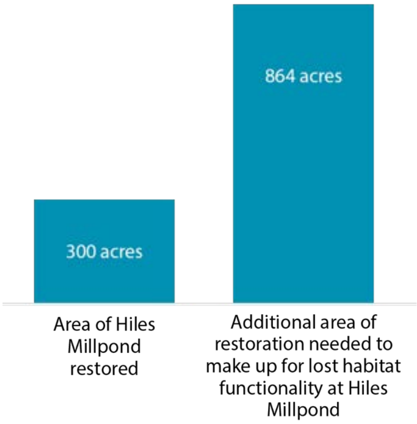


Exhibit 5.22. Additional restoration needed for Hiles Millpond

Case study acknowledgments

The Project Team would like to acknowledge Peter David (GLIFWC), Eric Chapman and Joe Graveen (LDF Band), and Peter McGeshick (Sokaogon Chippewa Community) for their valuable input and feedback in the development of this case study, and for participating in the cultural and ecological characterization of the Hiles Millpond.

Big Rice Lake

Big Rice Lake, located in St. Louis County in northeastern Minnesota, is approximately 1,870 acres (Exhibit 5.23). The area was traditionally used for ricing, sugar bush, and hunting activities; and archeological evidence indicates human use on sites surrounding the lake for hundreds – perhaps thousands – of years.

Exhibit 5.23. Map of Big Rice Lake

The lake is an important feeding and resting area for migrating waterfowl. In years of good Manoomin production, mallards, goldeneyes, wood ducks, blue winged teal, and ring-necked ducks use the lake. In 1992, Big Rice Lake became a Designated Wildlife Lake because of its "outstanding value to wildlife." Currently, the lake supports a bald eagle nesting territory, as well as muskrats, minks, beaver, otter, great blue herons, and trumpeter swans.

Threats to Manoomin at Big Rice Lake

Hydrologic changes, impacts from competing vegetation, and perhaps climate change have threatened Manoomin at Big Rice Lake. Manoomin is very sensitive to changes in water levels. Low or stable water conditions over long periods can encourage the proliferation of other vegetation, such as ginoozhegoons (pickerelweed), which can outcompete Manoomin for space and resources. Ginoozhegoons has expanded considerably on Big Rice Lake, especially on the eastern half of the lake. In addition to the artificial controls on water levels, climate change could change precipitation patterns, which may increase both the likelihood of drought and the frequency of heavy rain events that can cause high water levels and flooding in Big Rice Lake.

Actions taken to improve Manoomin at Big Rice Lake

Natural resource managers have taken several actions with the goal of increasing Manoomin at Big Rice Lake. In 1995, federal and state agencies built a rock weir at the outlet of the lake to increase the water flow out of the lake and reduce rapid water-level changes that can negatively impact Manoomin growth (MN DNR, 2013). Initially, the installation of the rock weir seemed to improve Manoomin coverage at Big Rice Lake; however, despite adjustments to the weir and varied beaver management, the more stable water level appears to have favored ginoozhegoons over Manoomin (Exhibit 5.24).

Since 2006, a cooperative effort of several federal, state, and tribal partners has taken additional management activities to further support Manoomin (Vogt, 2020b). In addition to allowing water levels to vary naturally, natural resource managers are cutting ginoozhegoons. Natural resource managers use an airboat with chains to disturb the substrate of Big Rice Lake to encourage the germination of Manoomin seed in several test plots (Vogt, 2020b). These efforts control about 100 acres of ginoozhegoons each year, but Manoomin regrowth in cut areas has been minimal (Vogt, 2020b). Over the years, partners have also trapped beavers and removed beaver dams to control water levels.

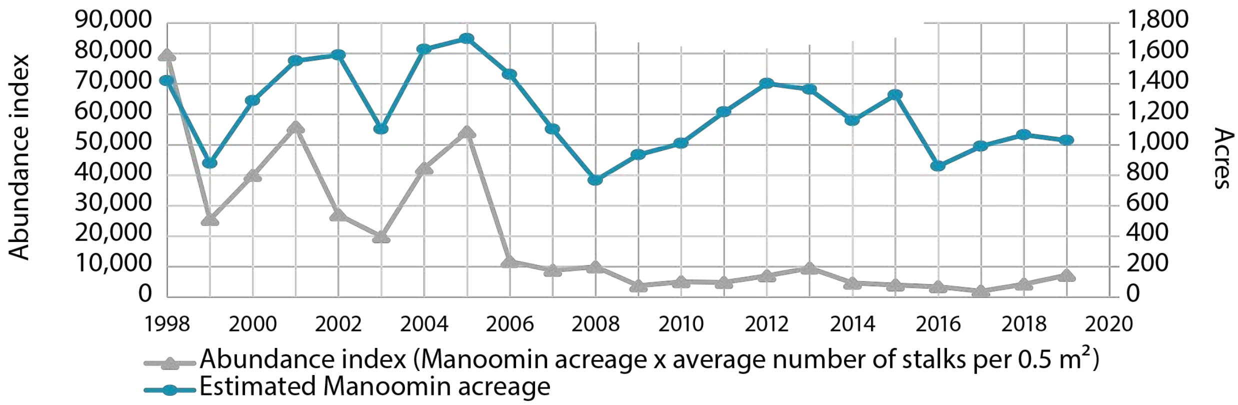


Exhibit 5.24. Manoomin abundance index and acres on Big Rice Lake

Source: Vogt, 2020b.

Cultural and ecological characterization at Big Rice Lake

Big Rice Lake's Manoomin and its associated habitat were characterized over three time periods.

1900 to 1994: Before rock weir construction

Based on the combined ranking of the cultural and ecological metrics, Big Rice Lake was characterized as "pretty good." During this period, Big Rice Lake was dominated by Manoomin with variable production across years, which provided high-quality waterfowl and wildlife habitats, and the opportunity for harvesting. The lake was culturally and historically important to Ojibwe Bands who used the lake during this period and exercised their treaty rights.

1995 to 2005: After rock weir construction

Immediately after the installation of the rock weir in 1995, Manoomin coverage at Big Rice Lake improved in some years. However, over time the more stable water level favored ginoozhegoons over Manoomin, and Manoomin began to decline, although it remained at the "pretty good" ranking score based on the combined ranking of cultural and ecological metrics.

2006 to 2019: With active management of Manoomin

By 2006, Big Rice Lake ranked as "very bad" based on the combined ranking of cultural and ecological metrics. Hydrologic changes, competition from ginoozhegoons, and perhaps other unknown factors led to the dramatic decline of Manoomin. From 2006 to 2019, natural resource managers took active management steps to recover Manoomin at Big Rice Lake; however, it remained sparse in coverage, with only a few small, moderate-to-good density stands found on the lake. As a result, community members were unable to harvest, prepare, and share Manoomin in ways practiced by their ancestors.

This also limited sharing, transmittal, and generation of Anishinaabe practices. The decline in Manoomin may have also negatively affected migratory waterfowl that use the lake.

Cultural and ecological functionality provided by Manoomin and its associated habitat at Big Rice Lake decreased over time, both in total and for individual metrics (Exhibit 5.25).

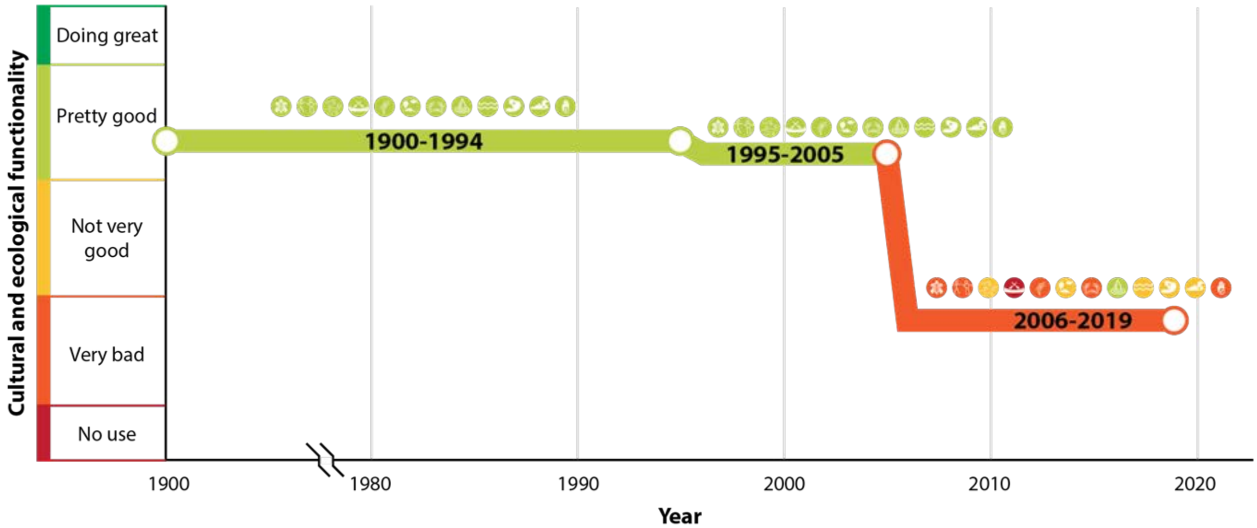


Exhibit 5.25. Characterization of cultural and ecological functionality provided by Manoomin and its associated habitat at Big Rice Lake

Additional restoration needed

Since the 1990s, natural resource managers have tried to improve the conditions of Manoomin and its associated habitat at Big Rice Lake; however, recent actions have not been successful and conditions continue to be diminished.

Restoration funds have recently been awarded to undertake further actions at the lake (Helmberger, 2019). If these actions were to improve functionality, we could use an HEA to demonstrate the additional equivalent units of restoration that would be needed to counter-balance the severity and timespan of degradation. For example, if actions were implemented over the next 20 years (2020 to 2040) to improve habitat functionality by 2.5%, we would need over 400,000 acres of similar Manoomin restoration to counter-balance the lost habitat functionality that has occurred over time (from 1995 to 2019). This is equivalent in size to over 200 Big Rice Lakes. The table below provides the HEA results, assuming several hypothetical scenarios of restoration improving habitat functionality (Exhibit 5.26); it is important to note that we do not know what actions are needed to create these percent improvements or if they are achievable. The main purpose of these scenarios is to highlight that if only minimal restoration is achieved at Big Rice Lake (which may be anticipated, given the long history of attempting restoration, with minimal response), then significant equivalent amounts of this restoration would be needed to balance the prolonged period of degradation at this lake.

Exhibit 5.26. HEA results, assuming several hypothetical scenarios of improvements in habitat functionality

Hypothetical percentage of improvement in habitat functionality from 2020 to 2040	Acres needed to counter-balance historical losses given hypothetical improvement[a]	Number of Big Rice Lakes needed to counter-balance historical losses given hypothetical improvement
2.5%	426,100	228
5.0%	213,100	114
10.0%	106,500	57
20.0%	53,300	29

a. Acres rounded to the nearest hundred.

This case study demonstrates how difficult it is to restore degraded Manoomin and its associated habitat, and how important it is to protect existing Manoomin habitat, as actions taken at Big Rice Lake have not improved its ability to support the various functions of Manoomin. A future characterization of Big Rice Lake could consider the effects of new restoration funding aimed at returning the natural functionality of the lake (Helmberger, 2019). This would refine and improve the current estimate of additional amount of restoration needed. Future restoration actions will include increased efforts to remove ginoozhegoons and return the outlet of the lake to natural rock rapids by removing the rock weir and accumulated sediment (Helmberger, 2019).

Case study acknowledgments

The Project Team would like to acknowledge Darren Vogt (1854 Treaty Authority) and Nancy Schuldt (Fond du Lac Band of Lake Superior Chippewa) for their valuable input and feedback in the development of this case study. In addition, the Project Team would like to thank Thomas Howes (Fond du Lac Band of Lake Superior Chippewa), Tara Geshick (Bois Forte Band of Lake Superior Chippewa), Daniel Ryan (U.S. Forest Service), and Melissa Thompson and Tom Rusch (Minnesota Department of Natural Resources) for participating in the cultural and ecological characterization of Big Rice Lake.

Twin Lakes

Exhibit 5.27. Map of Twin Lakes

The Twin Lakes are located in St. Louis County in northeastern Minnesota. Sandy Lake is approximately 120 acres and Little Sandy Lake is approximately 90 acres (Exhibit 5.27). The Twin Lakes are located immediately downstream of the tailings basin for U.S. Steel's Minntac iron ore operation. Prior to mining operations, the Twin Lakes produced good stands of Manoomin and were important ricing sites for Ojibwe Bands and vital habitat for a range of wildlife species.

Threats to Manoomin at the Twin Lakes

U.S. Steel's Minntac iron ore operation facility includes two mining areas, several processing plants, a heating and utility plant, a water reservoir, and a tailings basin (MWH, 2004). Construction of the tailings basin began in 1966 (MWH, 2004). Part of the seepage from the tailings basin discharges to the east into the Sand River, flows into the Twin Lakes, and into the Sand River watershed. Discharge from the tailings basin has changed the chemical composition and hydrologic condition of the Twin Lakes by increasing sulfate levels and, to a lesser extent, increasing the volume of water in the lakes.

Ongoing sulfate loading renders restoration ineffective at the Twin Lakes

The Twin Lakes are severely degraded by sulfate-laden mine waste from U.S. Steel's tailings basin. Because sulfate concentrations are high, any attempts to restore Manoomin stands that do not address this fundamental issue have proven largely ineffective. For example, multiple attempts by natural resource managers to adjust water levels through beaver management (in the 1970s to 1990s and 2015 to 2018) have not improved Manoomin stands in a measurable way. Modest reseeding efforts (in 1991 and 1992) have also not been effective. Restoration efforts are not successful because sulfate levels at the Twin Lakes are at least 10 times higher than the Manoomin sulfate standard; the current sulfate standard is 10 mg/L (Exhibit 5.20; Tribal Wild Rice Task Force, 2018).

In 2010, U.S. Steel was required to construct a seepage collection system to collect some of the mine wastewater discharging at the base of the tailings basin. While this reduced the total volume of water discharging from the mine site, it did not fully stop it. As a result, mine waste high in sulfate continued to contaminate the Twin Lakes after the collection system was installed. The 1854 Treaty Authority monitored lake conditions before the installation of the seepage collection system (2010) and after (2011 to 2019). Data collected included information on water quality (sulfate and other water quality indicators) and water-depth recordings; as well as data from inlet and outlet field surveys, vegetation surveys, and aerial surveys (Vogt, 2020a). Results showed that sulfate levels remained elevated well above the standard over the nine years of monitoring after the installation of the seepage system, and remained substantially unchanged from conditions prior to the installation (Exhibit 5.28).

During the monitoring study, very limited Manoomin stalks were also observed across the Twin Lakes over the same time period. In 2015, U.S. Steel planted test plots to determine if Manoomin had the potential to grow in the Twin Lakes. In this small-scale test plot, U.S. Steel reseeded with 40 pounds of Manoomin. After seeding, Manoomin success has varied but has been limited across years (Vogt, 2020a). Full-scale reseeding was not attempted.

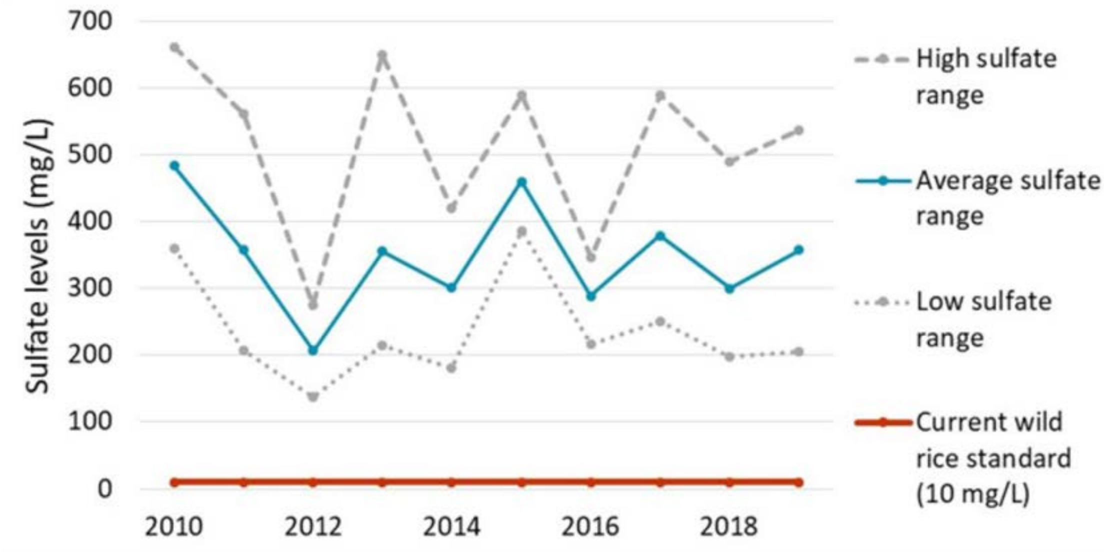


Exhibit 5.28. Sulfate concentrations at the inlet to the Twin Lakes compared to current standard sulfate levels (10 mg/L) for Manoomin, 2010 to 2019

Source: Vogt, 2020a.

Cultural and ecological characterization at the Twin Lakes

The Twin Lakes' Manoomin and its associated habitat were characterized over four time periods.

1950 to 1965: Before construction of the tailings basin

Based on the combined ranking of cultural and ecological metrics, conditions at the Twin Lakes were characterized as "doing great" during this period. Prior to the discharge of mine waste into the Twin Lakes, both lakes had moderately dense to dense stands of Manoomin. The Bois Forte Band of Chippewa, Grand Portage, and other community members historically harvested Manoomin in these lakes. In addition, Manoomin supported waterfowl (e.g., mallard, black ducks, green winged teal, wood ducks), fish such as northern pike, and other wildlife during this period (Minnesota Division of Game and Fish, 1966a, 1966b).

1966 to 1989: After construction of the tailings basin

After the discharge of mine waste started, Manoomin coverage in the Twin lakes steadily declined. Compared to a 1966 vegetation survey of the Twin Lakes (Minnesota Division of Game and Fish, 1966a, 1966b), a 1987 survey found that Manoomin was essentially absent from both lakes, while water levels were considerably higher and water clarity increased dramatically (State of Minnesota, 1987). By 1989, the Twin Lakes ranked as “no use” based on the combined ranking of cultural and ecological metrics.

1990 to 2009: With limited restoration actions

During this period, some actions were undertaken to recover Manoomin, including beaver management and small-scale reseeding efforts. However, these actions did not address the fundamental issue of high levels of sulfate and were largely ineffective at restoring the abundance of Manoomin and its associated habitat at the Twin Lakes. Given the absence of Manoomin on the lakes, community members were unable to harvest, prepare, and share Manoomin in ways practiced by their ancestors. The lost use of the Twin Lakes also limits sharing, transmittal, and generation of Anishinaabe practices at these lakes. During this period, the ranking of the Twin Lakes remained near “no use” based on the combined ranking of cultural and ecological metrics.

2010 to 2019: After construction of the seepage collection system

After U.S. Steel constructed the seepage system, Manoomin remained essentially absent from the Twin Lakes. With the lakes unable to support Manoomin, community members remained unable to harvest, prepare, and share Manoomin in ways practiced by their ancestors. During this period, the ranking of the Twin Lakes remained near “no use” based on the combined ranking of cultural and ecological metrics.

Cultural and ecological functionality provided by Manoomin and its associated habitat at the Twin Lakes declined over time, both in aggregate and for the individual metrics (Exhibit 5.29).

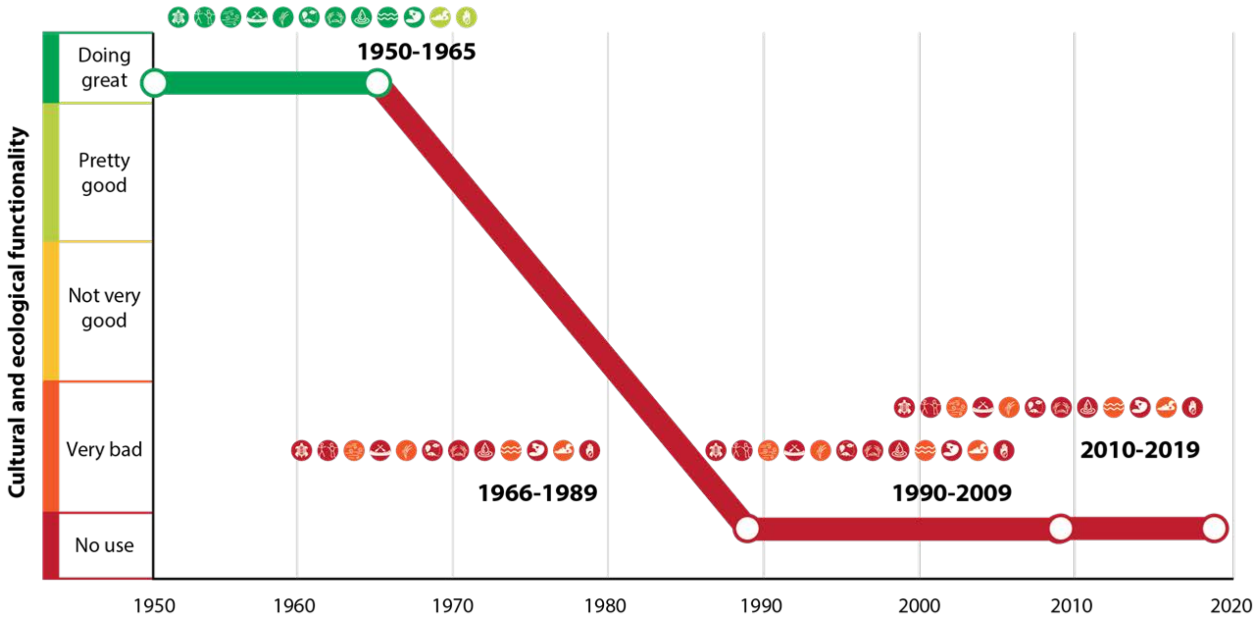


Exhibit 5.29. Characterization of cultural and ecological functionality provided by Manoomin and its associated habitat at the Twin Lakes

Additional restoration needed

Since the installation of a tailings basin for the U.S. Steel's Minntac facility in the mid-1960s, the abundance of Manoomin at the Twin Lakes has steadily declined. Actions taken at the Twin Lakes to improve Manoomin and its associated habitat have been limited and have not addressed the fundamental problem of sulfate loading from the mine. If actions were taken to improve conditions in the future, we could use an HEA to demonstrate the additional equivalent units of restoration needed to counter-balance the severity and timespan of degradation. For example, if actions were implemented over the next 20 years (2020 to 2040) to improve habitat functionality by 2.5%, over 100,000 acres of similar Manoomin restoration would be needed to counter-balance the lost habitat functionality that has occurred over time (from 1966 to 2019). This is equivalent in size to over 550 Twin Lakes.

Exhibit 5.30 provides the HEA results, assuming several hypothetical scenarios of improvements in habitat functionality; it is important to note that we do not know what actions are needed to create these percent improvements, but they would likely require addressing the fundamental problem of sulfate loading from the mine. The main purpose of these scenarios is to highlight that if only minimal restoration is achieved at Twin Lakes (which may be anticipated, given the long history of attempting restoration, with minimal response), then significant equivalent amounts of this restoration would be needed to balance the prolonged period of degradation at these lakes.

Exhibit 5.30. HEA results, assuming several hypothetical scenarios of improvements in habitat functionality

Hypothetical percentage of improvement in habitat functionality from 2020 to 2040	Acres needed to counter-balance historical losses given hypothetical improvement[a]	Number of Twin Lakes needed to counter-balance historical losses given hypothetical improvement
2.5%	116,700	556
5.0%	58,400	278
10.0%	29,200	139
20.0%	14,600	69

a. Acres rounded to the nearest hundred.

This case study demonstrates the difficulty in restoring Manoomin and its associated habitat when the root cause of the degradation – in this case, sulfate discharge – is not addressed. Given the difficulty of restoring degraded habitat, it is important to protect and preserve existing Manoomin habitat to ensure a future with Manoomin.

Case study acknowledgments

The Project Team would like to acknowledge Darren Vogt (1854 Treaty Authority) and Nancy Schuldt (Fond du Lac Band of Lake Superior Chippewa) for their valuable input and feedback in the development of this case study. The Project Team would also like to thank Wayne Dupuis (Fond du Lac Band of Lake Superior Chippewa), Tara Geshick (Bois Forte), John Coleman and Esteban Chiriboga (Great Lakes Indian Fish & Wildlife Commission), and Amy Myrbo for participating in the cultural and ecological characterization of the Twin Lakes.

6. Cross-case findings and lessons learned

In this chapter, we detail the cross-case findings and lessons learned developed through this study. The cross-case findings represent the collective wisdom of our project team on these seven unique case studies. While each case study is unique, with distinct attributes, here we focus on some common themes that emerged across the studies.

The Anishinaabe have long history of careful tending to Gichi-manidoo gitigaan through Manoomin stewardship; however, restoring Manoomin and its associated habitat remains a significant challenge under current conditions.

> The older term for rice beds, *Gichi-manidoo gitigaan* or the Great Spirit's Garden, "captures (among other concepts) the perspective that while Manoomin is a natural part of the landscape, careful tending to the crop can enhance its health and productivity, in the same way a dedicated gardener benefits her plants."
>
> – David et al., 2019

The Anishinaabe have a long relationship of careful tending to Manoomin to enhance its health and productivity (David et al., 2019). This stewardship is both spiritual and ecological in nature. Wild rice chiefs, for example, conduct ceremonies honoring Manoomin to help protect the crop and ensure its abundance (David et al., 2019). With tribal and other partners, wild rice chiefs also regulate water levels, remove competitive vegetation, and seed new areas. The contemporary restoration undertaken throughout the seven case studies described in this study reflect these stewardship practices.

- *Manoomin seeding* efforts have expanded since the reaffirmation of treaty rights in the Great Lakes region (David et al., 2019). Considerable resources have been expended to increase the abundance of Manoomin through seeding efforts. Most of our case studies include some Manoomin seeding efforts (see Exhibit 5.2). The level of effort varies from modest reseeding efforts in the Twin lakes to more extensive reseeding efforts at Lac Vieux Desert's Rice Bay.
- *Water-level management* can help regulate water levels to benefit Manoomin; these management actions can include traditional water-level management actions (e.g., removing beaver dams), as well as more complex water-level management activities. Most of the restoration efforts in our case studies include water-level management of some form (see Exhibit 5.2). Changing the operating regime of a dam on Lac Vieux Desert to lower water levels, for example, combined with Manoomin seeding efforts, helped to reestablish Manoomin on Lac Vieux Desert's Rice Bay.
- *Removal of competitive vegetation* on a rotational schedule can restore Manoomin density. In several case studies, the native plant ginoozhegoons is outcompeting Manoomin (Exhibit 2.1). Fond du Lac Band of Lake Superior Chippewa, for example, is undertaking mechanical removal of ginoozhegoons at *Perch Lake* and Big Rice Lake to restore Manoomin habitat (Fond du Lac Band, 2018).

Success of these restoration actions has been incremental and at times challenging. Restoration actions taken at historically high-producing Manoomin waters – including Big Rice Lake, Twin Lakes, Lac Vieux Desert's Rice Bay, and *Perch Lake* – have not returned Manoomin and its associated habitat to historical cultural and ecological functionality. And, in some cases, restoration actions have been largely ineffective with Manoomin abundance and density continuing to decline. For example, natural resource managers have tried to improve the conditions of Manoomin and its associated habitat at Big Rice Lake since the 1990s; however, actions have had limited success and Manoomin conditions continue to be diminished.

Several case studies also highlight the need to return to the concept of traditional stewardship and carefully tend to Manoomin through sustained, long-term resource management At Perch Lake, the Fond du Lac Band of Lake Superior Chippewa developed a management strategy that brings lake levels to flood stage every four years in order to stress perennial species, such as ginoozhegoons that otherwise outcompete Manoomin. This long-term restoration approach provides Manoomin with a competitive advantage in the immediate years following the flood stage (Fond de Lac Band, 2018).

Even in places where Manoomin restoration has shown success, more restoration is often needed given the significant historical losses in Manoomin cultural and ecological functionality.

The combined HEA approach applied in this study accounts for the amount of time that Manoomin habitat has been degraded and the time required for restored Manoomin habitat to recover or reach improved functionality. For several case studies, water level modifications through dams and agricultural diching or mining activities led to a decline in Manoomin habitat over 100 years ago. For example, Lac Vieux Desert was first dammed around 1870 for logging operations, and by 1907 the WVIC began operating the lake as a storage reservoir. In 1937, WVIC replaced the wooden dam with a reinforced concrete and steel structure. Changes in water levels caused by the dam initiated a decline in Manoomin and, from 1938 to 1952, Manoomin declined steadily and community members stopped harvesting it during this period (Barton, 2018; Labine, 2017). In addition, mine tailings were carried from a copper ore processing plant that operated from 1902 to 1919 around Keweenaw Bay. Connected to Keweenaw Bay, Sand Point Sloughs, a culturally important site for KBIC, and its natural resources have been exposed to high concentrations of heavy metals for many years.

Even with successful restoration, Manoomin habitat at many of our case study sites has had significant cultural and ecological losses over a long period of time, which often means that many more acres of restoration are needed to counter-balance the lost habitat functionality than the case study footprint. At Lac Vieux Desert's Rice Bay, the equivalent of 12 restoration efforts (from 1991 to 2019) are needed to counter-balance the lost cultural and ecological habitat functionality (from 1900 to 1990), while at Sand Point Sloughs, 22 equivalent restoration efforts (from 1991 to 2019) are needed to counter-balance the lost cultural and ecological habitat functionality (from 1920 to 1990).

At some locations, restoration actions may never fully recover all cultural and ecological functionality given that long time period of loss. At Twin Lakes, for example, actions taken to improve Manoomin and its associated habitat have been limited and have not addressed the fundamental problem of sulfate loading from the mine. Given the significant cultural and ecological losses that have occurred since the installation of a tailings basin for the U.S. Steel's Minntac facility in the mid-1960s, it is challenging to foresee a scenario where restoration actions could fully recover all lost functionality. In these cases, protection and/or restoration of Manoomin habitat at additional locations may be one approach to compensate for all the losses that occurred over time.

Seeding to enhance existing Manoomin stands and to introduce it to new locations can be worthwhile and necessary; places with favorable habitat features and conditions seem conducive to growing Manoomin.

Manoomin seeding in waters with favorable physical or hydrologic features can be an effective and inexpensive way to restore Manoomin (David et al., 2019). In addition, seeding at both sites where Manoomin is known to have historically occurred, and sites where there are no records, but hydrologic conditions seem suitable, can be worthwhile and necessary – "worthwhile because of the many ecological and cultural benefits rice provides and because rice abundance in the state remains lower than it was prior to European contact, and necessary because rice seed has a very limited natural ability to disperse" (David et al., 2019, p. 68). Natural resource managers around the Lake Superior region have had some success in identifying good Manoomin habitat, based on physical or hydrologic features, and seeding Manoomin. In two of our seven case studies, natural resource managers selected areas that were not known to have any Manoomin, but were thought to have favorable conditions for Manoomin growth – suitable soils, clean water, and modifications in water-level management. The following two case studies are showing preliminary success in their seeding efforts. At Hiles Millpond, biologists realized that the ecological benefits of this place could be significantly enhanced by establishing Manoomin. With modest seeding and slight modifications in water-level management, resource managers successfully established Manoomin across the Hiles Millpond. At Net River Impoundment and Vermillac Lake, KBIC worked with the Michigan Department of Natural Resources to identify areas for Manoomin restoration, and the Net River Impoundment and Vermillac Lake were selected as lakes with potential for Manoomin beds. After successful seeded test plots at both lakes, KBIC has expanded seeding efforts and has seen successful establishment of Manoomin across these locations. In addition, cultural teachings and practices related to Manoomin are beginning to occur at the Net River Impoundment.

Although the results of seeding efforts are encouraging, more study is needed to confirm whether seeding can lead to culturally and ecologically high-quality Manoomin habitat. In addition, given that the period of degradation is often longer than the period of restoration, additional Manoomin restoration may be needed to counter-balance the lost habitat functionality that has occurred over time. At Net River Impoundment and Vermillac Lake, for example, nearly 12 equivalent restoration efforts (from 2014 to 2019) are needed to counter-balance the lost cultural and ecological habitat functionality (from 1990 to 2013).

Restoration must be adaptive; what may have worked in the past may not be successful in the future, given additional threats.

Many tribal, state, and federal agencies have been involved in Manoomin restoration around the Lake Superior region for decades and, in the case of tribal communities, for much longer. However, in some cases, actions taken in the past that have had some success at restoring Manoomin are no longer successful. For example, more frequent heavy rainfall events in the spring and summer have negatively affected Manoomin in Lac Vieux Desert's Rice Bay. These above-average precipitation events, which have led to "ghost rice" or empty seed hulls that never fill and brown spot disease in Manoomin beds, are likely driving the decline of Manoomin abundance on Rice Bay. In addition, Sand Point Sloughs is connected to Lake Superior, and affected by changes in the lake's water level and invasive and competitive species. These regional threats to the sloughs may be affecting Manoomin abundance and are largely beyond local control. The decrease in ecological and cultural functionality provided by Manoomin in recent years at several of our case study sites suggests the need for adaptive management of Manoomin habitats. Actions taken that may have been successful in restoring Manoomin in the past may need to be adjusted to respond to additional threats, such as climate change, to be successful in the future.

As conditions change and as we face uncertainty in future environmental conditions, it will be critical to collect monitoring data, evaluate the degree of success of restoration actions based on the interpretation of those data, and then make adaptations, or changes, as needed to future restoration actions to adapt to changing environmental conditions. Adaptive management could include taking initial restoration actions, and then using new information for future decisions. Or it can include exploring a range of options during all phases of restoration to select the best path forward to achieving restoration objectives. Long-term adaptive management of Manoomin and its associated habitat will rely on monitoring and make adjustments in the future based on monitoring results.

Monitoring should be incorporated into all future restoration projects.

Monitoring can help wild rice chiefs and other natural resource managers assess the health of existing Manoomin habitats, evaluate the success of different restoration actions, and make informed resource management decisions. Monitoring can provide information about ecological trends, including Manoomin productivity and biomass, as well as information about other components of Manoomin waters, such as water quality and use of waters by muskrats, beaver, geese, swans, and other beings. It can also provide information about cultural trends, such as harvest levels by tribal members and exercise of treaty-reserved harvesting rights. Monitoring can also evaluate the effectiveness of restoration or inform adaptive management actions. Because of the high variability in the productivity and biomass of Manoomin from year-to-year, monitoring is most useful when undertaken over several years (Kjerland, 2015b). Monitoring should be completed using methods that are both scientifically robust and culturally respectful (Kjerland, 2015a, 2015b).

This project illustrates the critical importance of monitoring data. The seven case studies in this project would not have been possible, if not for existing monitoring data. Around the Lake Superior region, several agencies have undertaken long-term monitoring studies. Since the 1980s, GLIFWC has conducted Manoomin harvest surveys for tribal (off-reservation) and state (statewide) licensed ricers in Wisconsin (David et al., 2019). Nearly all of this harvest comes from the ceded territory. GLIFWC also uses aerial surveys to approximate rice abundance information for over 200 waterbodies each year (David et al., 2019). NOAA is using hyperspectral imaging to delineate aquatic vegetation, with Manoomin as the primary species. In 1998, the 1854 Treaty Authority initiated a Manoomin monitoring program on lakes and rivers within the 1854 Ceded Territory in northern Minnesota (Vogt, 2020b).

This study relies upon the long-term monitoring data from these efforts to understand the cultural and ecological conditions of Manoomin. Where available, case study teams incorporated monitoring data into their cultural and ecological characterization of Manoomin and its associated habitat. For example, the Lac Vieux Desert Band and GLIFWC mapped Manoomin acreage on Lac Vieux Desert's Rice Bay from 2000 to 2019 as part of the 10-year trial Lac Vieux Desert Wild Rice Restoration Plan with the Wisconsin Valley Improvement Company (WVIC; Exhibit 6.1). These data provided background on the condition of Manoomin with restoration actions (the 1991 to 2012 time period) and during the decline in Manoomin abundance with above-average precipitation (2013 to 2019 time period). Our study underscores the importance of long-term monitoring. There should be a concerted effort to inventory all Manoomin waters across the Great Lakes.

Traditional ecological knowledge can help understand habitat functionality across the Lake Superior region.

Cultural leaders, community members, wild rice chiefs, Manoomin harvesters, and elders have essential knowledge and perspectives that can inform the characterization of cultural and ecological functionality provided by Manoomin over long time periods. Our Project Team was composed of many cultural leaders, community members, harvesters, and wild rice chiefs who shaped the development of our cultural and ecological metrics; and informed the characterization of Manoomin at specific sites. In a few instances, our Project Team relied on their wild rice chiefs and elders to provide cultural and traditional ecological knowledge about a place. For example, the Fond du Lac Band of Lake Superior

Chippewa case study team received input from an elder and wild rice chief to characterize a time period for Perch Lake where the case study team had limited knowledge and limited ecological monitoring data.

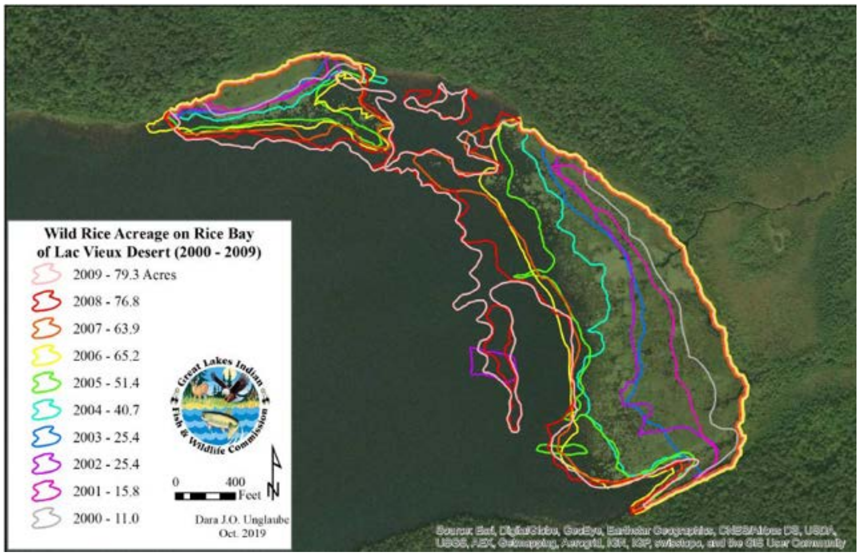


Exhibit 6.1. Manoomin distribution and acreage on Rice Bay on Lac Vieux Desert, 2000–2009

Credit: GLIFWC, 2019.

Educating tribal and nontribal community members can ensure successful Manoomin restoration.

While Manoomin is one of the most valuable aquatic plants in the Lake Superior region, the benefits and values of Manoomin are often unknown or underappreciated by the general public (David et al., 2019). Education and information about the importance of Manoomin can encourage the stewardship of Manoomin and improve restoration outcomes. On Lac Vieux Desert, for example, some lakeshore owners and boaters viewed Manoomin as a nuisance. After taking the time to educate the non-tribal community about the importance of Manoomin and why it is worth protecting, the LVD Band now works closely with them to ensure the existence of Manoomin in Rice Bay and other parts of the lake.

Preserving existing Manoomin habitat is critical to ensuring a future with Manoomin.

Given the significant challenges in restoring Manoomin that has become degraded, a key management strategy for Manoomin is to protect and preserve existing Manoomin stands and the clean water resources and habitats in which it thrives. In many places, dramatic changes to wetland and lake systems – including hydrologic changes from dams and agricultural ditching and mining activities – has had unforeseen consequences. Protecting areas with Manoomin habitat could reduce some stressors to Manoomin, and allow the plant to adapt to climate change and other changing conditions. Manoomin habitats may be protected through a number of different actions, including first ensuring there is a comprehensive characterization (mapping) of the habitat across the Great Lakes Region, such as the use of hyperspectral imaging to delineate Manoomin habitat. Acquisitions and conservation easements may also be part of the strategy to protect Manoomin habitat. In addition, instituting best management practices to protect existing high-quality habitat from existing stressors should also be considered. This may include controlling invasive species; limiting activities with adverse consequences in sensitive habitats, such as discharging mine waste; and developing climate monitoring and adaptive management plans. Finally, educational outreach could be an important aspect of preserving Manoomin habitat, including outreach to lakeshore landowners with Manoomin stands about the value of this habitat, and to the general public with respect to the ecological and cultural value of Manoomin.

7. Conclusion and next steps

This report documents and characterizes the importance and functions of Manoomin and its associated habitat to cultural perspectives and identity, community connections, and cultural and spiritual practices of the Anishinaabe people; as well as to biodiversity and ecosystem integrity. Using a set of cultural and ecological metrics and a combined HEA approach, we characterized a range of degraded Manoomin waters where restoration actions have been undertaken, with locations dispersed over the Lake Superior region. We quantified lost cultural and ecological functionality in terms of the additional amount of equivalent restoration that would be needed to counter-balance the losses.

We find that restoration is worthwhile, with demonstrable improvements documented in our case studies. However, our case studies also highlight the challenges to return degraded Manoomin stands to full functionality. Many restoration actions have improved cultural and ecological functionality, but have not been successful at fully returning Manoomin to historical conditions or to the potential capacity implied by conditions at the site. In places where Manoomin restoration has shown some success, we find that additional restoration is often needed, given historical losses in cultural and ecological functionality. The challenges in restoring Manoomin habitat after it is degraded serve to highlight the critical importance of protecting existing Manoomin stands.

To provide a path forward for Indigenous communities, tribal and non-tribal governments, organizations, and staff who are working to actively manage and restore Manoomin across the Great Lakes, we would like to offer several possible next steps to further assess the cultural and ecological importance of Manoomin.

Expand the geographic scope of this study

This study focuses on seven case studies around the Lake Superior region. We selected the case studies in places that were of particular importance to our team and had adequate data and information to inform the characterization. As we were only able to delve deep into a limited number of the case studies, it is difficult to generalize our case study findings from these seven places to the Lake Superior region or the Great Lakes basin more broadly.

A cumulative sample of case studies could allow us to aggregate information from places around the Great Lakes – including the full Lake Superior region and across lakes Michigan, Huron, Erie, and Ontario – to allow for greater generalization. With a more representative sample of case studies, we could provide additional insights into threats to Manoomin and different restoration approaches used across the Great Lakes, and better understand the cultural and ecological losses (or gains) in Manoomin and its associated habitat throughout the region. This could help target critical resources to protect the remaining populations of Manoomin and restore Manoomin habitat across the Great Lakes region.

Incorporate cultural and ecological characterizations into annual monitoring efforts

Many of the sites are newly restored, such as Hiles Millpond and the Net River Impoundment, or have recently acquired additional resources to complete more restoration, such as Big Rice Lake and Lac Vieux Desert's Rice Bay. Characterizing future restoration conditions at these places could allow for a continued understanding of how well restoration returns the cultural and ecological functionality of the place and, in some cases, could refine the output from the HEA approach. For example, Big Rice Lake could be characterized after additional restoration efforts are implemented to determine how well those actions return the lake's natural functionality.

Cultural metrics could also inform annual monitoring efforts. Combined with ecological monitoring metrics (e.g., water quality, water level, and Manoomin biomass and stalk density), cultural metrics incorporate Indigenous knowledge, cultural values, beliefs, and practices into the monitoring process; and provide a more holistic understanding of determining if restoration actions are achieving target goals or returning conditions to historical or baseline conditions. Without Indigenous metrics, the cultural values, beliefs, and practices are unseen or invisible and, therefore, the restoration is not adequately characterized. The characterization must be driven and refined by the people in the community. In particular, cultural metrics will need to reflect the unique history of the community or the place, as well as the place-based use of Manoomin or other natural resources.

In the Great Lakes, continuous efforts are needed to protect, restore, and monitor Manoomin and its associated habitat. Understanding the success (or failure) of restoration actions in counterbalancing historical losses in cultural and ecological functionality can help determine how to target future resources toward restoring and protecting Manoomin. We hope that the information and knowledge gained through this study will help Indigenous communities, tribal and non-tribal governments, organizations, and staff in the Great Lakes region ensure a future with healthy Manoomin waters.

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Appendix

In this appendix, we provide the standalone communications materials developed for each case study. In each case study, we provide a brief overview of the place, and describe the threats to Manoomin at the place and the actions taken to improve the abundance of Manoomin at the place. We then describe the case study results, including the metrics used to characterize the cultural and ecological importance of the place, the characterized conditions of Manoomin habitat over time, and the results of the HEA model that calculates the amount of restoration needed to balance the reduced or lost functions. Case studies include:

- Restoration of **Lac Vieux Desert's Rice Bay** increases cultural and ecological functionality: Significant progress made but additional restoration could counter-balance losses
- Restoration of **Perch Lake** increases cultural and ecological services: Efforts by the Fond du Lac Band show some improvement in Manoomin coverage
- Restoration of Keweenaw Bay Indian Community's **Sand Point Sloughs** increases cultural and ecological functionality: Significant progress made but additional restoration could counter-balance losses
- Introduction of Manoomin at **Net River Impoundment and Vermillac Lake** provides cultural and ecological functionality: With favorable conditions, restoration can enhance Gichi-manidoo gitigaan
- Introduction of Manoomin at **Hiles Millpond** provides cultural and ecological functionality: With favorable conditions, restoration can enhance Manoomin habitat
- Efforts to manage **Big Rice Lake** have not improved Manoomin functionality: Manoomin continues to be affected by hydrologic conditions and other threats
- Low ecological and cultural functionality characterized at the **Twin Lakes**: Manoomin is unable to rebound due to ongoing sulfate loading from mine discharges.

Restoration of Lac Vieux Desert's Rice Bay increases cultural and ecological functionality

Significant progress made but additional restoration could counter-balance losses

Recent restoration efforts at Lac Vieux Desert's Rice Bay have improved the cultural and ecological functionality of the bay's Manoomin (wild rice) and its associated habitat. However, given the significant losses, much more restoration is needed. Based on the methods applied in this study, it would take an additional 3,034 acres of similar Manoomin restoration to counter-balance the lost cultural and ecological functionality that has occurred over time. This is equivalent in scale to 12 times the current restoration efforts at Rice Bay. In addition, future restoration actions will need to be adaptive to respond to changing precipitation patterns.

"Manoomin is like the canary in the coal mine for water quality. It grows in high water quality, and when water quality declines, so does Manoomin."

Roger Labine, Lac Vieux Desert Band of Lake Superior Chippewa
November 12, 2019

Credit: Todd Marsee, Michigan Sea Grant

Threats to Manoomin at Rice Bay

Lac Vieux Desert was dammed around 1870 for logging operations. By 1907 the Wisconsin Valley Improvement Company (WVIC) began operating the lake as a storage reservoir and used the dam to create uniform stream flow down the Wisconsin River to reduce flooding events, facilitate hydroelectric power generation, and regulate effluent discharge downstream. In 1937, WVIC replaced the wooden dam with a reinforced concrete and steel structure. The high water levels caused by the dam initiated a decline in Manoomin (Labine, 2017). From 1938 to 1952, Manoomin declined steadily and community members stopped harvesting it during this period (Barton, 2018). During this period, lakeside property owners became concerned about the erosion caused by rising lake levels.

More recently, heavy rainfall events have negatively affected Manoomin in Lac Vieux Desert [Roger Labine, Lac Vieux Desert Band of Lake Superior Chippewa (LVD Band), personal communication, February 15, 2020]. In the spring, Manoomin is in the floating leaf stage, and can be uprooted by heavy rainfall that raises water levels. In the summer, when Manoomin is in the flowering stage, heavy rainfall can knock Manoomin pollen down from the flower to the water's surface, which prevents pollination and results in "ghost rice" or empty hulls that never fill. In addition, the combination of heavy rainfall events and higher air temperatures may also increase the amount of brown spot – a destructive wild rice fungal disease – in Manoomin beds.

About Lac Vieux Desert's Rice Bay

Lac Vieux Desert, located in Vilas County, Wisconsin, and Gogebic County, Michigan, is over 4,000 acres. Historically, Manoomin covered many parts of Lac Vieux Desert, including Rice Bay, Thunder Bay, Slaughters Bay, Misery Bay, and along the northwestern shore to the Wisconsin River and parts of the south shore.

Rice Bay is a 243-acre bay on the northeastern portion of Lac Vieux Desert, which historically contained a significant stand of Manoomin that was traditionally managed and harvested by the LVD Band. West of Rice Bay is Ketegitigaaning, a ricing village used intermittently in the early 18th century by the LVD Band, followed by continuous habitation by 1900. In 2015, Rice Bay was registered as a Traditional Cultural Property on the National Register of Historic Places.

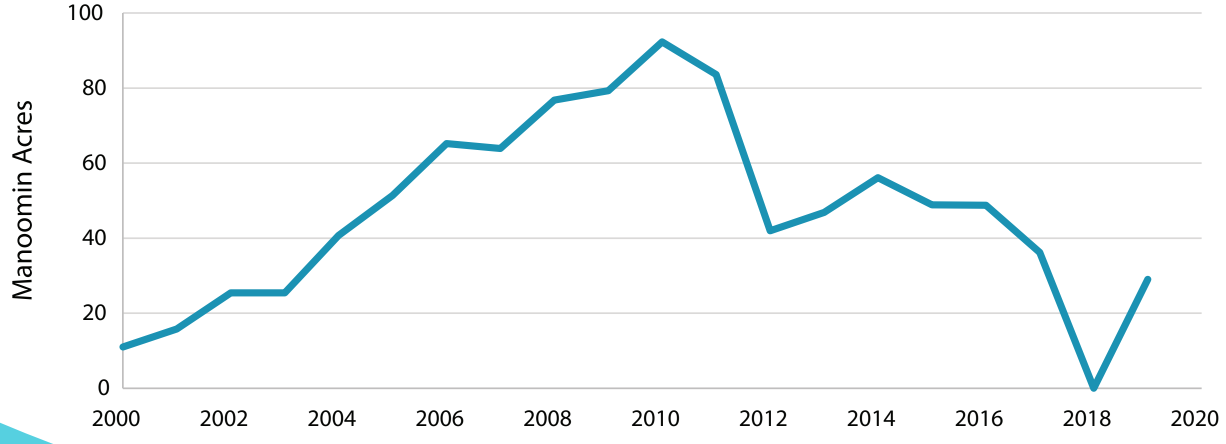
Actions taken to improve the abundance of Manoomin at Rice Bay

In 1991, a coalition of tribal, state, and federal governments and governmental agencies determined the operating regime of the dam on Lac Vieux Desert had been detrimental to Manoomin and its associated habitat (Onterra, 2012). By 2001, following a decade of negotiation and litigation, WVIC lowered the maximum operating level by about nine inches and provided financial contribution toward a Manoomin seeding and monitoring program (Barton, 2018). From 2002 to 2005, Lac Vieux Desert was seeded with 14,000 pounds of Manoomin, most of which occurred in Rice Bay (Labine, 2017). From 2007 through 2012, as Manoomin became reestablished on Rice Bay, the LVD Band held traditional ricing camps and workshops, which included traditional practices and activities (Barton and Labine, 2013).

From 2000 to 2010, the acreage of Manoomin on Rice Bay significantly increased. In 2000, Rice Bay had just 11 acres of Manoomin coverage (or 5% of Rice Bay). After the first year of seeding, Manoomin coverage increased to over 25 acres (or 10% of Rice Bay; top aerial photograph). With below-average rainfall conditions in 2010, the extent of Manoomin increased to over 92 acres (or 38% of Rice Bay; bottom aerial photograph). While the extent of Manoomin on Rice Bay was less than its historical coverage, it was considered an improvement over conditions caused by the operating regime of the concrete dam (Barton, 2018).

Since 2011, the acreage of Manoomin on Rice Bay has been declining, with 34 acres in 2019 (GLIFWC, 2019). Because Manoomin abundance on Rice Bay is generally greatest during low-water years, natural resource managers believe this may be due to above-average precipitation over the past seven years (Peter David, GLIFWC, personal communication, November 12, 2019).

Manoomin abundance on Lac Vieux Desert Lake's Rice Bay in 2003 (above) and 2010 (below). Credit: Peter David, Great Lakes Indian Fish & Wildlife Commission (GLIFWC).



Manoomin acreage on Rice Bay, 2000 to 2019

Credit: GLIFWC, 2019.

Approach to characterizing Manoomin at Rice Bay

Twelve metrics characterize the cultural and ecological functions of Rice Bay's Manoomin and its associated habitat. These metrics describe how Manoomin at Rice Bay contributes to maintaining connections with the Anishinaabe culture, how ecological functionality is supported and resilient to changing conditions, and how continued learning and sharing of Anishinaabe values are promoted.

Cultural Metrics

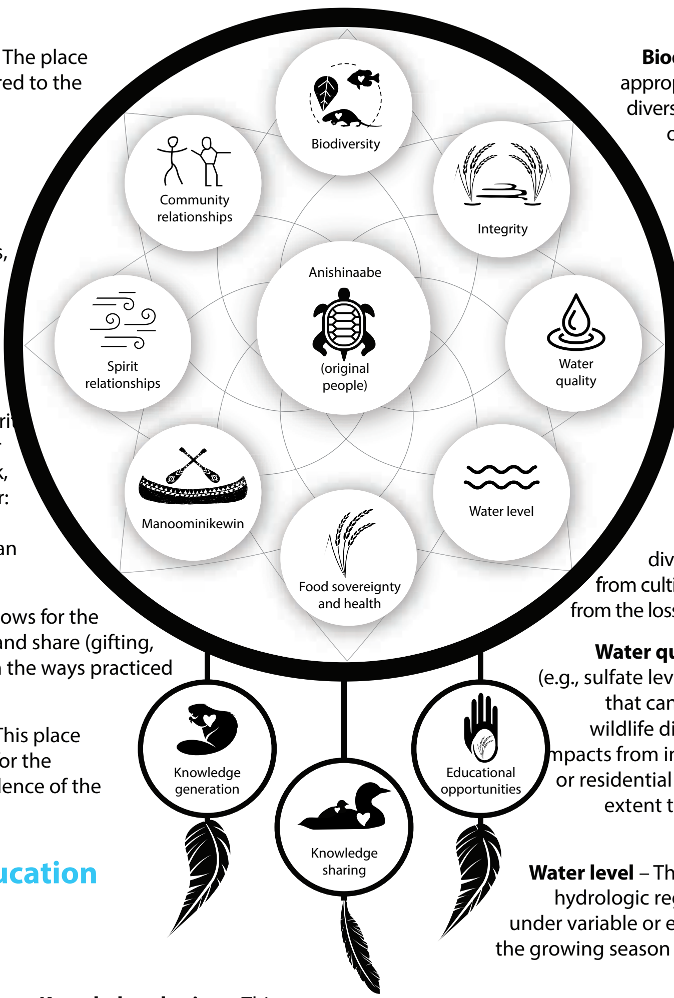
Anishinaabe (original people) – The place provides Manoomin, which is sacred to the Anishinaabe and central to the foundations of their culture, sovereignty, and treaty rights.

Community relationships – Manoomin at this place contributes to bonding, traditions, and strengthening family and community connections.

Spirit relationships – Manoomin at this place enables the Anishinaabe to maintain connections and balance with spirit beings (or relatives) from all other orders of creation (first order: rock, water, fire and wind; second order: other plant beings; third order: animal beings; fourth order: human beings).

Manoominikewin – This place allows for the Anishinaabe to harvest, prepare, and share (gifting, healing, and eating) Manoomin in the ways practiced by their ancestors for centuries.

Food sovereignty and health – This place provides the capacity to provide for the sustenance, health, and independence of the Anishinaabe.



Ecological Metrics

Biodiversity – Healthy Manoomin and appropriate habitat at this place supports diverse biological communities (e.g., free of invasive species) that indicate the capacity of the place to support abundant associated plant and animal species (e.g., other native aquatic vegetation, fish, waterfowl, muskrat), providing for spiritual and subsistence needs.

Integrity – Physical habitat and hydrology, and water and sediment chemistry support stands of Manoomin that exhibit natural annual variability; viable seed bank ensures that sustainable Manoomin populations will persist even after occasional poor production years. Natural genetic diversity is maintained without impact from cultivated strains, or reduced gene flow from the loss of nearby Manoomin populations.

Water quality – This place has clean water (e.g., sulfate levels below 10 ppm) and sediments that can support robust stand density and wildlife diversity; is free of contamination or impacts from industrial, agricultural, recreational, or residential influence; and is of sufficient areal extent to sustain a Manoomin population.

Water level – This place has a natural or managed hydrologic regime that can maximize resilience under variable or extreme climatic conditions across the growing season (maintaining optimal depth range and flow).

Cultural and Ecological Education Metrics

Knowledge generation – This place allows for continued learning and generation of the Anishinaabe practices, values, beliefs, and language through experience.

Knowledge sharing – This place allows for the continued sharing and transmittal of the Anishinaabe practices, values, beliefs, and language among family members and community.

Educational opportunities – This place provides opportunities for language, land stewardship, and other educational programs, such as educational rice camps.

Cultural and ecological characterization at Rice Bay

Rice Bay's Manoomin and its associated habitat were characterized over four time periods. Each metric was ranked using the following five-point descriptive scale: No use, Very bad, Not very good, Pretty good, Doing great

1900 to 1936: With a wooden dam

Based on the combined ranking of cultural and ecological metrics, Rice Bay was characterized as "doing great" during this period. In the early 1900s, Ketegitigaaning was inhabited and the community harvested Manoomin in Rice Bay for gifting, healing, and consumption. The area also boasted a rich biodiversity; and hunting, trapping, fishing, and gathering local resources were common.

1937 to 1990: With a concrete and steel dam

After the replacement of the wooden dam with a concrete and steel structure, Manoomin declined steadily until the mid-1950s to the point that it was no longer harvestable by community members. During this time period, community members moved away from the lake and into surrounding towns, and stopped harvesting Manoomin in Rice Bay. The "disappearance of Manoomin started the deterioration of the Lac Vieux Desert community," where bonding, traditions, and community connections ceased (Roger Labine, LVD Band, personal communication, November 12, 2019). There was a steady decline in cultural and ecological functionality provided by Manoomin from 1937 to the mid-1950s, when Rice Bay was characterized as "very bad" based on the combined ranking of cultural and ecological metrics.

1991 to 2012: With restoration actions

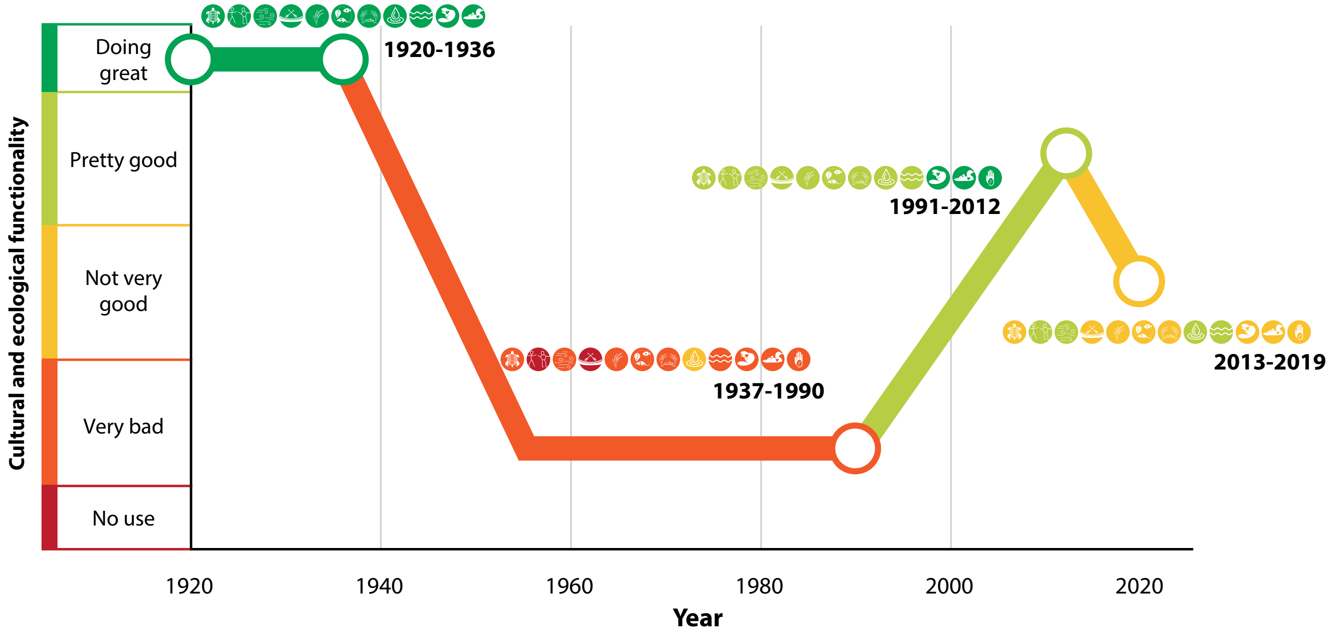
Once restoration actions began in the 1990s, cultural and ecological functionality provided by Manoomin improved. By 2008, the LVD Band opened Rice Bay for Manoomin harvest and began hosting rice camps in the area for the first time since 1940. Although the community began knowledge sharing, knowledge generation, and educational opportunities increased, it remained difficult to get many community members interested in Manoomin because of its absence over the last 50 years. Even so, restoration actions led to an increase in cultural and ecological functionality. By 2012, Rice Bay ranked as "pretty good" based on the combined ranking of cultural and ecological metrics.

2013 to 2019: With restoration actions and above-average precipitation

With heavy rainfall events negatively affecting Manoomin beds during the growing season, cultural and ecological functionality at Rice Bay have declined. Currently, Rice Bay is ranked as "not very good" based on the combined ranking of cultural and ecological metrics. The decrease in ecological and cultural functionality provided by Manoomin in recent years suggests the need for adaptive management of Manoomin. Actions taken that may have been successful in restoring Manoomin in the past may need to be adjusted to respond to additional threats, such as climate change, to be successful in the future.

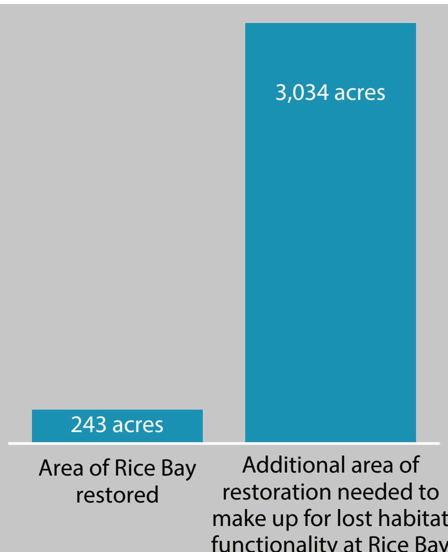
Cultural and ecological characterization at Rice Bay

Cultural and ecological functionality provided by Manoomin and its associated habitat at Rice Bay have changed over time, both in total and for individual metrics.



Additional Restoration Needed

Based on the characterization of the degree of cultural and ecological function over the four time periods, a Habitat Equivalency Analysis demonstrates the additional equivalent units of restoration needed to counter-balance the severity and timespan of degradation. Given the success of restoration at the 243-acre Rice Bay, 3,034 acres of similar Manoomin restoration is needed to counter-balance the lost habitat functionality that has occurred over time. In other words, 12 equivalent restoration efforts at Rice Bay (from 1991 to 2019) are needed to counter-balance the lost cultural and ecological habitat functionality (from 1937 to 1990).



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About this effort

This case study is part of the Lake Superior Manoomin Cultural and Ecosystem Characterization Study. The project was initiated by a team of Lake Superior Basin Anishinaabe communities, and federal and state agencies, with technical support from Abt Associates. This project aims to describe the importance of Manoomin to help foster community stewardship and education; and to inform Manoomin management, protection, and policy in the Lake Superior region and throughout the Great Lakes. Funding for this project was received via Great Lakes Restoration Initiative. For more information on the Initiative and Action Plan go to https://www.glri.us/.

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The Project Team would like to acknowledge Roger Labine (LVD) and Peter David (GLIFWC) for their valuable input and feedback in the development of this case study, and for participating in the cultural and ecological characterization of Lac Vieux Desert's Rice Bay.

Restoration of Perch Lake increases cultural and ecological services

Efforts by the Fond du Lac Band show some improvement in Manoomin coverage

Recent restoration efforts at Perch Lake, or Aatawemegokokaaning, have improved the cultural and ecological services of the lake's Manoomin (wild rice) and its associated habitat. However, given the significant historical losses, much more restoration is needed. Based on methods applied in this study, it would take an additional 5,204 acres of similar Manoomin restoration to counter-balance the lost cultural and ecological services that have occurred over time. This is equivalent in scale to 13 times the current restoration efforts at Perch Lake.

> **Although Manoomin coverage at Perch Lake has tremendously improved today, both the cultural and ecological balance are not where they were 150 years ago. For example, Canadian geese and swans were almost eliminated from Perch Lake, and are only now just coming back to the lake. The hardest part of restoration is getting that balance back.**
>
> *Nancy Schuldt, the Fond du Lac Band, January 3, 2020*

Credit: Lake Superior National Estuarine Research Reserve education intern Riley Oliver

Threats to Manoomin at Perch Lake

Historically, Perch Lake had abundant Manoomin habitat. In the early 1900s, many streams and wetland areas were ditched and drained to accommodate farming. After Perch Lake was ditched for agriculture around 1918 to 1921, the lake experienced a decline in Manoomin (Nancy Schuldt, personal communication, October 7, 2019).

To try to minimize the impacts of ditching, a concrete dam was installed at the lake outlet in 1936. The dam was managed to mimic the natural fluctuation of the water to benefit Manoomin. By the 1960s, the dam fell into disrepair and was non-functional. For the following several decades, lake levels were lower and stagnant, which allowed ginoozhegoons (pickerelweed) to displace Manoomin and become the dominant vegetation in the lake's rice waters (Fond du Lac Band, 2018, 2019).

About Perch Lake

Perch Lake is located on the Fond du Lac Band of Lake Superior Chippewa Reservation in Minnesota. It is an approximately 650-acre, double-basin lake. The shallow, southern portion of the lake is approximately 400 acres, and it is the largest Manoomin-containing habitat on the Reservation (Fond du Lac Band, 2008). The northern basin also supports some Manoomin along its fringes.

Perch Lake is an important traditional cultural property, used as a wild rice lake, a fisheries/spearing and netting site, and hunting grounds (Fond du Lac Band, 2018). Historical evidence suggests that Manoomin has been present at Perch Lake for over 2,000 years, with historical stands on approximately 392 acres (Fond du Lac Band, 2018).

Actions taken to improve the abundance of Manoomin at Perch Lake

In 1998, a new water control structure was built at the outlet of Perch Lake to manage water levels for Manoomin and improve hydrologic function throughout the watershed (Fond du Lac Band, 2018). In 2001, the Fond du Lac Band began intensive mechanical vegetation removal of ginoozhegoons, a native perennial species that occupies the same habitat as Manoomin and often outcompetes Manoomin (Fond du Lac Band, 2018). Using a sedge mat cutter and aquatic harvesters, the Fond du Lac Band removed ginoozhegoons vegetation at least twice yearly. This process led to high Manoomin density in restored areas initially. However, three to five years after each removal, ginoozhegoons became dominant again, which called for a rotating schedule for removing this competing plant.

In 2012, Perch Lake experienced a 500-year flood in mid-summer, and the Fond du Lac Band used the water control structure to keep water levels high and eliminate as much ginoozhegoons as possible. The following year, Manoomin stands were so thick that it was difficult to travel through the lake. Learning from the natural flood event, the Fond du Lac Band then developed a management strategy to bring lake levels to flood stage every four years to stress perennial species, such as ginoozhegoons, which compete with Manoomin for habitat. Although this strategy also limits Manoomin production in flood years, it provides Manoomin with a competitive advantage in the years following a flood stage year (Fond du Lac Band, 2018).

With water level management and mechanical removal of competitive vegetation, the Fond du Lac Band has successfully restored Manoomin to over 200 acres on Perch Lake (Fond du Lac Band, 2019).

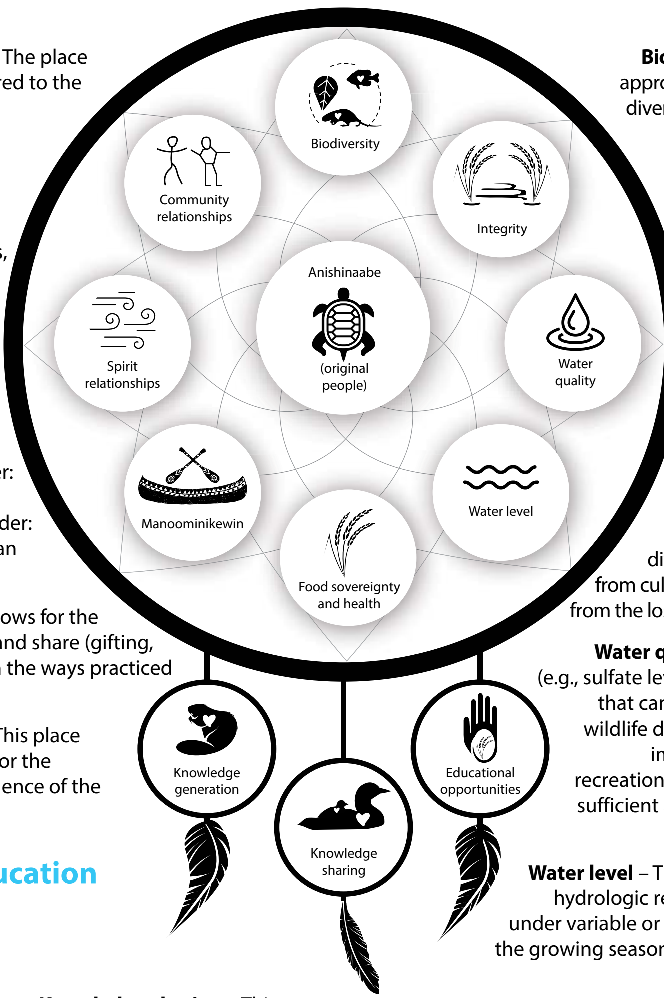
Sedge mat cutter. Credit: Fond du Lac Band, 2018.

Aquatic harvester. Credit: Fond du Lac Band, 2018.

Perch Lake. Credit: Lake Superior National Estuarine Research Reserve education intern Riley Oliver.

Approach to characterizing Manoomin at Perch Lake

Twelve metrics characterize the cultural and ecological functions of Perch Lake's Manoomin and its associated habitat. These metrics describe how Manoomin at Perch Lake contributes to maintaining connections with the Anishinaabe culture, how it supports ecological functionality and is resilient to changing conditions, and how it allows for continued learning and sharing of Anishinaabe values.



Cultural Metrics

Anishinaabe (original people) – The place provides Manoomin, which is sacred to the Anishinaabe and central to the foundations of their culture, sovereignty, and treaty rights.

Community relationships – Manoomin at this place contributes to bonding, traditions, and strengthening family and community connections.

Spirit relationships – Manoomin at this place enables the Anishinaabe to maintain connections and balance with spirit beings (or relatives) from all other orders of creation (first order: rock, water, fire and wind; second order: other plant beings; third order: animal beings; fourth order: human beings).

Manoominikewin – This place allows for the Anishinaabe to harvest, prepare, and share (gifting, healing, and eating) Manoomin in the ways practiced by their ancestors for centuries.

Food sovereignty and health – This place provides the capacity to provide for the sustenance, health, and independence of the Anishinaabe.

Ecological Metrics

Biodiversity – Healthy Manoomin and appropriate habitat at this place supports diverse biological communities (e.g., free of invasive species) that indicate the capacity of the place to support abundant associated plant and animal species (e.g., other native aquatic vegetation, fish, waterfowl, muskrat), providing for spiritual and subsistence needs.

Integrity – Physical habitat and hydrology, and water and sediment chemistry support stands of Manoomin that exhibit natural annual variability; viable seed bank ensures that sustainable Manoomin populations will persist even after occasional poor production years. Natural genetic diversity is maintained without impact from cultivated strains, or reduced gene flow from the loss of nearby Manoomin populations.

Water quality – This place has clean water (e.g., sulfate levels below 10 ppm) and sediments that can support robust stand density and wildlife diversity; is free of contamination or impacts from industrial, agricultural, recreational, or residential influence; and is of sufficient areal extent to sustain a Manoomin population.

Water level – This place has a natural or managed hydrologic regime that can maximize resilience under variable or extreme climatic conditions across the growing season (maintaining optimal depth range and flow).

Cultural and Ecological Education Metrics

Knowledge generation – This place allows for continued learning and generation of the Anishinaabe practices, values, beliefs, and language through experience.

Knowledge sharing – This place allows for the continued sharing and transmittal of the Anishinaabe practices, values, beliefs, and language among family members and community.

Educational opportunities – This place provides opportunities for language, land stewardship, and other educational programs, such as educational rice camps.

Cultural and ecological characterization at Perch Lake

Manoomin and its associated habitat at Perch Lake were characterized over four time periods. Each metric was ranked using the following five-point descriptive scale: No use, Very bad, Not very good, Pretty good, Doing great

1900 to 1920: Before agricultural ditching

Before it was ditched for agriculture, Perch Lake historically had abundant Manoomin stands. Fond du Lac resource managers estimate that nearly 60% of the lake had extensive Manoomin stands during this time, and it was harvested by the community. Based on the combined ranking of cultural and ecological metrics, Perch Lake was characterized as "doing great" during this first time period.

1921 to 1970: With agricultural ditching

After agricultural ditching of Perch Lake, Manoomin and its associated habitat declined abruptly. Lower and stagnant water levels allowed ginoozhegoons to become the dominant vegetation in the lake, displacing Manoomin, which resulted in a decline in use of the lake by waterfowl and other wildlife. Band members were unable to harvest Manoomin in the ways they did historically, which limited the generation and sharing of Anishinaabe practices, values, and beliefs. During this period of time, Perch Lake was characterized as "not very good" based on the combined ranking of cultural and ecological metrics.

1971 to 1997: Before the new water control structure and restoration actions

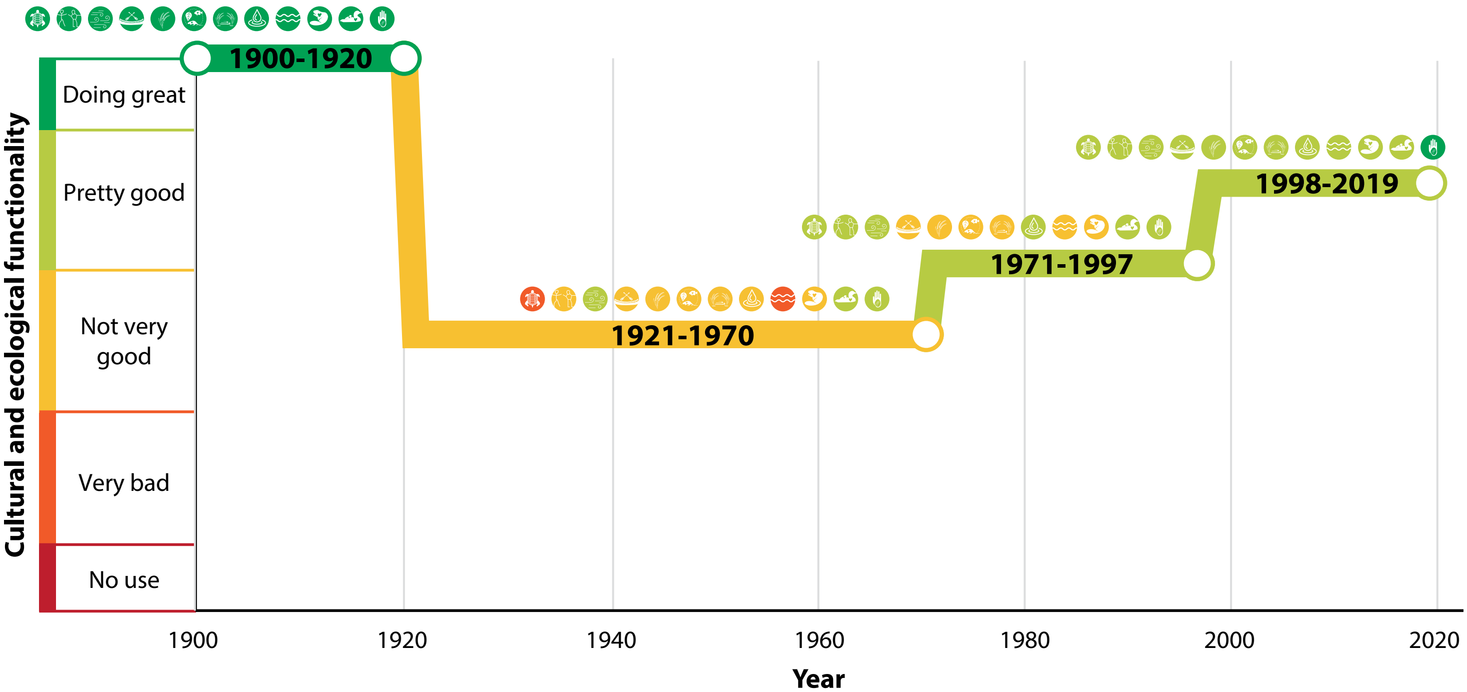
During this period, Perch Lake had a significant decline in Manoomin abundance and functionality; approximately 75% of the lake was covered with plant species that occupy the same habitat as and compete with Manoomin. Although Perch Lake's ecological and cultural functionality remained low, Band members continued to try to harvest at the lake; therefore, the lake provided some cultural services during this period. Many elders and wild rice chiefs believe Manoomin is a blessing and is seen as a golden age of their youth. For these reasons, Perch Lake ranked as "pretty good," which was slightly higher than the previous time period.

1998 to 2019: With the new water control structure and restoration actions

The water control structure built at the outlet of Perch Lake in 1998 helped restore the hydrologic conditions of the lake and improve Manoomin and its associated habitat. Active management of the lake started in 2001 and accelerated in 2012, which further restored hydrologic conditions of the lake and removed competing vegetation, all benefiting Manoomin. During this time period, the Fond du Lac Band was fairly successful at restoring Manoomin on Perch Lake. Manoomin covers over 200 acres of Perch Lake, which is about 30% of its historical coverage. Currently, Perch Lake is ranked as "pretty good" based on the combined ranking of cultural and ecological metrics.

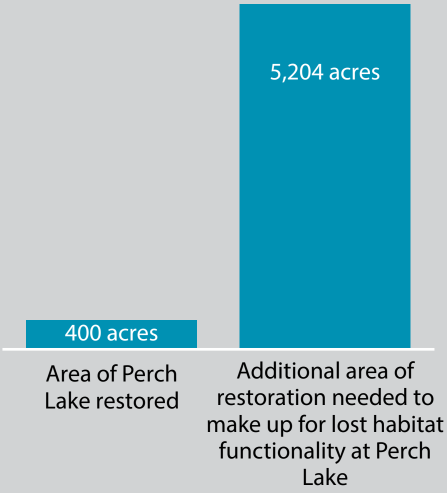
Cultural and ecological characterization at Perch Lake

The cultural and ecological functionality provided by the Manoomin and its associated habitat at Perch Lake varied over time, both in aggregate and for individual metrics.



Additional restoration needed

Using the characterization of Perch Lake over the four time periods, a habitat equivalency analysis demonstrates the additional equivalent units of restoration needed to counter-balance the severity and timespan of degradation. Given the success of restoration over the shallow, southern 400 acres of Perch Lake, approximately 5,204 acres of similar Manoomin restoration are needed to counter-balance the lost habitat functionality that has occurred over time. In other words, 13 equivalent restoration efforts at Perch Lake (from 1971 to 2019) are needed to counter-balance the lost cultural and ecological habitat functionality (from 1921 to 1970).



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About this effort

This case study is part of the Lake Superior Manoomin Cultural and Ecosystem Characterization Study. The project was initiated by a team of Lake Superior Basin Anishinaabe communities, and federal and state agencies, with technical support from Abt Associates. This project aims to describe the importance of Manoomin to help foster community stewardship and education; and to inform Manoomin management, protection, and policy in the Lake Superior region and throughout the Great Lakes. Funding for this project was received via Great Lakes Restoration Initiative. For more information on the Initiative and Action Plan go to https://www.glri.us/.

Acknowledgments

The Project Team would like to acknowledge Nancy Schuldt and Thomas Howes (Fond du Lac Band) for their valuable input and feedback in the development of this case study, and for participating in the cultural and ecological characterization of Perch Lake. We would also like to acknowledge the Fond du Lac Band elders and the wild rice chief who helped us characterize Perch Lake.

Restoration of Keweenaw Bay Indian Community's Sand Point Sloughs increases cultural and ecological functionality

Significant progress made but additional restoration could counter-balance losses

Recent restoration efforts on eight acres at Keweenaw Bay Indian Community's (KBIC's) Sand Point Sloughs have improved the cultural and ecological functionality of the sloughs' Gichi-manidoo gitigaan (The Great Spirit's Garden); however, given the significant historical losses, much more restoration is needed. Based on methods applied in this study, it would take an additional 175 acres of similar Manoomin (wild rice) restoration to counter-balance the lost cultural and ecological functionality that have occurred over time. This is equivalent in scale to 22 times the current restoration efforts at the sloughs. In addition, future restoration actions will need to be adaptive to respond to changing climate conditions.

Threats to Manoomin at Sand Point Sloughs

Connected to Lake Superior, Sand Point Sloughs is part of a dynamic coastal system. In the early 20th century, a copper ore processing plant, Mass Mill, operated on the west side of Keweenaw Bay on the south shore of Lake Superior. During the copper ore processing, approximately six billion pounds of mine tailings, locally known as stamp sands, were disposed into Keweenaw Bay. Lake currents continue to carry these tailings southward and redeposit them onto Sand Point, located just four miles south of the Mass Mill. Sand Point has an extensive beach area with approximately 2.5 miles of lake front and is connected to the sloughs. These tailings contain high concentrations of heavy metals that have the potential to cause environmental harm.

More recently, Sand Point Sloughs has been affected by regional hydrologic conditions – including higher water levels – that are occurring at a regional scale and are beyond local control. As a plant species sensitive to changes in water level, higher water levels have negatively affected the establishment and abundance of Manoomin in Sand Point Sloughs. The sloughs' connection to Lake Superior also opens the pathway to aquatic invasive species, such as carp and reed canary grass. Carp, for example, are bottom feeders that uproot Manoomin (Premo et al., 2014). Manoomin abundance may be impeded by competing native vegetation, such as ginoozhegoons (pickerelweed); and by excessive browsing by wildlife on new stands, such as waterfowl.

About Sand Point Sloughs

Sand Point Sloughs are relatively shallow backwater sloughs connected to Lake Superior that are culturally important to the KBIC. Native people used this area for hundreds of years, as indicated by the existence of ancient burial grounds and stories that have been passed on through oral tradition (KBIC, 2003). Manoomin is believed to have been present in Sand Point Sloughs prior to the 1900s (Ravindran et al., 2014). Today, the site contains the KBIC Pow Wow grounds, a traditional healing clinic, extensive wetlands, and Manoomin beds. A marina, campground, lighthouse, and recreational beaches signify the community's appreciation of this area.

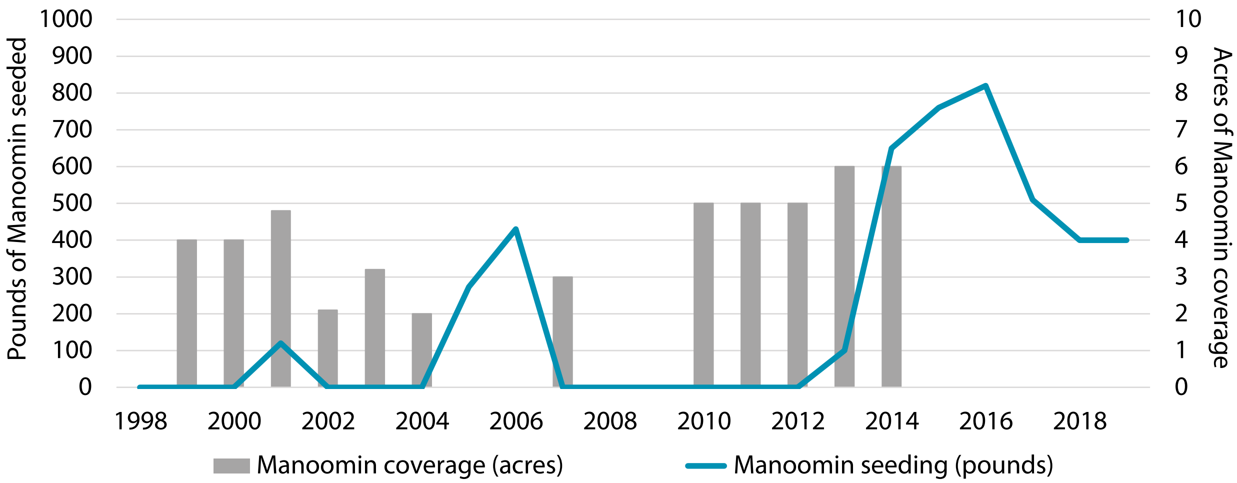
This area also holds ecological value as habitat. It provides for a number of species including medicinal plants, insects, fish, and other non-human relatives.

Actions taken to improve the abundance of Manoomin at Sand Point Sloughs

Sand Point Sloughs are a KBIC Tribal Trust property, wholly owned by KBIC and located entirely within KBIC L'Anse Reservation boundaries. KBIC took over management of the sloughs in the early 1990s, and shortly after began efforts to reintroduce Manoomin. Between 1991 and 1997, KBIC seeded nearly 1,800 pounds of Manoomin across 8 acres of Sand Point Sloughs. By 1999, Manoomin density was sufficient for KBIC to engage in the tradition of ricing. Between 1999 and 2002, community members harvested an estimated 60 to 150 pounds per year (Ravindran et al., 2014). Since 2013, KBIC has seeded annually at Sand Point Sloughs. KBIC continues to tend to this site in an effort to keep Manoomin teachings and traditions vital. However, since 2002, community members have not been able to harvest Manoomin at Sand Point Sloughs due to decreased abundance of Manoomin related to regional hydrologic conditions.

Floating wild rice. Credit: KBIC NRD

In addition to seeding efforts, KBIC and partners have undertaken remediation along the Sand Point shoreline, which was listed as a brownfield site. Remediation efforts included capping stamp sands to stabilize the tailings; planting native plants, trees, and shrubs to increase habitat for birds and other wildlife; and installing mounds and boulders to provide relief in the topography, reduce erosion, and protect valuable coastal wetlands, including Manoomin beds (Ravindran et al., 2014).



Manoomin seeding and acres of Manoomin coverage at the Sand Point Sloughs, 1999 to 2019 (data were not collected before 1999, and Manoomin coverage data were not recorded after 2014). Sources: Ravindran et al., 2014; Karena Schmidt, personal communication, October 31, 2019.

Approach to characterizing Manoomin at Sand Point Sloughs

Twelve metrics characterize the cultural and ecological functions of Sand Point Sloughs' Manoomin and its associated habitat. These metrics describe how Manoomin at the Sloughs contributes to maintaining connections with the Anishinaabe culture, how it supports ecological functionality and is resilient to changing conditions, and how it allows for continued learning and sharing of Anishinaabe values.

Cultural Metrics

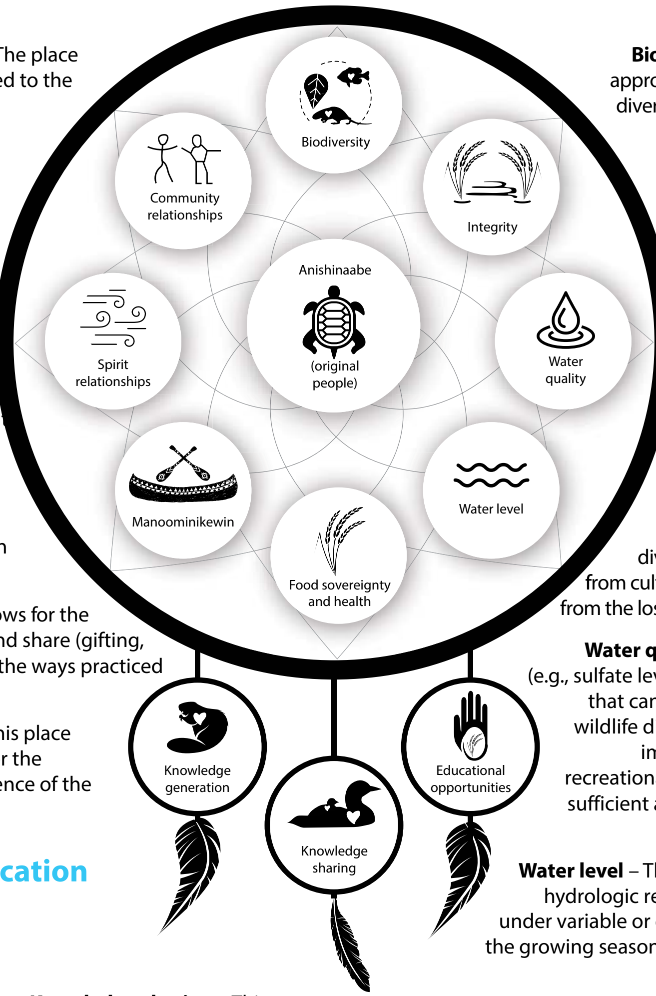
Anishinaabe (original people) – The place provides Manoomin, which is sacred to the Anishinaabe and central to the foundations of their culture, sovereignty, and treaty rights.

Community relationships – Manoomin at this place contributes to bonding, traditions, and strengthening family and community connections.

Spirit relationships – Manoomin at this place enables the Anishinaabe to maintain connections and balance with spirit beings (or relatives) from all other orders of creation (first order: rock, water, fire and wind; second order: other plant beings; third order: animal beings; fourth order: human beings).

Manoominikewin – This place allows for the Anishinaabe to harvest, prepare, and share (gifting, healing, and eating) Manoomin in the ways practiced by their ancestors for centuries.

Food sovereignty and health – This place provides the capacity to provide for the sustenance, health, and independence of the Anishinaabe.



Ecological Metrics

Biodiversity – Healthy Manoomin and appropriate habitat at this place supports diverse biological communities (e.g., free of invasive species) that indicate the capacity of the place to support abundant associated plant and animal species (e.g., other native aquatic vegetation, fish, waterfowl, muskrat), providing for spiritual and subsistence needs.

Integrity – Physical habitat and hydrology, and water and sediment chemistry support stands of Manoomin that exhibit natural annual variability; viable seed bank ensures that sustainable Manoomin populations will persist even after occasional poor production years. Natural genetic diversity is maintained without impact from cultivated strains, or reduced gene flow from the loss of nearby Manoomin populations.

Water quality – This place has clean water (e.g., sulfate levels below 10 ppm) and sediments that can support robust stand density and wildlife diversity; is free of contamination or impacts from industrial, agricultural, recreational, or residential influence; and is of sufficient areal extent to sustain a Manoomin population.

Water level – This place has a natural or managed hydrologic regime that can maximize resilience under variable or extreme climatic conditions across the growing season (maintaining optimal depth range and flow).

Cultural and Ecological Education Metrics

Knowledge generation – This place allows for continued learning and generation of the Anishinaabe practices, values, beliefs, and language through experience.

Knowledge sharing – This place allows for the continued sharing and transmittal of the Anishinaabe practices, values, beliefs, and language among family members and community.

Educational opportunities – This place provides opportunities for language, land stewardship, and other educational programs, such as educational rice camps.

Cultural and ecological characterization at Sand Point Sloughs

Sand Point Sloughs' Manoomin and its associated habitat were characterized over four time periods. Each metric was ranked using the following five-point descriptive scale: No use, Very bad, Not very good, Pretty good, Doing great

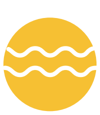
This characterization begins after the copper ore processing plant ceased operations around the 1920s.

1920 to 1990: Before KBIC ownership

Based on the combined ranking of cultural and ecological metrics, Sand Point Sloughs was characterized as "not very good" during this period. This ranking reflects the absence of Manoomin from the sloughs and the deposition of mine tailings onto Sand Point. Although Manoomin was absent, the sloughs were still a place of cultural and ecological importance: waterfowl and other wildlife foraged at the sloughs; and community members fished, hunted, and gathered there and held Pow Wows on the grounds. Given the intrinsic cultural and ecological values of the sloughs, some cultural metrics – including spirit relationships, knowledge sharing, and food sovereignty – were characterized with a higher ranking.

1991 to 1998: With active management of Manoomin

Once KBIC took over management of Sand Point Sloughs in the early 1990s and began seeding activities, Manoomin grew modestly. Although community members could not yet harvest Manoomin, the presence of Manoomin significantly improved the ranking of most cultural and ecological metrics. During this period, Sand Point Sloughs ranked as "pretty good" based on the combined ranking of cultural and ecological metrics.



For each of the four time periods, the water level metric was ranked as "not very good." Due to their location, the Sand Point Sloughs are influenced by regional factors such as Lake Superior water levels, which are beyond local control.

1999 to 2005: With active management and harvesting of Manoomin

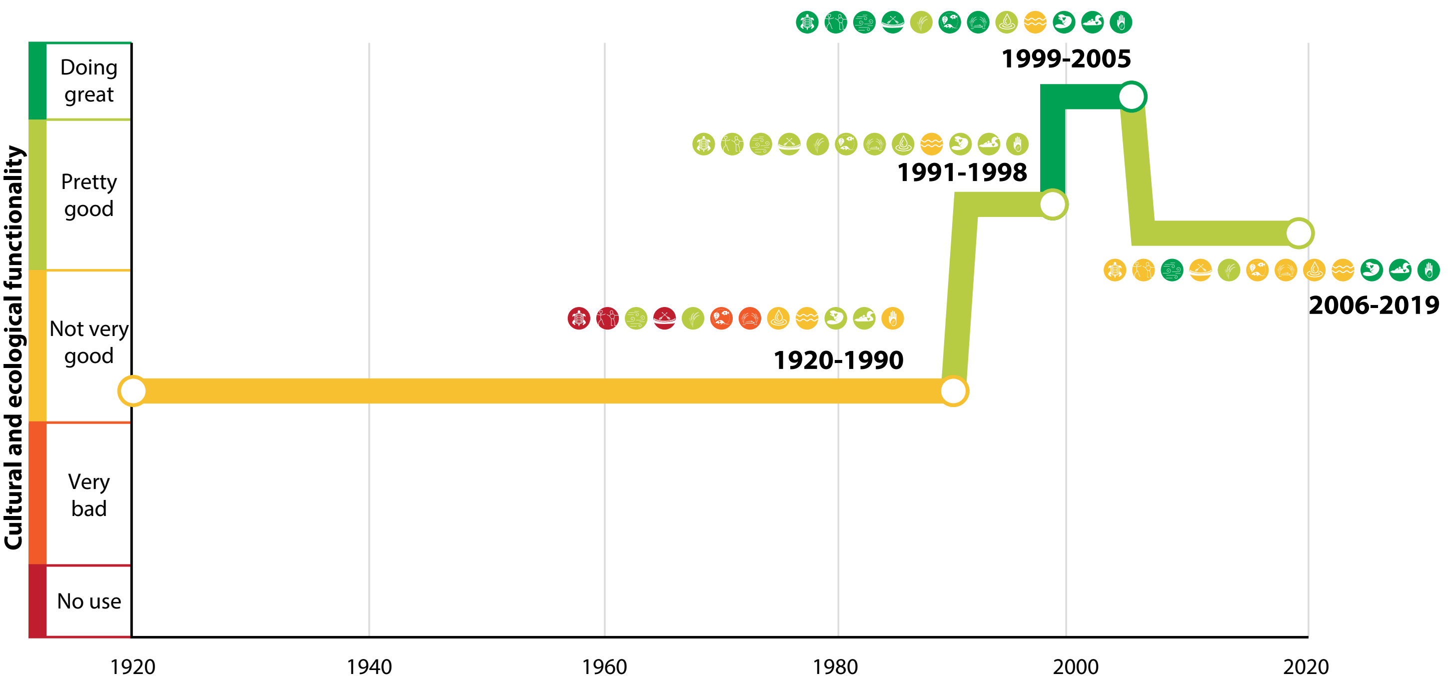
Once Manoomin was adequately established at Sand Point Sloughs, KBIC was able to open Sand Point Sloughs to their community members for harvesting. Harvesting allowed the recovery and sharing of Anishinaabe practices, values, beliefs, and language at the sloughs in ways that had not been practiced for years. During this period, Sand Point Sloughs ranked as "doing great" based on the combined ranking of improved cultural and ecological metrics.

2006 to 2019: With higher water levels

Sand Point Sloughs is connected to Lake Superior, and is affected by changes in the lake's water level and invasive and competitive species. Invasive species and competing vegetation that have been documented at Sand Point Sloughs may be impacting Manoomin abundance. Water levels have also fluctuated in Sand Point Sloughs, with lower water levels recorded in 2006 and 2007, and higher water levels in recent years (Ravindran et al., 2014). During this period, Sand Point Sloughs' functionality decreased to "pretty good" based on the combined ranking of cultural and ecological metrics. The decrease in ecological and cultural functionality provided by Manoomin in recent years suggests the need for adaptive management of Manoomin. Actions taken that may have been successful in restoring Manoomin in the past may need to be adjusted to respond to additional threats, such as climate change, to be successful in the future.

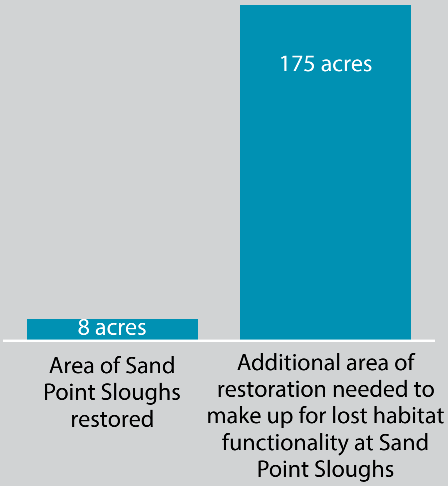
Cultural and ecological characterization at Sand Point Sloughs

The cultural and ecological functionality provided by the Manoomin and its associated habitat at Sand Point Sloughs varied over time, both in aggregate and for individual metrics.



Additional restoration needed

Based on the characterization of the degree of cultural and ecological function over the four time periods, a Habitat Equivalency Analysis demonstrates the additional equivalent units of restoration needed to counter-balance the severity and timespan of degradation. Given the success of restoration on 8 acres of Sand Point Sloughs, 175 acres of similar Manoomin restoration is needed to counter-balance the lost habitat functionality that has occurred over time. In other words, 22 equivalent restoration efforts at Sand Point Sloughs (from 1991 to 2019) are needed to counter-balance lost cultural and ecological habitat functionality (from 1920 to 1990).



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Acknowledgments

The Project Team would like to acknowledge Evelyn Ravindran, Karena Schmidt, and Erin Johnston (KBIC) for their valuable input and feedback in the development of this case study, and for participating in the cultural and ecological characterization of KBIC's Sand Point Sloughs.

Introduction of Manoomin at Net River Impoundment and Vermillac Lake provides cultural and ecological functionality

With favorable conditions, restoration can enhance Gichi-manidoo gitigaan

Tending to Gichi-manidoo gitigaan (The Great Spirit's Garden) through Manoomin (wild rice) seeding efforts at Net River Impoundment and Vermillac Lake has benefited natural resources at these locations. Seeding the Net River Impoundment also has the potential to create a Manoomin seed bank for other lakes in the area, including Vermillac Lake.

Efforts to introduce Manoomin in these waterbodies have shown preliminary success. Therefore, additional seeding could help counter-balance the lost ecological functionality and inspire cultural practices to occur at these locations. Based on methods applied in this study, it would take an additional 1,129 acres of similar Manoomin seeding to counter-balance the lost ecological functionality that have occurred over time, which is equivalent in scale to nearly 12 times the current restoration efforts at the Net River Impoundment and Vermillac Lake.

Credit: KBIC NRD.

Threats to Manoomin at Net River Impoundment and Vermillac Lake

Both the Net River Impoundment and Vermillac Lake possibly had Manoomin beds in the past. Many believe that historical trails around the Net River Impoundment indicate traditional use of these places for cultural practices (Evelyn Ravindran, KBIC personal communication, August 20, 2019). Land use changes have altered the local landscape, which may have contributed to the presence or absence of Manoomin at these places.

About Net River impoundment and Vermillac Lake

The Net River is nearly 15 miles long and flows from Baraga County to Iron County, Michigan. Impounded in 1990 as a wetland mitigation site to provide waterfowl benefits, the Net River Impoundment is now 35 acres in size. Vermillac (or Worm) Lake is a 423-acre lake in Baraga County. Both the Net River Impoundment and Vermillac Lake are located outside the L'Anse Indian Reservation, but within Ceded Territory.

Actions taken to improve Manoomin at Net River Impoundment and Vermillac Lake

KBIC is receiving more and more teachings from Manoomin and is working to understand which locations on the L'Anse Indian Reservation and within Ceded Territory have conditions that are conducive to grow and sustain Manoomin (BIA, 2019). KBIC is interested in having local sources of Manoomin as seed banks for future restoration activities; as well as places where community members can harvest, prepare, and gift Manoomin. KBIC is currently assessing suitable Manoomin habitat across their territory, and focusing restoration in lakes with the most favorable conditions for Manoomin.

In the early 2010s, KBIC worked with the Michigan Department of Natural Resources to identify additional areas for Manoomin restoration. The Net River Impoundment and Vermillac Lake were selected as lakes with potential for Manoomin beds, and KBIC seeded test plots at both lakes. Given their success, KBIC then seeded the Net River Impoundment and Vermillac Lake with nearly 2,000 pounds of Manoomin seed. Cultural teachings and practices related to Manoomin are beginning to occur at the Net River Impoundment. KBIC continues to seed 97 acres across both lakes with nearly 2,000 pounds of Manoomin each year.

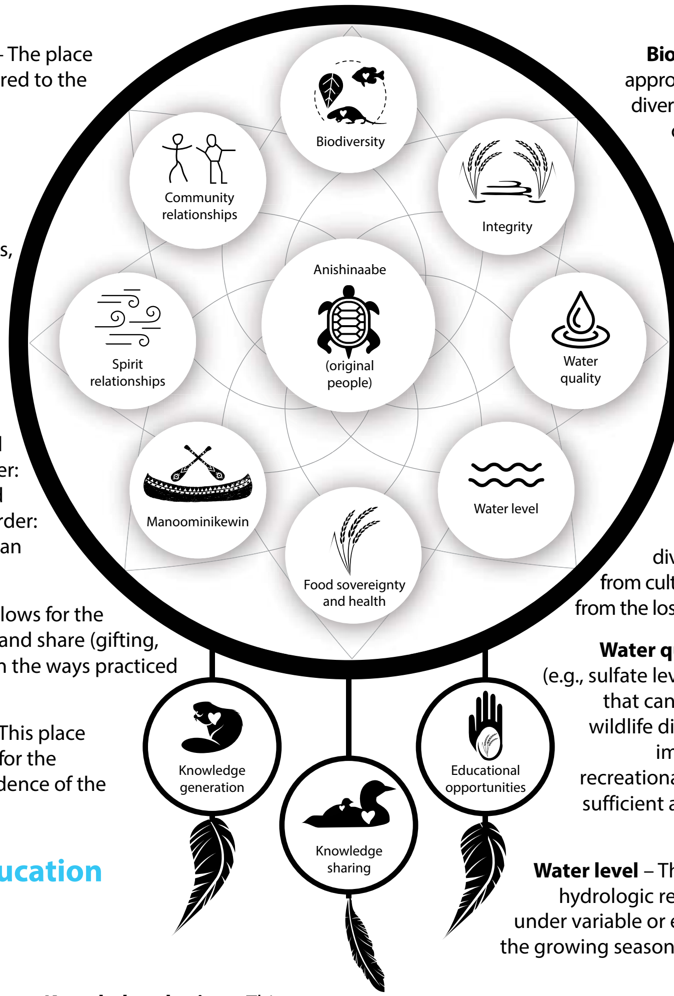
The ultimate goal of seeding efforts at the Net River Impoundment is to produce a Manoomin seed source for Vermillac Lake and other KBIC restoration sites. In keeping with the principles of the honorable harvest, KBIC aims to achieve conditions that will allow the rice to reseed itself to feed wildlife and nourish the people.

Survey point. Credit: KBIC NRD.

Rice stand. Credit: KBIC NRD.

Approach to characterizing Manoomin at Net River Impoundment and Vermillac Lake

Twelve metrics characterize the cultural and ecological functions of the Net River Impoundment's and Vermillac Lake's Manoomin and associated habitats. These metrics describe how Manoomin at these areas contributes to maintaining connections with the Anishinaabe culture, how ecological functionality is supported and resilient to changing conditions, and how continued learning and sharing of Anishinaabe values are promoted.



Cultural Metrics

Anishinaabe (original people) – The place provides Manoomin, which is sacred to the Anishinaabe and central to the foundations of their culture, sovereignty, and treaty rights.

Community relationships – Manoomin at this place contributes to bonding, traditions, and strengthening family and community connections.

Spirit relationships – Manoomin at this place enables the Anishinaabe to maintain connections and balance with spirit beings (or relatives) from all other orders of creation (first order: rock, water, fire and wind; second order: other plant beings; third order: animal beings; fourth order: human beings).

Manoominikewin – This place allows for the Anishinaabe to harvest, prepare, and share (gifting, healing, and eating) Manoomin in the ways practiced by their ancestors for centuries.

Food sovereignty and health – This place provides the capacity to provide for the sustenance, health, and independence of the Anishinaabe.

Ecological Metrics

Biodiversity – Healthy Manoomin and appropriate habitat at this place supports diverse biological communities (e.g., free of invasive species) that indicate the capacity of the place to support abundant associated plant and animal species (e.g., other native aquatic vegetation, fish, waterfowl, muskrat), providing for spiritual and subsistence needs.

Integrity – Physical habitat and hydrology, and water and sediment chemistry support stands of Manoomin that exhibit natural annual variability; viable seed bank ensures that sustainable Manoomin populations will persist even after occasional poor production years. Natural genetic diversity is maintained without impact from cultivated strains, or reduced gene flow from the loss of nearby Manoomin populations.

Water quality – This place has clean water (e.g., sulfate levels below 10 ppm) and sediments that can support robust stand density and wildlife diversity; is free of contamination or impacts from industrial, agricultural, recreational, or residential influence; and is of sufficient areal extent to sustain a Manoomin population.

Water level – This place has a natural or managed hydrologic regime that can maximize resilience under variable or extreme climatic conditions across the growing season (maintaining optimal depth range and flow).

Cultural and Ecological Education Metrics

Knowledge generation – This place allows for continued learning and generation of the Anishinaabe practices, values, beliefs, and language through experience.

Knowledge sharing – This place allows for the continued sharing and transmittal of the Anishinaabe practices, values, beliefs, and language among family members and community.

Educational opportunities – This place provides opportunities for language, land stewardship, and other educational programs, such as educational rice camps.

Cultural and ecological characterization at Net River Impoundment and Vermillac Lake

Manoomin and its associated habitat at the Net River Impoundment and Vermillac Lake were characterized over two time periods. Each metric was ranked using the following five-point descriptive scale:

No use, Very bad, Not very good, Pretty good, Doing great

This characterization begins after the Net River was impounded as a wetland mitigation bank in 1990.

1990 to 2013: Before Manoomin seeding

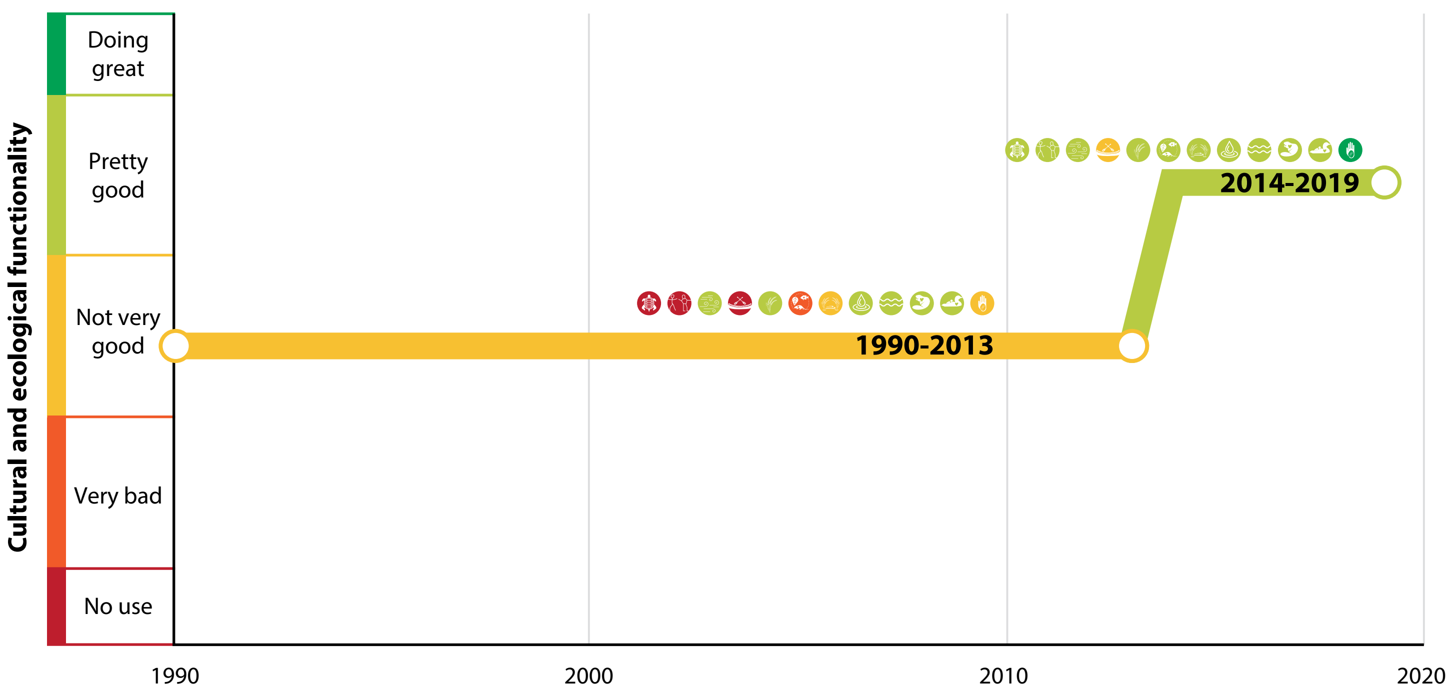
Based on the combined ranking of cultural and ecological metrics, conditions at the Net River Impoundment and Vermillac Lake were characterized as "not very good" during this period. This ranking reflects the absence of Manoomin from the Net River Impoundment and Vermillac Lake before 2013. Although Manoomin was absent, these areas were culturally and ecological important. Community members used these sites for gathering, fishing, and hunting activities; during these activities, families passed down knowledge to their children or grandchildren about traditional practices and resources. Given the intrinsic cultural and ecological value of these places, some metrics – including spirit relationships, food sovereignty, knowledge generation and sharing, and water level and quality – ranked higher in cultural and ecological characterization.

2014 to 2019: After Manoomin seeding

Once KBIC began seeding the Net River Impoundment and Vermillac Lake, Manoomin grew at these places. Currently, Manoomin supports wildlife and other ecosystem functions. These places have the potential for Manoomin harvesting in the future, although they cannot yet support it. The presence of Manoomin significantly improved the ranking of most of the cultural and ecological metrics. During this period, conditions at the Net River Impoundment and Vermillac Lake ranked as "pretty good" based on cultural and ecological metrics. Although Manoomin provides cultural and ecological functionality, additional management of water levels at the Net River Impoundment could continue to improve the abundance of Manoomin and the long-term sustainability of healthy Manoomin beds.

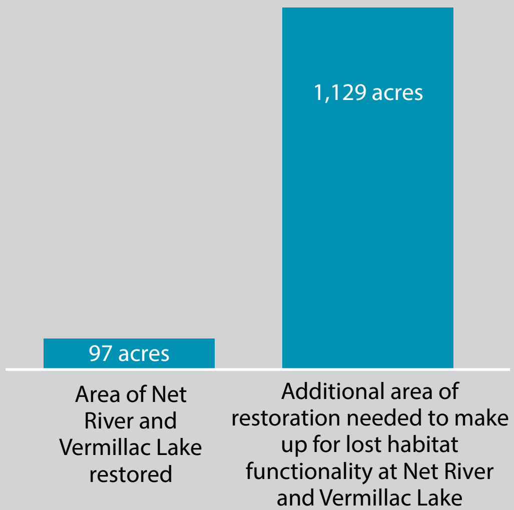
Cultural and ecological characterization at Net River Impoundment and Vermillac Lake

Cultural and ecological functionality provided by Manoomin and its associated habitat at the Net River Impoundment and Vermillac Lake have increased over time, both in aggregate and for the individual metrics.



Additional restoration needed

Based on the characterization of the degree of cultural and ecological function over the two time periods, a Habitat Equivalency Analysis can demonstrate the additional equivalent units of restoration needed to counter-balance the severity and timespan of degradation. With seeding, resource managers successfully established Manoomin across the Net River Impoundment and Vermillac Lake. However, given that the period of degradation is much larger (over 20 years) than the period of restoration (around 5 years), an additional 1,129 acres of similar Manoomin restoration is needed to counter-balance the lost habitat functionality that has occurred over time. In other words, nearly 12 equivalent restoration efforts at the Net River Impoundment and Vermillac Lake (from 2014 to 2019) are needed to counter-balance the lost cultural and ecological habitat functionality (from 1990 to 2013).



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About this effort

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Acknowledgments

The Project Team would like to acknowledge Evelyn Ravindran, Karena Schmidt, and Erin Johnston (KBIC) for their valuable input and feedback in the development of this case study; and for participating in the cultural and ecological characterization of KBIC's Net River Impoundment and Vermillac Lake.

Introduction of Manoomin at Hiles Millpond provides cultural and ecological functionality

With favorable conditions, restoration can enhance Manoomin habitat

Establishing Manoomin (wild rice) at Hiles Millpond significantly enhances its cultural and ecological functionality. It also helps to make up for the loss of Manoomin on other waters throughout the region. Although recent restoration efforts have shown preliminary success, Manoomin has been absent from Hiles Millpond for a long time. Therefore, additional restoration could help counter-balance lost cultural and ecological functionality. Based on the methods applied in this study, 864 additional acres of similar Manoomin restoration would counter-balance the lost cultural and ecological functionality that have occurred over time. This is equivalent in scale to nearly three times the current restoration efforts at Hiles Millpond. The successful introduction of Manoomin at Hiles Millpond suggests that naturally suitable soils, combined with seeding and modifications in water-level management, can yield high-quality Manoomin and habitat.

Threats to Manoomin at Hiles Millpond

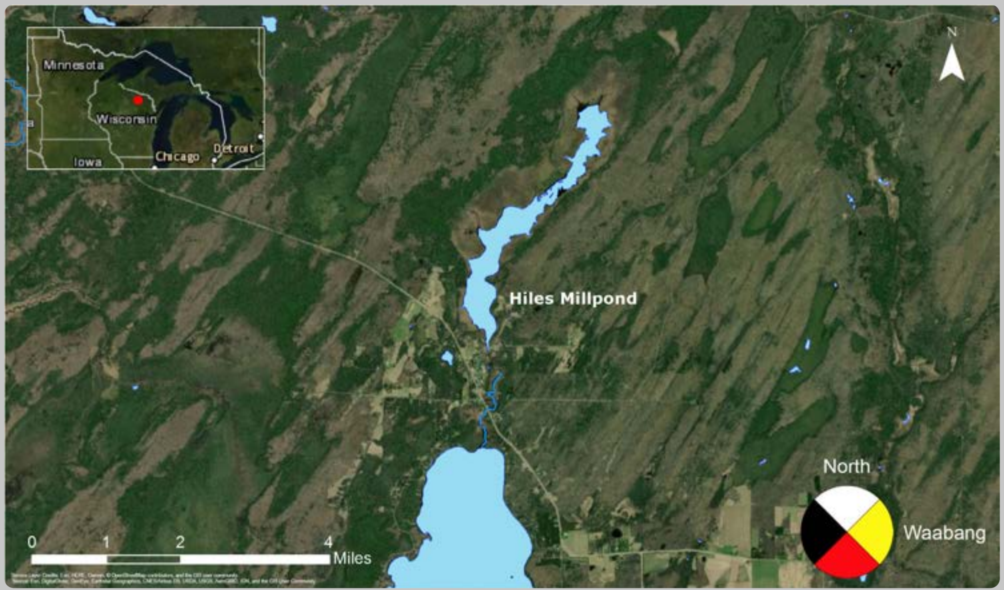
Water became ponded at Hiles Millpond in the late 1880s when the Hiles Lumber Company built a dam for logging purposes. Although there is no record of the presence of Manoomin at Hiles Millpond, it may have been there prior to dam construction since Manoomin is in nearby waters. If Manoomin was present at Hiles Millpond historically, it could have been negatively affected by changes in water levels associated with construction of the dam.

The area and waters around the Town of Hiles were traditionally used by the Lac du Flambeau Band of Lake Superior Chippewa Indians (LDF Band), the Sokaogon Chippewa Community, and other Ojibwe Bands and their ancestors. However, use of the area by Bands for hunting, gathering, fishing, and trapping was limited during much of the last century up until the 1980s. Use of this area increased after this time when relations with the local community in the Town of Hiles improved.

About Hiles Millpond

Hiles Millpond is an approximately 300-acre lake located in Forest County, Wisconsin, an 1842 Ceded Territory.

The millpond provides excellent wildlife habitat, especially for waterfowl, furbearers, eagles, and other wetland-dependent species. The lake also supports a northern pike and panfish fishery.



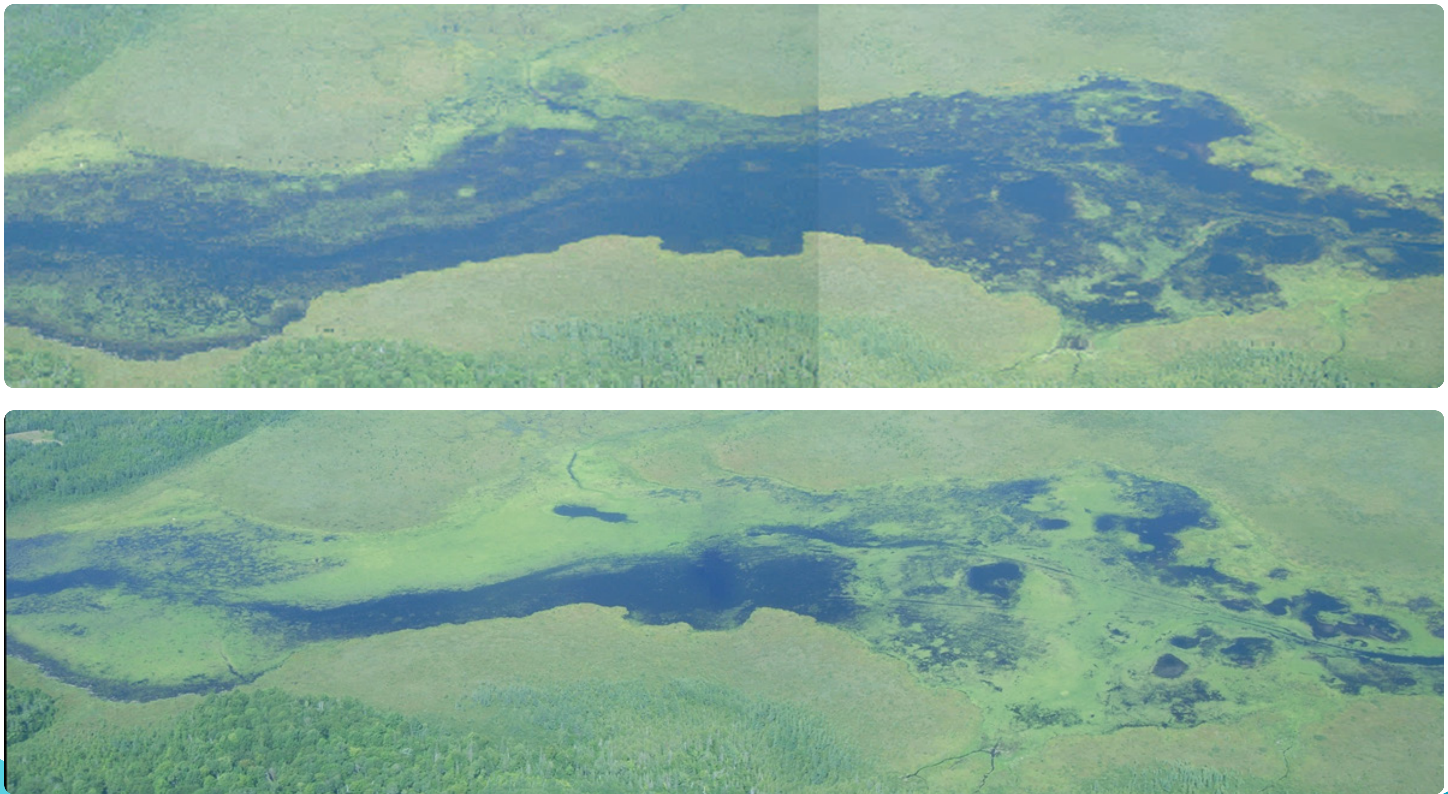
Actions taken to improve the abundance of Manoomin at the Hiles Millpond

In 1992, safety inspections found several problems with the dam structure at Hiles Millpond. To meet contemporary safety standards, the Town of Hiles needed to replace the dam structure. Since the town lacked adequate funds, federal, state, tribal, and nongovernmental organizations entered into a cooperative effort. A Memorandum of Understanding included a provision for the town to cooperate with the Forest Service to manage the millpond for productive wildlife and fish habitats, including possible manipulation of water levels, following completion of the project. The dam and water control structure were rebuilt in fall 1993.

Shortly after, biologists realized that the ecological benefits of Hiles Millpond could be significantly enhanced by establishing Manoomin on the millpond. Establishing Manoomin could also help to make up for the loss of Manoomin on other waters in the region, many of which were difficult or impossible to recover due to excessive development, conflicting uses, or other threats to Manoomin (Peter David, GLIFWC, personal communication, November 27, 2019).

In 1998, GLIFWC and the Forest Service cooperatively seeded the Hiles Millpond flowage with a relatively modest amount of Manoomin (329 pounds). Small patches of Manoomin then expanded modestly over the next several years. In 2011, Manoomin expanded significantly under natural drought conditions, which led biologists to believe that Manoomin might increase if the typical summer water level was lowered slightly.

Although the Town of Hiles was initially concerned that lower water levels might negatively affect the northern pike fishery, it ultimately agreed to manage the water level for Manoomin. Once lowered, Manoomin showed an immediate response. Manoomin abundance increased significantly from 2013, before water levels were lowered, to 2014, following a lowering of water levels. In recent years, over 125 acres of Manoomin can be found growing across the lake (Peter David, GLIFWC, personal communication, November 27, 2019).



Manoomin abundance on a portion of the Hiles Millpond, 2013 above, and 2014 below, following a lowering of water levels. Credit: Peter David, GLIFWC

Approach to characterizing Manoomin at Hiles Millpond

Twelve metrics characterize the cultural and ecological functions of Hiles Millpond Manoomin and its associated habitat. These metrics describe how Manoomin at Hiles Millpond contributes to maintaining connections with the Anishinaabe culture, how ecological functionality is supported and resilient to changing conditions, and how continued learning and sharing of Anishinaabe values are promoted.

Cultural Metrics

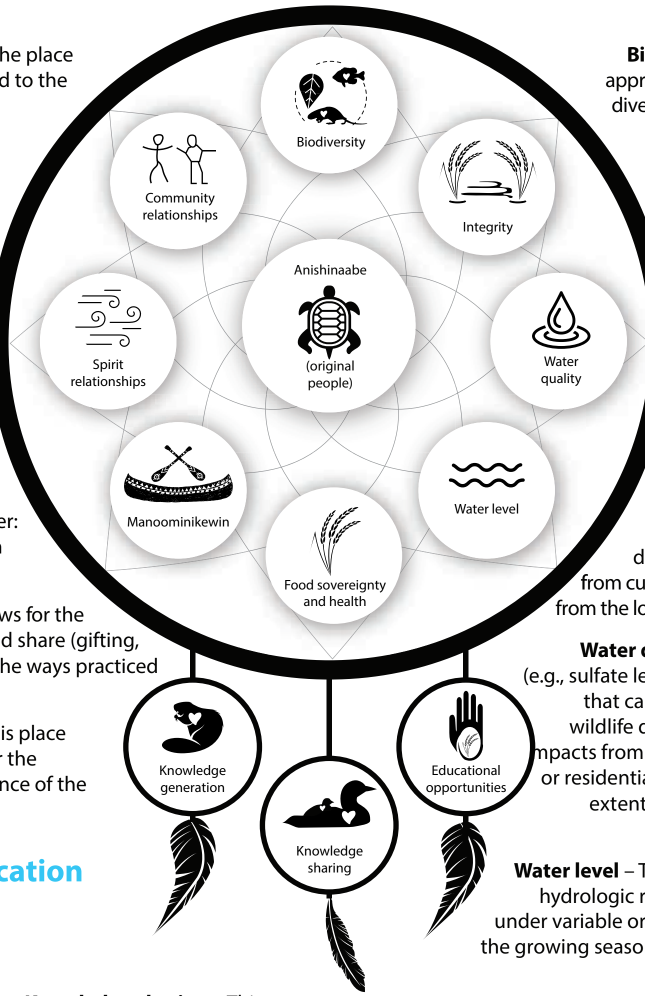
Anishinaabe (original people) – The place provides Manoomin, which is sacred to the Anishinaabe and central to the foundations of their culture, sovereignty, and treaty rights.

Community relationships – Manoomin at this place contributes to bonding, traditions, and strengthening family and community connections.

Spirit relationships – Manoomin at this place enables the Anishinaabe to maintain connections and balance with spirit beings (or relatives) from all other orders of creation (first order: rock, water, fire and wind; second order: other plant beings; third order: animal beings; fourth order: human beings).

Manoominikewin – This place allows for the Anishinaabe to harvest, prepare, and share (gifting, healing, and eating) Manoomin in the ways practiced by their ancestors for centuries.

Food sovereignty and health – This place provides the capacity to provide for the sustenance, health, and independence of the Anishinaabe.



Ecological Metrics

Biodiversity – Healthy Manoomin and appropriate habitat at this place supports diverse biological communities (e.g., free of invasive species) that indicate the capacity of the place to support abundant associated plant and animal species (e.g., other native aquatic vegetation, fish, waterfowl, muskrat), providing for spiritual and subsistence needs.

Integrity – Physical habitat and hydrology, and water and sediment chemistry support stands of Manoomin that exhibit natural annual variability; viable seed bank ensures that sustainable Manoomin populations will persist even after occasional poor production years. Natural genetic diversity is maintained without impact from cultivated strains, or reduced gene flow from the loss of nearby Manoomin populations.

Water quality – This place has clean water (e.g., sulfate levels below 10 ppm) and sediments that can support robust stand density and wildlife diversity; is free of contamination or impacts from industrial, agricultural, recreational, or residential influence; and is of sufficient areal extent to sustain a Manoomin population.

Water level – This place has a natural or managed hydrologic regime that can maximize resilience under variable or extreme climatic conditions across the growing season (maintaining optimal depth range and flow).

Cultural and Ecological Education Metrics

Knowledge generation – This place allows for continued learning and generation of the Anishinaabe practices, values, beliefs, and language through experience.

Knowledge sharing – This place allows for the continued sharing and transmittal of the Anishinaabe practices, values, beliefs, and language among family members and community.

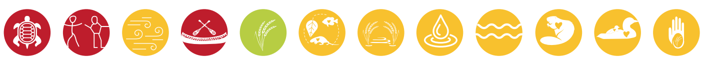
Educational opportunities – This place provides opportunities for language, land stewardship, and other educational programs, such as educational rice camps.

Cultural and ecological characterization at Hiles Millpond

Manoomin and its associated habitat at Hiles Millpond were characterized over three time periods. Each metric was ranked using the following five-point descriptive scale: No use, Very bad, Not very good, Pretty good, Doing great

The characterization starts in 1980 because prior to that time community members were less likely to travel to Hiles Millpond to harvest Manoomin, and undertake other traditional hunting and gathering practices.

1980 to 1997: Before Manoomin seeding



Based on the combined ranking of cultural and ecological metrics, Hiles Millpond was characterized as "very bad" during this period. Because of the absence of Manoomin in the millpond, most of the metrics – particularly cultural metrics – ranked low on the score range.

1998 to 2013: After Manoomin seeding

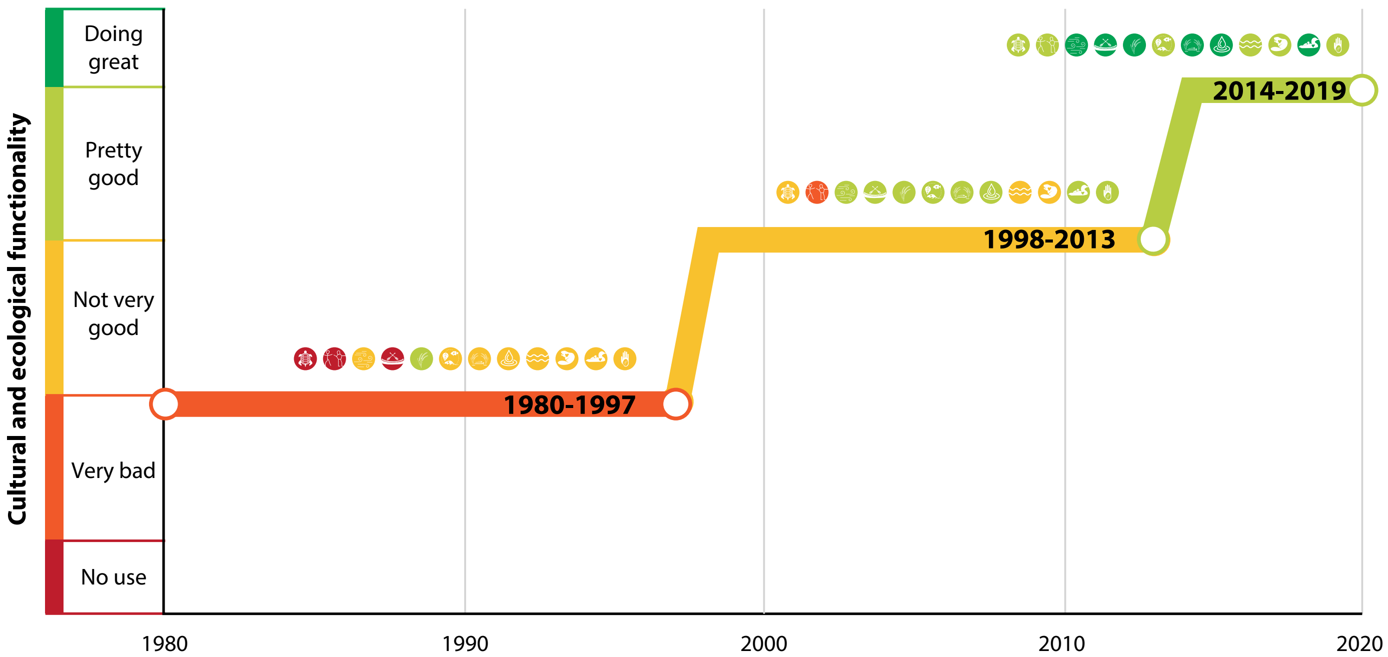
Once seeding activities began in 1998, Manoomin began to grow at the Millpond. The presence of Manoomin improved the rankings for most of the cultural and ecological metrics. In particular, the presence of Manoomin at Hiles Millpond allowed for some harvesting, preparation, and sharing of Manoomin by the community. It also improved the Anishinabee's connections and balance with spirit beings and relatives, and it supported diverse biological communities. During this period, Hiles Millpond ranked as "not very good" based on the combined ranking of the cultural and ecological metrics.

2014 to 2019: With water level management

After resource managers adjusted water levels for Manoomin in 2014, its coverage continued to expand. More Manoomin allowed for harvesting, preparation, and sharing of Manoomin in ways practiced by ancestors. It also allowed for knowledge generation and sharing of Anishinaabe practices, values, beliefs, and language. Although Manoomin provides many cultural and ecological functionality, additional management of water levels could continue to improve Manoomin and its associated habitat at Hiles Millpond. During this period, Hiles Millpond ranked as "pretty good" based on the combined ranking of cultural and ecological metrics.

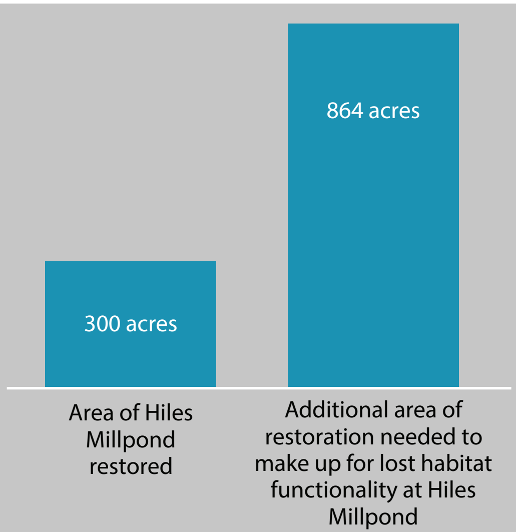
Cultural and ecological characterization at Hiles Millpond

Cultural and ecological functionality provided by Manoomin and its associated habitat at Hiles Millpond have increased over time, both in aggregate and for individual metrics.



Additional restoration needed

Based on the characterization of the degree of cultural and ecological function over the three time periods, a Habitat Equivalency Analysis demonstrates the additional equivalent units of restoration needed to counter-balance the severity and timespan of degradation. With modest seeding and slight modifications in water-level management, resource managers successfully established Manoomin across the Hiles Millpond. The analysis indicates that an additional 864 acres of similar Manoomin restoration is needed to counter-balance the lost habitat functionality that has occurred over time. In other words, nearly three equivalent restoration efforts at Hiles Millpond (from 1998 to 2019) are needed to counter-balance the lost cultural and ecological habitat functionality (from 1980 to 1997).



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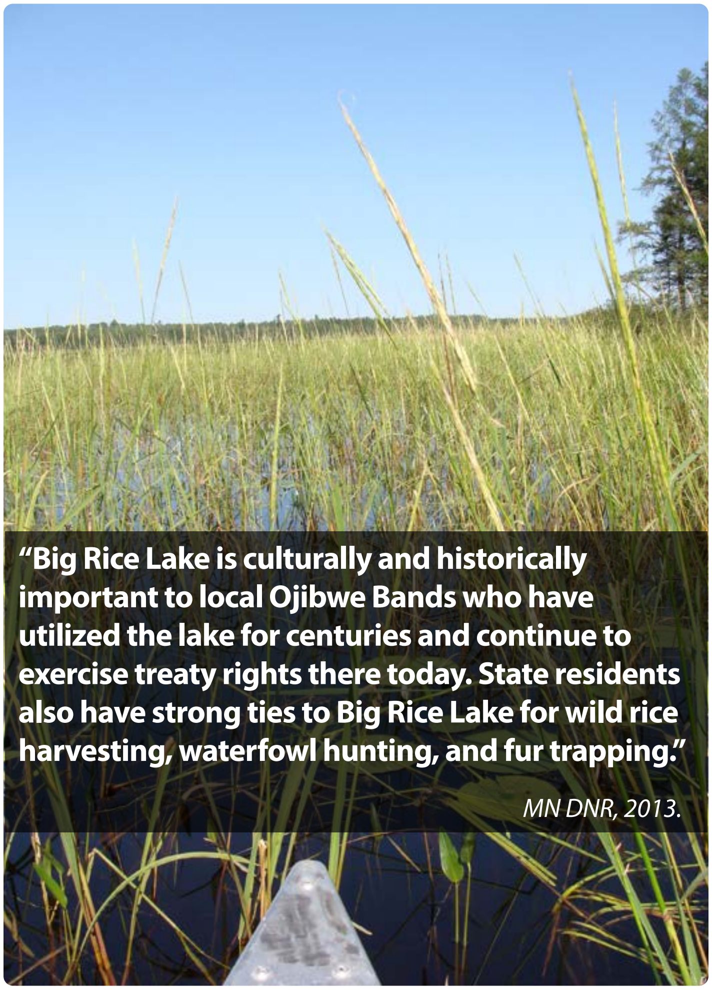
Acknowledgments

The Project Team would like to acknowledge Peter David (GLIFWC), Eric Chapman and Joe Graveen (LDF Band), and Peter McGeshick (Sokaogon Chippewa Community) for their valuable input and feedback in the development of this case study, and for participating in the cultural and ecological characterization of the Hiles Millpond.

Efforts to manage Big Rice Lake have not improved Manoomin functionality

Manoomin continues to be affected by hydrologic conditions and other threats

Historically, Big Rice Lake was one of the best-producing Manoomin (wild rice) lakes in northeastern Minnesota, and Manoomin on this lake provided cultural, ecological, and educational services to the Anishinaabe people. Over the last two decades, natural resource managers actively managed Big Rice Lake to improve conditions of Manoomin and its associated habitat. However, their actions – including water management, vegetation control, and beaver control – have been largely ineffective in recent years and Manoomin abundance continues to remain low. Manoomin and its habitat at Big Rice Lake have declined across all cultural and ecological metrics, and ginoozhegoons (pickerelweed) continues to outcompete Manoomin in parts of the lake. This case study highlights the difficulties in restoring degraded Manoomin and its associated habitat, and the importance of protecting it.



Credit: 1854 Treaty Authority.

Threats to Manoomin at Big Rice Lake

Hydrologic changes, impacts from competing vegetation, and perhaps climate change have threatened Manoomin at Big Rice Lake. Manoomin is very sensitive to changes in water levels. Low or stable water conditions over long periods can encourage the proliferation of other vegetation, such as ginoozhegoons (pickerelweed), which can outcompete Manoomin for space and resources. Ginoozhegoons has expanded considerably on Big Rice Lake, especially on the eastern half of the lake. In addition to the artificial controls on water levels, climate change could change precipitation patterns, which may increase both the likelihood of drought and the frequency of heavy rain events that can cause high water levels and flooding in Big Rice Lake.

About Big Rice Lake

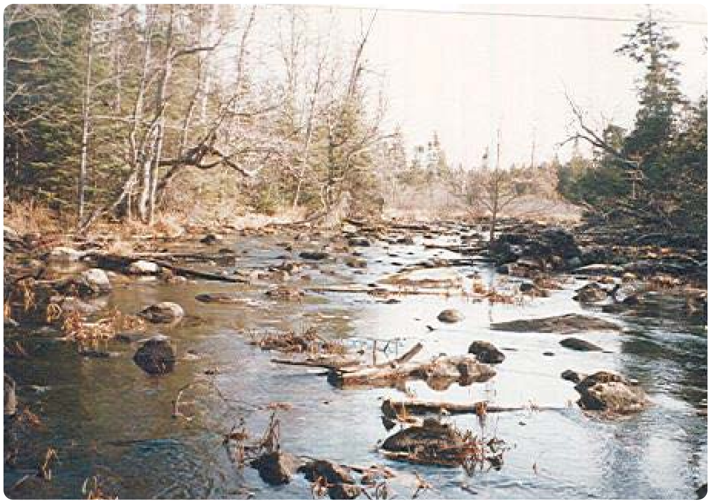
Big Rice Lake, located in St. Louis County in northeastern Minnesota, is approximately 1,870 acres. The area was traditionally used for ricing, sugar bush, and hunting activities; and archaeological evidence indicates human use on sites surrounding the lake for hundreds – perhaps thousands – of years.

The lake is an important feeding and resting area for migrating waterfowl. In years of good Manoomin production, mallards, goldeneyes, wood ducks, blue winged teal, and ring-necked ducks use the lake. In 1992, Big Rice Lake became a Designated Wildlife Lake because of its "outstanding value to wildlife." Currently, the lake supports a bald eagle nesting territory, as well as muskrats, minks, beaver, otter, great blue herons, and trumpeter swans.

Actions taken to improve the abundance of Manoomin at Big Rice Lake

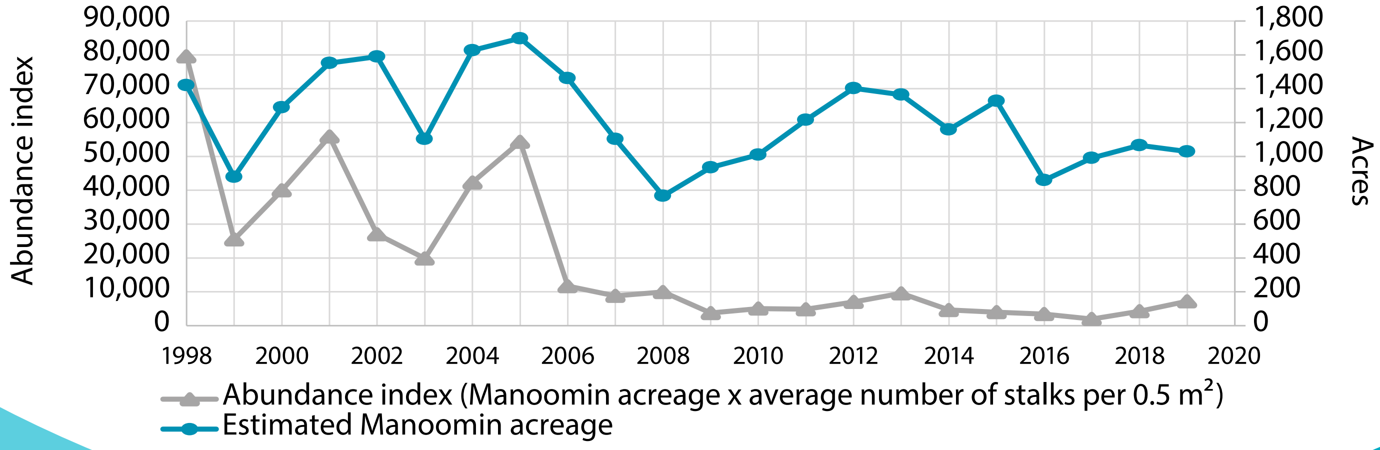
Natural resource managers have taken several actions to increase Manoomin at Big Rice Lake. In 1995, federal and state agencies built a rock weir at the outlet of the lake to increase the water flow out of the lake and reduce rapid water-level changes that can negatively impact Manoomin growth (MN DNR, 2013). Initially, the installation of the rock weir seemed to improve Manoomin coverage at Big Rice Lake; however, despite adjustments to the weir and varied beaver management, the more stable water level appears to have favored ginoozhegoons over Manoomin.

Since 2006, a cooperative effort of several federal, state, and tribal partners has taken additional management activities to further support Manoomin (Vogt, 2020). In addition to allowing water levels to vary naturally, natural resource managers are cutting ginoozhegoons. Natural resource managers use an airboat with chains to disturb the substrate of Big Rice Lake to encourage the germination of Manoomin seed in several test plots (Vogt, 2020). These efforts control about 100 acres of ginoozhegoons each year, but Manoomin regrowth in cut areas has been minimal (Vogt, 2020). Over the years, partners have also trapped beavers and removed beaver dams to control water levels.



Natural rock rapids at the outlet of Big Rice Lake in 1992.
Credit: MN DNR, 2019.

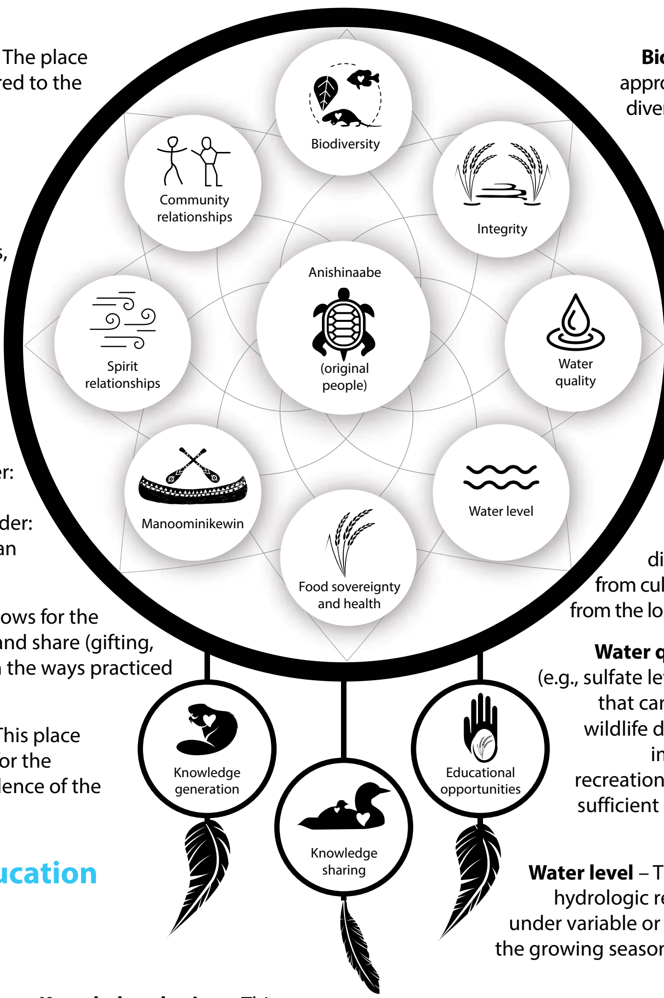
Rock weir at the outlet of Big Rice Lake in 2016.
Credit: MN DNR, 2019.



Manoomin abundance index and acres on Big Rice Lake.

Approach to characterizing Manoomin at Big Rice Lake

Twelve metrics characterize the cultural and ecological functions of Big Rice Lake's Manoomin and its associated habitat. These metrics describe how Manoomin at Big Rice Lake contributes to maintaining connections with the Anishinaabe culture, how ecological functionality is supported and resilient to changing conditions, and how continued learning and sharing of Anishinaabe values are promoted.



Cultural Metrics

Anishinaabe (original people) – The place provides Manoomin, which is sacred to the Anishinaabe and central to the foundations of their culture, sovereignty, and treaty rights.

Community relationships – Manoomin at this place contributes to bonding, traditions, and strengthening family and community connections.

Spirit relationships – Manoomin at this place enables the Anishinaabe to maintain connections and balance with spirit beings (or relatives) from all other orders of creation (first order: rock, water, fire and wind; second order: other plant beings; third order: animal beings; fourth order: human beings).

Manoominikewin – This place allows for the Anishinaabe to harvest, prepare, and share (gifting, healing, and eating) Manoomin in the ways practiced by their ancestors for centuries.

Food sovereignty and health – This place provides the capacity to provide for the sustenance, health, and independence of the Anishinaabe.

Ecological Metrics

Biodiversity – Healthy Manoomin and appropriate habitat at this place supports diverse biological communities (e.g., free of invasive species) that indicate the capacity of the place to support abundant associated plant and animal species (e.g., other native aquatic vegetation, fish, waterfowl, muskrat), providing for spiritual and subsistence needs.

Integrity – Physical habitat and hydrology, and water and sediment chemistry support stands of Manoomin that exhibit natural annual variability; viable seed bank ensures that sustainable Manoomin populations will persist even after occasional poor production years. Natural genetic diversity is maintained without impact from cultivated strains, or reduced gene flow from the loss of nearby Manoomin populations.

Water quality – This place has clean water (e.g., sulfate levels below 10 ppm) and sediments that can support robust stand density and wildlife diversity; is free of contamination or impacts from industrial, agricultural, recreational, or residential influence; and is of sufficient areal extent to sustain a Manoomin population.

Water level – This place has a natural or managed hydrologic regime that can maximize resilience under variable or extreme climatic conditions across the growing season (maintaining optimal depth range and flow).

Cultural and Ecological Education Metrics

Knowledge generation – This place allows for continued learning and generation of the Anishinaabe practices, values, beliefs, and language through experience.

Knowledge sharing – This place allows for the continued sharing and transmittal of the Anishinaabe practices, values, beliefs, and language among family members and community.

Educational opportunities – This place provides opportunities for language, land stewardship, and other educational programs, such as educational rice camps.

Cultural and ecological characterization at Big Rice Lake

Big Rice Lake's Manoomin and its associated habitat were characterized over three time periods. Each metric was ranked using the following five-point descriptive scale: No use, Very bad, Not very good, Pretty good, Doing great

1900 to 1994: Before rock weir construction

Based on the combined ranking of the cultural and ecological metrics, Big Rice Lake was characterized as "pretty good." During this period, Big Rice Lake was dominated by Manoomin with variable production across years, which provided high-quality waterfowl and wildlife habitats, and the opportunity for harvesting. The lake was culturally and historically important to Ojibwe Bands who used the lake during this period and exercised their treaty rights.

1995 to 2005: After rock weir construction

Immediately after the installation of the rock weir in 1995, Manoomin coverage at Big Rice Lake improved in some years. However, over time the more stable water level favored ginoozhegoons over Manoomin, and Manoomin began to decline, although it remained at the "pretty good" ranking score based on the combined ranking of cultural and ecological metrics.

Credit: 1854 Treaty Authority.

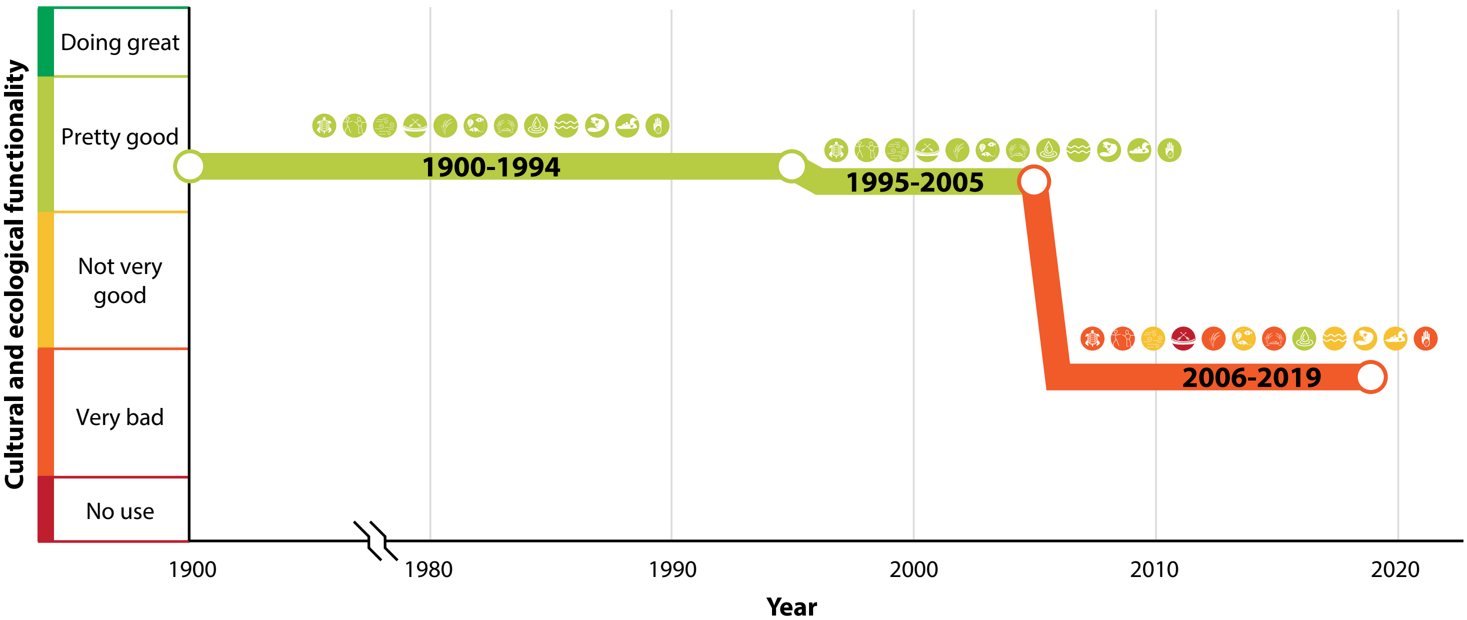
2006 to 2019: With active management of Manoomin

By 2006, Big Rice Lake ranked as "very bad" based on the combined ranking of cultural and ecological metrics. Hydrologic changes, competition from ginoozhegoons, and perhaps other unknown factors led to the dramatic decline of Manoomin. From 2006 to 2019, natural resource managers took active management steps to recover Manoomin at Big Rice Lake; however, it remained sparse in coverage, with only a few small, moderate-to-good density stands found on the lake. As a result, community members were unable to harvest, prepare, and share Manoomin in ways practiced by their ancestors. This also limited sharing, transmittal, and generation of Anishinaabe practices. The decline in Manoomin has also negatively affected migratory waterfowl that use the lake.

Credit: 1854 Treaty Authority.

Cultural and ecological characterization of Big Rice Lake

Cultural and ecological services provided by Manoomin and its associated habitat at Big Rice Lake decreased over time, both in total and for individual metrics.



Additional restoration needed

Since the 1990s, natural resource managers have tried to improve the conditions of Manoomin and its associated habitat at Big Rice Lake; however, recent actions have not been successful and conditions continue to be diminished.

Restoration funds have recently been awarded to undertake further actions at the lake (Helmberger, 2019). If these actions were to improve functionality, we could use a Habitat Equivalency Analysis (HEA) to demonstrate the additional equivalent units of restoration that would be needed to counter-balance the severity and timespan of degradation. For example, if actions were implemented over the next 20 years (2020 to 2040) to improve habitat functionality by 2.5%, we would need over 400,000 acres of similar Manoomin restoration to counter-balance the lost habitat functionality that has occurred over time (from 1995 to 2019). This is equivalent in size to over 200 Big Rice Lakes. The table to the right provides the HEA results, assuming several hypothetical scenarios of improvements in habitat functionality; it is important to note that we do not know what actions are needed to create these percent improvements. The main purpose of these scenarios is to highlight that if only minimal restoration is achieved at Big Rice Lake (which may be anticipated, given the long history of attempting restoration, with minimal response), then significant equivalent amounts of this restoration would be needed to balance the prolonged period of degradation at this lake.

Hypothetical percentage of improvement in habitat functionality from 2020 to 2040	**Acres needed to counter-balance historical losses given hypothetical improvement** *(Acres rounded to the nearest hundred)*	**Number of Big Rice Lakes needed to counter-balance historical losses given hypothetical improvement**
2.5%	426,100	228
5.0%	213,100	114
10.0%	106,500	57
20.0%	53,300	29

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Acknowledgments

The Project Team would like to acknowledge Darren Vogt (1854 Treaty Authority) and Nancy Schuldt (Fond du Lac Band of Lake Superior Chippewa) for their valuable input and feedback in the development of this case study. In addition, the Project Team would like to thank Thomas Howes (Fond du Lac Band of Lake Superior Chippewa), Tara Geshick (Bois Forte Band of Lake Superior Chippewa), Daniel Ryan (U.S. Forest Service), and Melissa Thompson and Tom Rusch (Minnesota Department of Natural Resources) for participating in the cultural and ecological characterization of Big Rice Lake.

Low ecological and cultural functionality characterized at the Twin Lakes

Manoomin is unable to rebound due to ongoing sulfate loading from mine discharges

Historically, Sandy Lake and Little Sandy Lake, also known as the Twin Lakes, were important ricing sites for Ojibwe Bands in northeastern Minnesota. Manoomin (wild rice) on these lakes provided cultural and ecological services to the Anishinaabe people. Since U.S. Steel constructed a tailings basin for their Minntac iron ore operation in the mid-1960s, Manoomin has declined drastically in these lakes, with only remnant plants and no stands existing today. While some restoration actions – including beaver dam management and small-scale Manoomin reseeding – have been attempted, they have not addressed the fundamental problem of sulfate discharge from the mine. A seepage collection system, constructed to collect mine waste water discharging from the tailings basin, has not fully stopped the flow of sulfate into the lakes. This case study highlights the difficulties in restoring degraded Manoomin habitat, the relationship between water pollution and Manoomin, and the importance of protecting existing Manoomin and its associated habitat.

Threats to Manoomin at the Twin Lakes

U.S. Steel's Minntac iron ore operation facility includes two mining areas, several processing plants, a heating and utility plant, a water reservoir, and a tailings basin (MWH, 2004). Construction of the tailings basin began in 1966 (MWH, 2004). Part of the seepage from the tailings basin discharges to the east into the Sand River, flows into the Twin Lakes, and into the Sand River watershed. Discharge from the tailings basin has changed the chemical composition and hydrologic condition of the Twin Lakes by increasing sulfate levels and, to a lesser extent, increasing the volume of water in the lakes.

Water seeping out of the Minntac tailings basin and moving toward the Twin Lakes in Minnesota. Credit: GLIFWC, 2016.

About the Twin Lakes

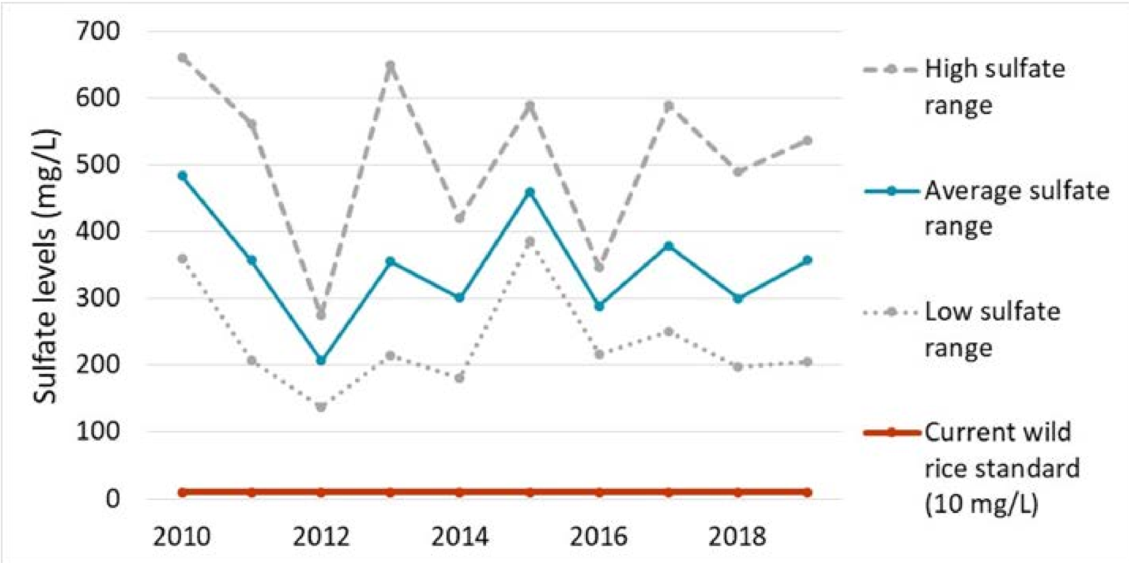
The Twin Lakes are located in St. Louis County in northeastern Minnesota. Sandy Lake is approximately 120 acres and Little Sandy Lake is approximately 90 acres. The Twin Lakes are located immediately downstream of the tailings basin for U.S. Steel's Minntac iron ore operation. Prior to mining operations, the Twin Lakes produced good stands of Manoomin and were important ricing sites for Ojibwe Bands and vital habitat for a range of wildlife species.

Ongoing sulfate loading renders restoration ineffective at the Twin Lakes

The Twin Lakes are severely degraded by sulfate-laden mine waste from U.S. Steel's tailings basin. Because sulfate concentrations are high, any attempts to restore Manoomin stands that do not address this fundamental issue have proven largely ineffective. For example, multiple attempts by natural resource managers to adjust water levels through beaver management (in the 1970s to 1990s and 2015 to 2018) have not improved Manoomin stands in a measurable way. Modest reseeding efforts (in 1991 and 1992) have also not been effective. Restoration efforts are not successful because sulfate levels at the Twin Lakes are at least 10 times higher than the Manoomin sulfate standard; the current sulfate standard is 10 mg/L (see graph below; Tribal Wild Rice Task Force, 2018).

In 2010, U.S. Steel was required to construct a seepage collection system to collect some of the mine wastewater discharging at the base of the tailings basin. While this reduced the total volume of water discharging from the mine site, it did not fully stop it. As a result, mine waste high in sulfate continued to contaminate the Twin Lakes after the collection system was installed. The 1854 Treaty Authority monitored lake conditions before the installation of the seepage collection system (2010) and after (2011 to 2019). Data collected included information on water quality (sulfate and other water quality indicators) and water-depth recordings; as well as data from inlet and outlet field surveys, vegetation surveys, and aerial surveys (Vogt, 2020). Results showed that sulfate levels remained elevated well above the standard over the nine years of monitoring after the installation of the seepage system, and remained substantially unchanged from conditions prior to the installation (see graph below).

During the monitoring study, very limited Manoomin stalks were also observed across the Twin Lakes. In 2015, U.S. Steel planted test plots to determine if Manoomin had the potential to grow in the Twin Lakes. In this small-scale test plot, U.S. Steel reseeded with 40 pounds of Manoomin. After seeding, Manoomin success has varied but has been limited across years (Vogt, 2020). Full-scale reseeding was not attempted.



Sulfate concentrations at the inlet to the Twin Lakes compared to current standard sulfate levels (10 mg/L) for Manoomin, 2010 to 2019.

Approach to characterizing Manoomin at the Twin Lakes

Twelve metrics characterize cultural and ecological functions of the Twin Lakes' Manoomin and its associated habitat. These metrics describe how Manoomin at the Twin Lakes contributes to maintaining connections with the Anishinaabe culture, how ecological functionality is supported and resilient to changing conditions, and how continued learning and sharing of Anishinaabe values are promoted.

Cultural Metrics

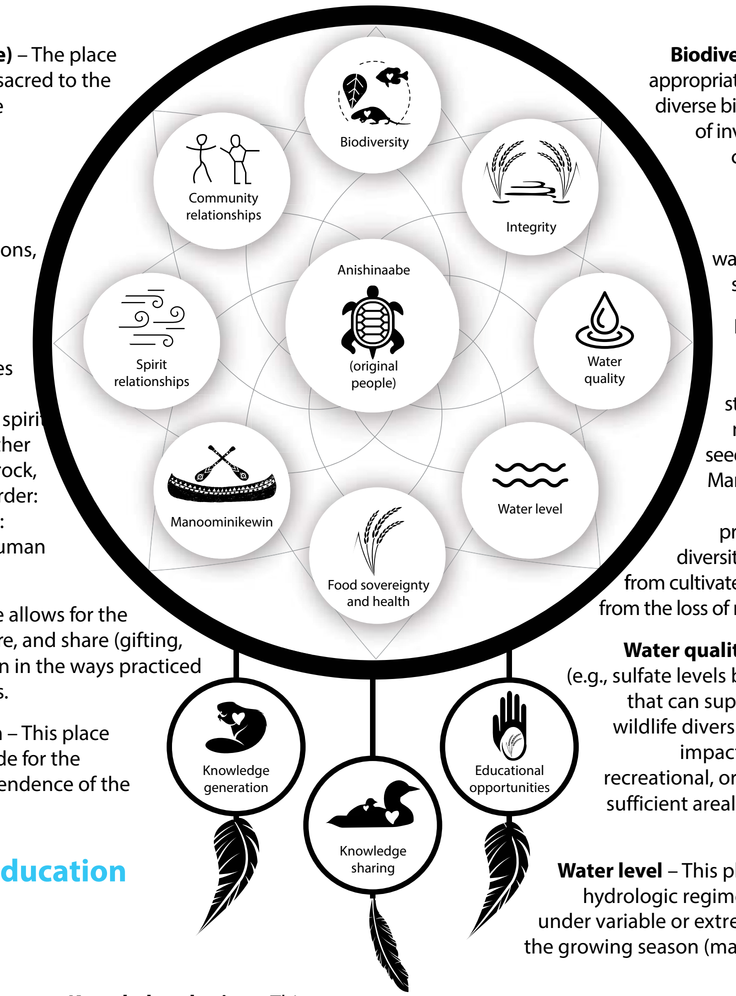
Anishinaabe (original people) – The place provides Manoomin, which is sacred to the Anishinaabe and central to the foundations of their culture, sovereignty, and treaty rights.

Community relationships – Manoomin at this place contributes to bonding, traditions, and strengthening family and community connections.

Spirit relationships – Manoomin at this place enables the Anishinaabe to maintain connections and balance with spirit beings (or relatives) from all other orders of creation (first order: rock, water, fire and wind; second order: other plant beings; third order: animal beings; fourth order: human beings).

Manoominikewin – This place allows for the Anishinaabe to harvest, prepare, and share (gifting, healing, and eating) Manoomin in the ways practiced by their ancestors for centuries.

Food sovereignty and health – This place provides the capacity to provide for the sustenance, health, and independence of the Anishinaabe.



Ecological Metrics

Biodiversity – Healthy Manoomin and appropriate habitat at this place supports diverse biological communities (e.g., free of invasive species) that indicate the capacity of the place to support abundant associated plant and animal species (e.g., other native aquatic vegetation, fish, waterfowl, muskrat), providing for spiritual and subsistence needs.

Integrity – Physical habitat and hydrology, and water and sediment chemistry support stands of Manoomin that exhibit natural annual variability; viable seed bank ensures that sustainable Manoomin populations will persist even after occasional poor production years. Natural genetic diversity is maintained without impact from cultivated strains, or reduced gene flow from the loss of nearby Manoomin populations.

Water quality – This place has clean water (e.g., sulfate levels below 10 ppm) and sediments that can support robust stand density and wildlife diversity; is free of contamination or impacts from industrial, agricultural, recreational, or residential influence; and is of sufficient areal extent to sustain a Manoomin population.

Water level – This place has a natural or managed hydrologic regime that can maximize resilience under variable or extreme climatic conditions across the growing season (maintaining optimal depth range and flow).

Cultural and Ecological Education Metrics

Knowledge generation – This place allows for continued learning and generation of the Anishinaabe practices, values, beliefs, and language through experience.

Knowledge sharing – This place allows for the continued sharing and transmittal of the Anishinaabe practices, values, beliefs, and language among family members and community.

Educational opportunities – This place provides opportunities for language, land stewardship, and other educational programs, such as educational rice camps.

Cultural and ecological characterization at the Twin Lakes

The Twin Lakes' Manoomin and its associated habitat were characterized over four time periods. Each metric was ranked using the following five-point descriptive scale: No use, Very bad, Not very good, Pretty good, Doing great

1950 to 1965: Before construction of the tailings basin

Based on the combined ranking of cultural and ecological metrics, conditions at the Twin Lakes were characterized as "doing great" during this period. Prior to the discharge of mine waste into the Twin Lakes, both lakes had moderately dense to dense stands of Manoomin. The Bois Forte Band of Chippewa, Grand Portage, and other community members historically harvested Manoomin in these lakes. In addition, Manoomin supported waterfowl (e.g., mallard, black ducks, green winged teal, wood ducks), fish such as northern pike, and other wildlife during this period (Minnesota Division of Game and Fish, 1966a, 1966b).

1966 to 1989: After construction of the tailings basin

After the discharge of mine waste started, Manoomin coverage in the Twin Lakes steadily declined. Compared to a 1966 vegetation survey of the Twin Lakes (Minnesota Division of Game and Fish, 1966a, 1966b), a 1987 survey found that Manoomin was essentially absent from both lakes, while water levels were considerably higher and water clarity increased dramatically (State of Minnesota, 1987). By 1989, the Twin Lakes ranked as "no use" based on the combined ranking of cultural and ecological metrics.

1990 to 2009: With limited restoration actions

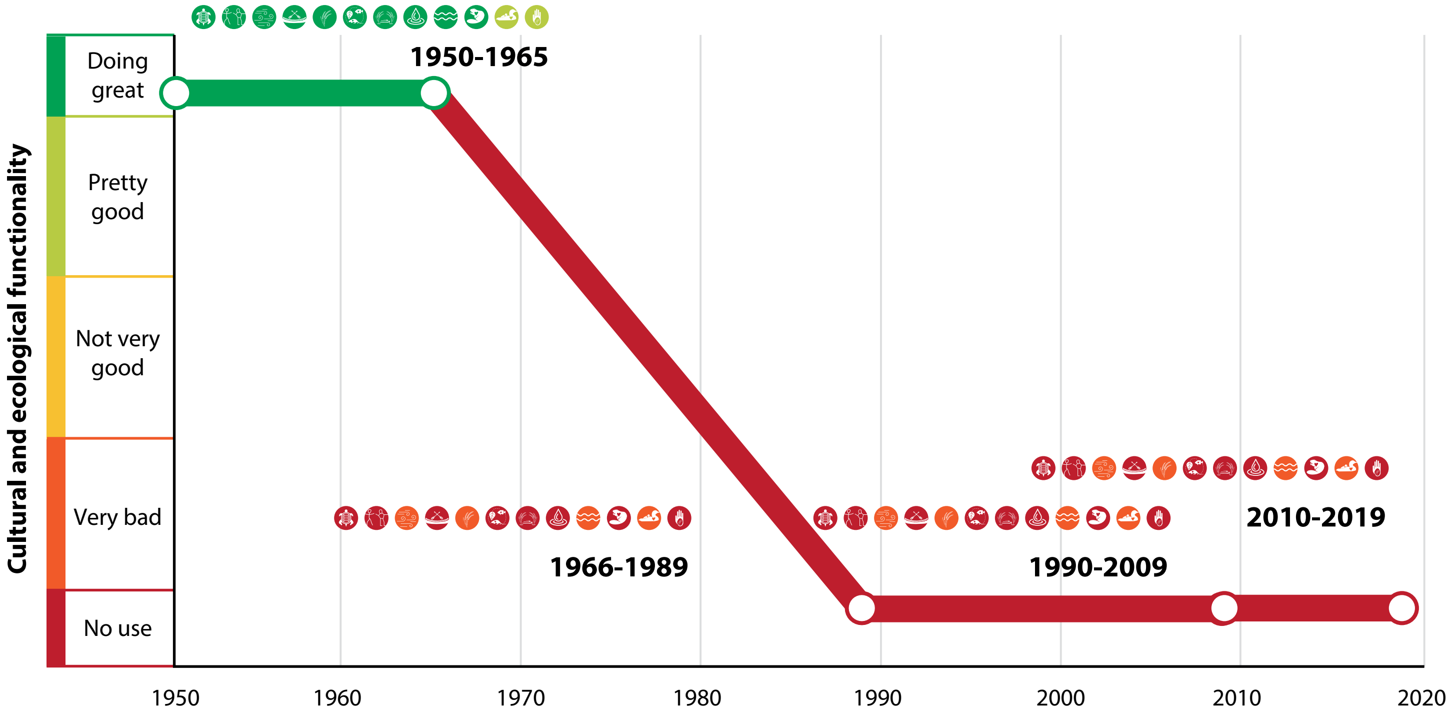
During this period, some actions were undertaken to recover Manoomin, including beaver management and small-scale reseeding efforts. However, these actions did not address the fundamental issue of high levels of sulfate and were largely ineffective at restoring the abundance of Manoomin and its associated habitat at the Twin Lakes. Given the absence of Manoomin on the lakes, community members were unable to harvest, prepare, and share Manoomin in ways practiced by their ancestors. The lost use of the Twin Lakes also limits sharing, transmittal, and generation of Anishinaabe practices at these lakes. During this period, the ranking of the Twin Lakes remained near "no use" based on the combined ranking of cultural and ecological metrics.

2010 to 2019: After construction of the seepage collection system

After U.S. Steel constructed the seepage system, Manoomin remained essentially absent from the Twin Lakes. With the lakes unable to support Manoomin, community members remained unable to harvest, prepare, and share Manoomin in ways practiced by their ancestors. During this period, the ranking of the Twin Lakes remained near "no use" based on the combined ranking of cultural and ecological metrics.

Cultural and ecological characterization of the Twin Lakes

Cultural and ecological functionality provided by Manoomin and its associated habitat at the Twin Lakes declined over time, both in aggregate and for the individual metrics.



Additional actions needed

Since the installation of a tailings basin for the U.S. Steel's Minntac facility in the mid-1960s, the abundance of Manoomin at the Twin Lakes has steadily declined. Actions taken at the Twin Lakes to improve Manoomin and its associated habitat have been limited and have not addressed the fundamental problem of sulfate loading from the mine. If actions were taken to improve conditions in the future, we could use a Habitat Equivalency Analysis (HEA) to demonstrate the additional equivalent units of restoration needed to counter-balance the severity and timespan of degradation. For example, if actions were implemented over the next 20 years (2020 to 2040) to improve habitat functionality by 2.5%, over 100,000 acres of similar Manoomin restoration would be needed to counter-balance the lost habitat functionality that has occurred over time (from 1966 to 2019). This is equivalent in size to over 550 Twin Lakes. The table to the right provides the HEA results, assuming several hypothetical scenarios of improvements in habitat functionality; it is important to note that we do not know what actions are needed to create these percent improvements, but they would likely require addressing the fundamental problem of sulfate loading from the mine. The main purpose of these scenarios is to highlight that if only minimal restoration is achieved at Twin Lakes (which may be anticipated, given the long history of attempting restoration, with minimal response), then significant equivalent amounts of this restoration would be needed to balance the prolonged period of degradation at these lakes.

Hypothetical percentage of improvement in habitat functionality from 2020 to 2040	**Acres needed to counter-balance historical losses given hypothetical improvement** *(Acres rounded to the nearest hundred)*	**Number of Twin Lakes needed to counter-balance historical losses given hypothetical improvement**
2.5%	116,700	556
5.0%	58,400	278
10.0%	29,200	139
20.0%	14,600	69

This case study demonstrates the difficulty in restoring Manoomin and its associated habitat when the root cause of the degradation – in this case, sulfate discharge – is not addressed. Given the difficulty of restoring degraded habitat, it is important to protect and preserve existing Manoomin habitat to ensure a future with Manoomin.

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About this effort

This case study is part of the Lake Superior Manoomin Cultural and Ecosystem Characterization Study. The project was initiated by a team of Lake Superior Basin Anishinaabe communities, and federal and state agencies, with technical support from Abt Associates. This project aims to describe the importance of Manoomin to help foster community stewardship and education; and to inform Manoomin stewardship, protection, and policy in the Lake Superior region and throughout the Great Lakes. Funding for this project was received via Great Lakes Restoration Initiative. For more information on the Initiative and Action Plan go to https://www.glri.us/.

Acknowledgments

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NOAA’s Office for Coastal Management

“Coastal management” is the term used by communities and organizations striving to keep the nation’s coasts safe from storms, rich in natural resources, and economically strong. The national lead for these efforts is NOAA’s Office for Coastal Management, an organization devoted to partnerships, science, and good policy. This agency, housed within the National Ocean Service, oversees major initiatives that include the National Coastal Zone Management Program, Coral Reef Conservation Program, Digital Coast, and National Estuarine Research Reserve System.

Minnesota Pollution Control Agency

Sampling and Analytical Methods for Wild Rice Waters

March 2018

Environmental Analysis and Outcomes Division

The analytical methods and sampling procedures provided in this document are incorporated by reference in Minn. R. pt. 7050.0224. They apply to the analysis and sampling of sediment for purposes of implementing the sulfate water quality standard applicable to wild rice waters.

Table of Contents

Background

The Minnesota Pollution Control Agency developed this procedure to ensure that samples taken for the purposes of calculating the numeric expression of the sulfate standard to protect wild rice (Minn. R. 7050.0224) are scientifically defensible and protective of the Class 4D wild rice use. The numeric expression of the sulfate standard is derived from the output of an equation that calculates a sulfate concentration necessary to maintain sulfide concentrations in sediment porewater less than or equal to 0.120 mg/L. The standard is derived using measured concentrations of total organic carbon (TOC) and total extractable iron (TEFe) in a sediment sample to calculate a protective sulfate concentration for each sediment sample. Due to natural processes, TOC and TEFe concentrations vary in the sediment of aquatic ecosystems, which means that the analysis of multiple sediment samples will produce a range of calculated sulfate concentrations that could serve as the numeric expression of the standard.

In order to protect the majority of wild rice habitat in a wild rice water, the numeric sulfate standard for a wild rice water is defined as the 20th percentile of at least 15 protective sulfate concentrations calculated from sediment samples randomly selected from the wild rice habitat. Sediment is only sampled from areas of wild rice habitat, since wild rice does not grow at all locations within a wild rice water.

This document establishes the methodology that must be used to collect sediment samples from wild rice habitat in wild rice waters, analyze the samples, apply the equation, and determine the numeric sulfate standard.

The terms used in this document have the following meanings.

- Wild rice water is the entire WID identifying a Class 4D wild rice water as shown in Minn. R. 7050.0471.
- Wild Rice Habitat (WRH) are the area(s) of the wild rice water that (1) support or have supported wild rice, or (2) are identified as likely to support wild rice. Once the referencing period has ended, WRH has been delineated, and sediment samples have been taken, the WRH areas defined for a wild rice water do not change. The MPCA will post on its website maps for each wild rice water that has had WRH delineated.
- Each Candidate Sample Site (CSS) is a point randomly selected from within the WRH, identified by its spatial coordinate. At least 100 CSS points must be identified for each wild rice water prior to obtaining sediment samples that will be analyzed for the determination of a numeric sulfate standard. Sediment samples must be taken from at least 15 of the candidate sample sites.
- Referencing period identifies the time within which desktop review and on-site reconnaissance occurs in preparation for the final delineation of WRH and sampling of sediment. The referencing period ends when the first complete set of sediment samples is collected.
- The numeric sulfate standard of a wild rice water is defined as the 20th percentile of the 15 or more protective calculated sulfate concentrations.

Section 1. Sediment sampling procedure for wild rice waters

A. Identifying wild rice habitat areas

Before sediments are sampled, WRH must be delineated within the wild rice water. The entire wild rice water (WID) must be evaluated to determine WRH. The process of identifying WRH in a wild rice water must be completed in two steps: (1) a desktop review of available information prior to any field reconnaissance, and (2) a pre-sampling field reconnaissance of the wild rice water. The intent of these two steps is to produce a map of WRH within the wild rice water. The map produced from this survey must be in a format that is compatible with performing a random selection of candidate sample sites as described in part B.

Delineation of Areas of Potential WRH

Step 1. Desktop review: On a map or aerial photograph of the wild rice water, outline the areas of potential WRH based on the following information:

- Areas where existing information identifies the past location of wild rice plants. Examples of acceptable information are annotated maps, documented plant surveys, sampling events, or historical records from which the areas containing wild rice plants can be determined.
- Areas where satellite or aerial photographs indicate the past presence of floating-leaved or emergent plants.

Step 2. Pre-sampling field reconnaissance:

After conducting the desktop review, the map of potential WRH must be compared to direct observation by conducting a field survey during the growing season of wild rice. This field survey must be done at a time when wild rice plants can be effectively identified; the best time period is when the growth of wild rice is at least at the tiller stage (July through September).

Areas identified as potential WRH in the desktop review must be examined in the field for evidence of wild rice plants. The survey must include visual observation of all areas of potential WRH. The wild rice water must also be surveyed for evidence of wild rice plants outside of the areas identified in the desktop review. Available information must also be gathered about possible phenomena that may have reduced that year's wild rice population, such as unusually high water levels. If the available information show a likelihood that the year's wild rice population has been significantly impacted by such phenomena, the referencing period must be extended by performing additional field reconnaissance in a following year.

Information on each area of potential WRH must be recorded, including which hierarchy level each site falls into, as described here:

Level 1 – Areas that Support or Have Supported Wild Rice

#1a. Areas where wild rice is observed growing or where there is evidence of recent growth, such as rooted wild rice plants that have been grazed, or wild rice plant residue from previous year's growth.

#1b. Areas that have supported wild rice in the past, as identified from evidence included in the desktop review.

Level 2 – Areas Likely to Support Wild Rice

#2a. Areas with either floating-leaved plants or emergent plants where water depth is less than 120 cm. Examples of floating-leaved or emergent plants whose presence approximates the conditions for wild rice growth are yellow or white waterlilies (*Nuphar variegata* and *Nymphaea odorata*), pondweeds (*Potamogeton* species), watershield (*Brasenia schreberi*), pickerelweed (*Pontederia cordata*), and arrowhead (*Sagittaria latifolia*). WRH does not include areas dominated by species that form dense monocultures that exclude wild rice, such as cattails

(*Typha* species), phragmites *(Phragmites australis*), purple loosestrife (*Lythrum salicaria*), and reed canary grass (*Phalaris arundinacea*).

#2b. Areas where water depth is between 30 and 120 cm.

Delineating Final WRH

If any Level 1 area is identified, then the entirety of the Level 1 areas (both 1a and 1b) represent the final WRH for that wild rice water. If no Level 1 area is identified, then any Level 2a areas are the WRH. If no Level 2a areas are identified, then the Level 2b areas are the WRH. The map of the final delineated WRH must be used to define at least 100 random candidate sample sites, as described below in Part B.

B. Selecting sediment core sample sites

All sediment sampling must occur within the delineated WRH. Using the map of the delineated WRH within the wild rice water, identify the randomly located 100 candidate sample sites as potential locations for sediment sampling. Each candidate sample site must be geo-referenced, specifying latitude and longitude to 5 decimal places.

The CSS sites may be identified by laying a grid over the WRH and randomly locating potential sites where the gridlines overlap, or through the use of geographic information system (GIS) software that randomly selects points within the WRH layer.

Once at least 100 points of the CSS are randomly established within the WRH, the CSS points must be tabulated and randomly numbered. Sort the sites by the random numbers and number them in order from 1 to 100.

The candidate sample sites must be selected in order as sites for the collection of sediment samples for analysis. At least the first 15 samples must be collected. Additional samples may be collected, moving sequentially through the random number list, to ensure that sufficient samples are available in case the analysis of some samples fail the QA/QC procedures specified in Sections 2 and 3 of this document. At least 15 pairs of acceptable total organic carbon (TOC) and total extractable iron (TEFe) concentrations must be available from laboratory analysis in order to calculate the numeric expression of the standard, as specified in part 4 of this document.

A map showing WRH and the sites selected for sampling must be submitted to the MPCA and placed on the website that houses information on the Class 4D wild rice waters.

C. Conducting Sediment Sampling

The selected sample locations may be visited in any order and at any time during the open water season. Sampling can take place the same year as the WRH was delineated, or at a later date. For instance, sediment can be collected early the following summer, before emergent wild rice becomes dense. Sampling before the wild rice population is dense has the potential advantage of allowing navigation across the wild rice water without damaging emergent plants.

A global positioning system (GPS) receiver must be used to locate the position of the site in the field, and accuracy of the receiver must be at least 3 meters. Sediment must be collected in a place with overlying water that is within 3 meters of the predetermined location.

At each of the selected sampling points, use the following methods to collect a sediment core sample:

1. Each sediment sample is the top 10 centimeters of a sediment core after the overlying water has been removed.
2. Place the sediment sample into a clean container that is clearly labeled with an identification number associated with the table of random numbers, water body, collection date, latitude, and longitude.
3. Store the samples on ice in the field and keep the samples at ≤ 6° C until delivered to an analytical lab for analysis.

D. Data Reporting

Document and report to the MPCA the following information about the sediment sampling:

1. Name and WID of the wild rice water
2. Name of person responsible for desktop review, and summary of findings.
3. Reconnaissance date and names of field crew.
4. Sediment sampling date(s) and names of field crew.
5. Description of coring device and diameter of coring tube.

6. The map or aerial photograph of the wild rice water, marked with the areas of wild rice habitat delineated in part A, steps 1 and 2, and the location of the final sample points determined in part B.
7. A table of the CSS that gives the latitude and longitude of at least the first 100 randomly selected sites and identifies the final sample sites;

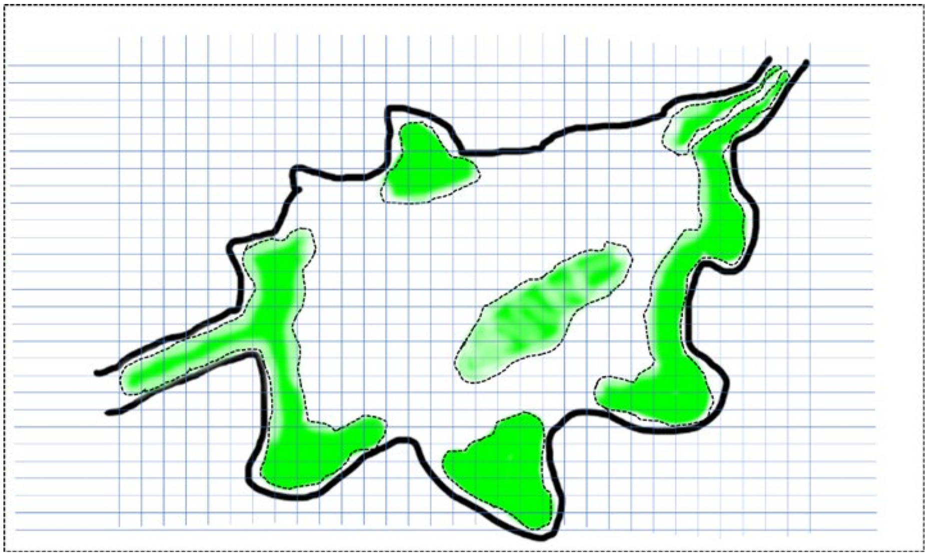

Figure 1. Example of grid overlay on a base map of a wild rice water with areas of wild rice habitat delineated. Potential sampling points are the grid intersections within areas of wild rice habitat. Alternatively, random sites within wild rice habitat can be randomly selected by GIS software.

Section 2. Analytical method for the determination of total extractable iron in sediment

This document describes the methods for the preparation and analysis of sediment samples for total extractable iron (TEFe) for analysis by Inductively Coupled Plasma-Atomic Emission Spectrometry Spectroscopy.

1. Prior to analysis, store the samples at ≤ 6° C to minimize biological activity. Samples must be analyzed within 180 days of collection date.
2. Dry and prepare the sample using either procedure 2a or 2b:

   2a.

   - Manually remove large materials such as rocks, shells, and sticks, and add a description of removed materials to the lab report.
   - Dry the sample in an oven at 50° C until constant weight is achieved.
   - Manually break the dried sample into pieces.
   - Pulverize the dry sample using a mill.

   2b.

   - Freeze-dry the sample.
   - Homogenize the sample using a stainless steel spatula.
   - Manually remove r~~emaining~~ large materials such as rocks, shells, and sticks, and add a description of removed materials to the lab report.

3. After the sample has been prepared, digest a small aliquot of the sample (0.25 +/- 0.02 grams) and all necessary QA/QC samples by adding 25 mL of 0.5 N hydrochloric acid to all digestion tubes. Digest samples (and all necessary QA/QC samples) on a hot block at 80-85° C or in a water bath at 80-85° C. Once samples reach 80° C, digest samples for 30 additional minutes. After 30 minutes, remove samples immediately and cool to room temperature, and bring to a constant volume. Immediately either centrifuge the tubes at 1000 rpm for 10 minutes or filter using a 0.45 µm PES-type filter. Remove an aliquot and dilute with reagent water to known volume for iron analysis. Determine iron in the diluted aliquot using Inductively Coupled Plasma-Atomic Emission Spectrometry. Report the results in mg/kg (dry weight).
4. Acceptable performance must be demonstrated on an ongoing basis. With every digestion batch, the laboratory must perform the following:

   - Low Background: At the beginning of each batch, analyze a blank (BLK) to determine reagent or laboratory contamination. The background level of the BLK must be below the report level before samples are analyzed.
   - Accuracy: With every batch of 20 samples processed as a group, analyze a Laboratory Control Sample (LCS). The LCS should be prepared at concentrations similar to those expected in the field samples and ideally at the same concentration used to prepare the matrix spike (MS). The acceptance criteria for recovery of the analyte in the LCS is 80 – 120%.

- Matrix spike. A MS must be prepared and analyzed with each batch of 20 samples processed as a group, or a minimum of 10% of the field samples analyzed, whichever is greater. The same solution used to fortify the LCS is used to fortify the MS. The acceptance criteria for recovery of the analyte in the MS is 80 – 120%.
- Precision: Analyze a Laboratory Duplicate (DUP) with each batch of field samples processed as a group, or 10% of the field samples analyzed, whichever is greater. The acceptance criteria for the relative percent difference (RPD) is ≤ 20%.

  RPD is a measure of precision, calculated as: RPD = (X1 – X2)/Xave x 100, where X1 and X2 are the concentrations of duplicates. Xave is the average of the two concentrations, calculated as: Xave = (X1 + X2)/2.

Section 3.Analytical method for the determination of total organic carbon in sediment

This document describes the methods for the preparation and analysis of sediment samples for the analysis of Total Organic Carbon (TOC) by Non-Dispersive Infrared Detection.

1. Prior to analysis, store the samples at ≤ 6° C to minimize biological activity. Samples must be analyzed within 28 days of collection date.
2. Dry and prepare the sample using either procedure 2a or 2b:

   2a.

   - Manually remove large materials such as rocks, shells, and sticks, and add a description of removed materials to the lab report.
   - Dry the sediment sample in an oven at 50° C until constant weight is achieved.
   - Manually break the dried sample into pieces.
   - Pulverize the remaining dry sediment using a mill.

   2b.

   - Freeze-dry the sample.
   - Homogenize the material using a stainless steel spatula,
   - Remove remaining large materials such as rocks, shells and sticks, and add a description of removed materials to the lab report .
3. After the sample has been prepared:

- Treat an aliquot of the homogenized sample with a 5% solution of H_3PO_4 to remove any inorganic carbon.
- Either air-dry or oven-dry (at 105°C) the sample until constant weight is achieved.
- Analyze the sample (and all necessary QA/QC samples) for Total Organic Carbon content using a Standard Operating Procedure based on EPA Method 9060A.
- Analyze all environmental samples in duplicate.
- Report the results in mg C/kg dry sediment, and as percent C in dry sediment.

4. Acceptable performance must be determined for every digestion batch by performing the following activities:
   - Low Background: At the beginning of each batch, analyze a blank (BLK) to determine reagent or laboratory contamination. The background level of the BLK must be below the report level before analyzing samples.
   - Accuracy: With every batch of 20 samples processed, analyze a Laboratory Control Sample (LCS). The LCS must prepared at the same concentrations as the field samples and at the same concentration used to prepare the matrix spike (MS). The acceptance criteria for recovery of the analyte in the LCS is 70 – 130%.

- Matrix spike: Prepare and analyze a MS with every 20 samples processed as a group, or a minimum of 10% of the field samples analyzed, whichever is greater. The same solution used to fortify the LCS is used to fortify the MS. The acceptance criteria for recovery of the analyte in the MS is 70 – 130%.

- Precision: Analyze a Laboratory Duplicate or a MS duplicate with every 20 samples processed as a group, or 10% of the field samples analyzed, whichever is greater. The acceptance criteria for the relative percent difference (RPD) is ≤ 30%.

  Analyze every environmental sample in duplicate. The RPD between duplicates must be ≤ 30%.

  RPD is a measure of precision, calculated as: RPD = (X1 – X2)/Xave x 100, where X1 and X2 are the concentrations of duplicates. Xave is the average of the two concentrations, calculated as: Xave = (X1 + X2)/2.

Section 4. Calculating the numeric sulfate standard using the equation.

A protective sulfate concentration (mg/L) is computed based on each sediment sample using the following equation:

$$MBLR120\ Sulfate = 0.0000854\ \times \frac{TEFe^{1.637}}{TOC^{1.041}}$$

If any sample has an organic carbon concentration that is lower than 0.20 percent carbon, then the concentration of 0.20 percent carbon must be substituted for the lower concentration. If any sample has an iron concentration greater than 83,421 micrograms/gram, then the concentration of 83,421 micrograms/gram must be substituted for the higher concentration.

The numeric expression of the sulfate standard is the 20th percentile of all calculated sulfate concentrations resulting from the application of the equation to each pair of organic carbon and iron concentrations (including any substituted concentrations).

There are several different ways to calculate percentiles; for this purpose, 20th percentile can be calculated through the use of the Microsoft Excel function PERCENTILE.INC, or through the following procedure:

1. Sort all calculated sulfate concentrations, ranked from low to high (e.g., 1st, 2nd, 3rd, 4th, etc.).
2. Calculate values for x and y in the following expression: x.y=0.2(N-1)+1 (N is the total number of calculated sulfate concentrations; if there are 15 samples, x.y = 3.8).
3. Calculate the 20th percentile as xth sulfate concentration plus [0.y times (value of xth+1 sulfate concentration minus the value of xth sulfate concentration)]. For instance, if there were 15 samples, the 20th percentile sulfate concentration would be:

   [value of 3rd + 0.8(value of 4th – value of 3rd)].

At least 15 pairs of TOC and TEFe concentrations must be used to calculate the numeric expression of the sulfate standard. All acceptable (based on Sections 2 and 3) concentrations of TOC and TEFe must be used to calculate the numeric expression of the sulfate standard, even if those concentrations were gathered from different sampling events.

If the numeric sulfate concentration is above 335 mg/L sulfate, then the numeric expression of the sulfate standard for the wild rice water from which the sediment samples were taken is 335 mg/L. If the numeric sulfate concentration is below 0.5 mg/L sulfate, then the numeric expression of the sulfate standard for the wild rice water from which the sediment samples were taken is 0.5 mg/L.

State of Minnesota

Minnesota Pollution Control Agency

In the Matter of Proposed Amendment to Minnesota Rules Chapters 7050 and 7053, Relating to Minnesota Rules 7050.0130, 7050.0220, 7050.0224, 7050.0470, 7050.0471, 7053.0135, 7053.0205, and 7053.0406,	MPCA Rebuttal Response to Public Comments
OAH Docket # 80-9003-34519	
Revisor ID 4324	December 1, 2017

MPCA Rebuttal Response to Public Comments Submitted During the Post-Hearing Public Comment Period.

I. Introduction

This document supplements information provided in the Minnesota Pollution Control Agency's (MPCA or Agency) Response to Comments Submitted during the Pre-Hearing Public Comment Period and at the Public Hearings, dated November 22, 2017 (Response to Comments).

This document contains the MPCA's detailed responses to public comments submitted during the post-hearing comment period following the final public hearing on November 2, 2017. The MPCA reviewed those comments and is addressing them in this Rebuttal Response to Public Comments Submitted During the Post-Hearing Public Comment Period (Rebuttal Response). The subjects of many of the public comments received were addressed previously in the MPCA's November 22, 2017 Response to Comments so that in this Rebuttal Response the MPCA will only respond in detail to those comments not previously addressed or that require a more complete response than was previously provided.[1]

The MPCA's Rebuttal Response consists of this document and a spreadsheet (Attachment 1) that identifies the comments received and the MPCA's response.

The next section of this document explains and discusses areas where the MPCA is proposing to rule language changes. The following section offers a response to comments. To the extent possible, the MPCA responds to some comments with short responses directly in the Attachment 1 spreadsheet in the column titled "MPCA Response." Where a more detailed response is necessary, the discussion is provided in this document.

The comment topics addressed in detail in Part III of this document are:

A. Scope of the Propose Rulemaking

B. Beneficial Use Comments

C. Waterbody Identification Numbers (WIDs)

D. Future Identification of Additional Class 4D Wild Rice Waters

[1] To meet the deadline for submitting post-hearing comments, MPCA focused on responding to comments available for review through November 17, 2017.

E. Application of Wild Rice Sulfate Standard to Streams

F. Comments on Specific Waters Proposed or Not Proposed as Wild Rice Waters

G. Comments on Developing the Magnitude of the Standard

H. Comments on the Duration, Flow Rate, Frequency, and Seasonality

I. Comments on NPDES Permitting

J. Sampling and Analytical Methods

K. Procedural Concerns

II. Proposed and Planned Rule Changes

Some commenters identified specific changes to the proposed rule language. In some cases, the MPCA agrees that the rule should be revised and has provided proposed revised language below. In other cases, the MPCA agrees that the rule language should be revised but is not ready at this point to provide specific language.

<u>Rule Part: 7050.0130, Subp. 2b.</u>

The MPCA plans to remove proposed rule language 7050.0130, Subp. 2b. (lines 1.11 to 1.12), the definition of cultivated wild rice water. EPA provided a comment stating, "Minn. R. § 7050.0130, Subpart 2b. Cultivated Waters. EPA's understanding is that the surface waters to which the proposed rules apply are those waters identified specifically in the proposed rules at Minn. R. § 7050.0471 and that none of the waters identified as wild rice waters at Minn. R. § 7050.0471 include sub areas that meet the definition of "cultivated waters." Unless otherwise specified in rule, EPA considers the Class 4D wild rice use (wild rice use) and criteria to be applicable to all waters identified in Minn. R. § 7050.0471." The MPCA agrees with EPA's interpretation and comment and has not (and will not in future) identify cultivated wild rice areas as Class 4D wild rice waters, because such waters do not need a sulfate standard. Therefore, we plan to remove the proposed definition.

<u>Rule Part 7050.0220, Subpart 1, B (1 – 4) ; 7050.0220, Subpart 3a.</u>

In several locations (line 2.19, line 2.22, line 3.2, line 3.8, and line 5.14), the MPCA added rule language to clarify that certain kinds of waters may hold multiple use classes and that the sulfate standard would apply to those waters if they were also specifically listed as Class 4D waters. The proposed rule language here was "4D when applicable to a wild rice water listed in part 7050.0471". EPA provided a comment that "4D is always applicable to water bodies listed in Minn. R. § 7050.0471 and so the phrase 'when applicable to a wild rice water listed in part 7050.0471' is superfluous. To avoid confusion as to whether there might be instances when 4D would not be applicable to a wild rice water listed in Minn. R. § 7050.0471, EPA recommended that the language be revised to simply say '4D for water bodies listed in part 7050.0471.'" The MPCA agrees with this comment and will make the recommended change.

<u>Rule Part 7050.0220, Subpart 3a, A</u>

In several locations (line 3.11, line 3.18, line 4.5, line 4.13, line 5.2, and line 5.16), the rule language contains tables that include columns listing use classes; the columns are then filled in with the related standards for each use class. Because the wild rice sulfate standard was originally listed within (as a subset of) Class 4A, it was delineated within these lists with the words "wild rice present". The MPCA proposed to retain the structure of the tables and replace the language "Sulfates, wild rice present, mg/L" with "sulfate in a wild rice water" and the 10 mg/L standard with a reference to the equation. EPA provided a comment that the rule language should have a column heading for the 4D use class. The MPCA agrees that this structure would be clearer and will work with the Revisor to determine the feasibility of making such a change.

Rule Part 7050.0220, Subp. 6c

As earlier mentioned, the MPCA proposes to delete the definition of "Cultivated wild rice water." With the deletion of that definition, there is no need to reference the term in the definition of "Wild rice waters", particularly since wild rice waters are defined to be those water bodies identified in part 7050.0471. Therefore, the MPCA plans to delete the sentence at lines 2.3-2.4 that reads, "Wild rice waters do not include cultivated wild rice waters."

Rule Part 7050.0224, Subp. 5, B.

A comment from EPA recommended that the first sentence (lines 7.22-7.24) be revised to clarify that the annual average concentration of sulfate is that in the surface water. The MPCA agrees and is proposing to change the rule language to read:

> B. The annual average concentration of sulfate in the surface water of a wild rice water must not exceed the concentration established as the calculated sulfate standard under subitem (1) or alternate sulfate standard under subitem (2) more than one year out of every ten years.

Rule Part 7050.0224, Subp. 5., B, (1)

This rule part contains the equation that is the primary option used to derive the numeric sulfate standard. EPA commented that "it is not possible to say with certainty that the relationships between sediment pore water sulfide and total organic carbon and total extractable iron used to calculate protective water column sulfate concentrations remain valid outside the range of the data used to develop the criterion." Comments from Nathan Johnson also raise this issue, stating "I would like to encourage the MPCA to carefully consider the range over which their empirical equation that relates the quantity of sulfide realized as a function of sediment iron, sediment carbon, and surface water sulfate…It is possible that a limitation on the model predictions could be imposed on this basis which would not allow high sulfate concentrations to be calculated by the model if the statistical strength of the model's predictive abilities towards the edge of the domains is limited.

Using the proposed equation to extrapolate to very high surface water sulfate concentrations (higher than those observed commonly in the observational dataset) represents a potential instance of applying the model beyond an appropriate domain of applicability. The same could be said for sediment carbon and iron."

The MPCA understands the concerns raised – namely that the equation is of unknown validity outside of the range of data used to develop it. "EPA recommends that potential input parameter values be constrained to reflect the range of concentrations observed in the studies upon which the criterion is based." The MPCA believes it is appropriate to respond to this concern by setting constraints on the implementation of the equation that would ensure that the equation is protective. The MPCA is proposing that input values of carbon cannot be lower than the minimum value in the range of data used to develop the equation, because carbon enhances sulfide production. The MPCA is proposing that input values of iron cannot be higher than the maximum value in the range of data used to develop the equation because iron removes sulfide from porewater.

The MPCA is proposing that output values of sulfate cannot be higher than the maximum value in the range of data used to develop the equation, 838 mg/L.

The constraint on sulfate is appropriate because observed sulfate levels were an input to the development of the equation, and the equation is of unknown validity outside the range used to develop it.

Such an approach will help assuage commenter concerns about exceedingly high sulfate levels that may result from the equation. The MPCA understands that this limitation will may raise more concerns for other commenters. The MPCA notes that this limitation only applies to one of three possible mechanisms to develop the numeric sulfate standard – the equation. While the equation is the primary mechanism for setting a sulfate standard, the alternate standard and a site-specific standard approach will also be available for appropriate conditions and could result in numeric standards that are higher or lower than calculated by the equation.

The MPCA is considering where and how to make such rule language changes (likely either here or in Subp. 5. B. (1)(d)) needed to implement this change.

<u>Rule Part 7050.0224, Subp. 5., B, (1),(a – c)</u>

These rule parts describe how sediment samples are to be collected and analyzed, based on the Sampling and Analytical Methods that are incorporated by reference. EPA provided comments that by adopting the methods by reference, "Minnesota may hamper its ability to respond to unforeseen technical issues that may arise as new sites are visited and for which application of the methods as written may lead to results that do not adequately protect the wild rice use as it occurs in a given water." EPA suggested various rule changes in pages 10 – 11 of its comment letter; the suggestions place more language directly in the rule but then do not incorporate the methods by reference.

Additionally, commenter Norman Miranda noted that "The dilemma I see for utility managers regardless of whatever protective limit is adopted is to convince their respective City Council and rate payers that a very limited number of samples and sample locations yielded adequate and conclusive data to justify a significant capital investment…I believe MPCA is on the right track offering a consistent sampling regiment of a fixed number of samples at a prescribed location array…I believe at least two sampling events conducted in appropriate but separate locations need to be conducted by the MPCA. I realize the MPCA has limited financial resources to conduct extensive sampling and analysis in multiple locations for every discharger. However, to offer some flexibility, I think the Rule should include a provision that municipalities/permitted facilities be given the opportunity to conduct additional sampling/testing beyond two events that would be required under the Rule. The ground rules for this additional sampling could include:

1. Regulated party must submit a plan for MPCA approval showing proposed alternative sample locations.
2. Sampling must follow MPCA "Sampling and Analytical Methods" and be conducted by approved lab/consultant.
3. Sampling/testing to be done before or concurrent with MPCA sampling as not to delay MPCA's schedule.
4. Cost of additional sampling events to be the responsibility of the Regulated Party.

In return I believe there should be language where the MPCA will give the Regulated Party's data set the same weight if all conditions are followed."

The MPCA does agree that some flexibility may be needed as more sampling occurs, and appreciates that many permittees want to do more sampling (and perhaps sooner) than the MPCA plans to undertake. While the MPCA has planned to do most sampling with our own resources, we have always planned to allow the use of data submitted by other parties (whether regulated/permitted parties or others) if it meets our requirements.

A primary goal of incorporating the sampling methodology into the rule was to provide clarity so that others can conduct sampling and to ensure that the sampling, which is foundational to the developing of a numeric sulfate standard, is completed consistently and accurately. The MPCA believes this is an important goal and will continue to incorporate the methods by reference. Changes to the methods will need to be made through rulemaking.

However, MPCA is proposing a rule language change at lines 8.6, 8.11, and 8.13 to require that analysis and sampling happen consistent with the methods, rather than requiring exact adherence to the methods. This will allow some flexibility if, for example, an analytical method is slightly updated. The MPCA is also proposing to add language that the sediment samples are collected in areas where wild rice is growing or may grow within the wild rice water.

The proposed rule language would then read:

> Where:
>
> (a) organic carbon is the amount of organic matter in dry sediment. The concentration is expressed as percentage of carbon, as determined ~~using~~ consistent with the method for organic carbon analysis in Sampling and Analytical Methods for Wild Rice Waters, which is incorporated by reference in item E;
>
> (b) iron is the amount of extractable iron in dry sediment. The concentration is expressed as micrograms of iron per gram of dry sediment, as determined ~~using~~ consistent with the method for extractable iron in Sampling and Analytical Methods for Wild Rice Waters;
>
> (c) sediment samples are collected ~~using~~ consistent with the procedures established in Sampling and Analytical Methods for Wild Rice Waters; and

The MPCA is then proposing additional related changes, likely to be codified as rule part 7050.0224, Subp. 5., E. which would read as follows:

> For each wild rice water identified in 7050.0471, the methods for selecting sediment sampling sites and for collecting, processing and analyzing sediment samples must be documented, including all QA/QC. Where methods are used that are consistent with but different from those specified in Sampling and Analytical Methods for Wild Rice Waters, the intended methods and how they will be used to calculate the numeric sulfate standard must be submitted to and approved by the Commissioner prior to sample collection.

The incorporation by reference would then be moved to Subp. 5., F.

The MPCA believes this change will allow flexibility when other parties wish to undertake sampling of wild rice waters needed to calculate a protective sulfate value, while ensuring the necessary consistency. The MPCA believes sampling by others could occur at any time; if MPCA sampling has already occurred, the intended methods should describe how both the MPCA gathered data and any additional data will be used in concert. Regardless of the method employed, it is intended that all sampling be documented as required by this rule language. The MPCA will make the final determination about the numeric sulfate standard for any given water body.

Rule Part 7050.0224, Subp. 5., B (2)

The MPCA proposes to change the phrase "ambient sulfate concentration" found in this rule part at lines 8.19 and 8.23 to "surface water sulfate concentration" to be consistent with the rule language change suggested by EPA for line 7.22.

The MPCA received several comments about the alternate standard. This section responds to many of those comments by describing how MPCA envisions that the alternate standard procedure would work and setting forth some proposed rule changes.

This alternate standard procedure develops a replicable approach to developing an alternate standard for areas where the equation does not fit – where there is high sulfate but low porewater sulfide. Some commenters (e.g., Mining Minnesota) have stated that the alternate standard procedure is unclear and creates confusion. They have said that the "Sampling Methods do not include a clear description of the purpose of the porewater sampling", and that the language "create[s] substantial confusion as to what water quality standards [will] actually be applied by the MPCA in any given circumstance."

The MPCA envisions that the alternate standard would be used in places where sediment and surface water sampling has been completed, the equation indicates that the calculated numeric standard is being exceeded in the surface water of the wild rice water, but there are indications that porewater sulfide may not be above the 120 µg/L protective threshold. These indications may be, for example, information about groundwater upwelling or evidence of thriving wild rice (see p. 67 of the TSD). In these situations, if MPCA has done the sediment sampling the MPCA may choose to go back to do porewater sulfide sampling; MPCA also envisions that a permittee may do porewater sulfide sampling and request that the alternate standard approach be used to develop the numeric sulfate standard.

One of MPCA's goals for this rule language was to set out a procedure that is sufficiently defined in rule to be approved by EPA as an alternate methodology to the equation for specifying a numeric sulfate standard. This would obviate the need for each individual sulfate standard developed via the alternate method to be submitted to EPA as a site-specific standard for their approval. In their comment letter, EPA noted that "The only situation where states would not need to submit any new or revised water quality criteria to EPA for review and approval would be where states have adopted and EPA has approved a 'performance-based' standard that relies on regulatory adoption of a process (i.e., a criterion derivation methodology) rather than a specific outcome (i.e., a concentration limit for a pollutant) . . . when such a performance-based approach is binding; sufficiently detailed; and contains suitable safeguards to ensure predictable, repeatable outcomes, EPA's approval of such an approach can also serve as approval of the outcomes as well. If a state's approach is not sufficiently detailed or lacks appropriate safeguards to produce predictable outcomes, EPA review of a specific outcome remains necessary." EPA's comments indicate that they do not find the current rule language to have sufficient specificity to meet this threshold, and suggest that MPCA could add sufficient detail to satisfy the requirements.

Other commenters (USS, Mining Minnesota, etc.) also felt that the alternate standard was vaguely described. The MPCA intends to provide more clarity and meet EPA's requirements for a performance-based rule by revising the rule language. As stated in the TSD on page 70, "it is likely that the maximum increase in porewater sulfide concentrations as a result of increased sulfate would be proportional to the increase in sulfate…With this understanding, a conservative alternate standard would be an increase in the observed ambient sulfate that is proportional to the degree that 120 µg/L is greater than the observed maximum porewater sulfide concentration. For instance, if the observed porewater sulfide was 80 µg/L and the observed surface water sulfate was 110 mg/L, a conservative sulfide standard would be 165 mg/L sulfate (120/80 * 110 mg/L)."

The MPCA plans to revise the rule language. The rule language currently reads (line 8.18 to 8.25):

(2) The commissioner may establish an alternate sulfate standard for a wild rice water when the ambient sulfate concentration is above the calculated sulfate standard and data demonstrates that sulfide concentrations in pore water are 120 micrograms per liter or less. Data must be gathered using the procedures specified in Sampling and Analytical Methods for Wild Rice Waters, which is incorporated by reference in item E. The alternate sulfate standard established must be either the annual average sulfate concentration in the ambient water or a level of sulfate the commissioner has determined will maintain the sulfide concentrations in pore water at or below 120 micrograms per liter.

The MPCA's planned revision, subject to review by the Revisor, would be

(2) The commissioner may establish an alternate sulfate standard for a wild rice water when the ~~ambient~~ surface water sulfate concentration is above the calculated sulfate standard and data demonstrates that sulfide concentrations in pore water are 120 micrograms per liter or less. Data must be gathered ~~using~~ consistent with the procedures specified in Sampling and Analytical Methods for Wild Rice Waters, which is incorporated by reference in item E. The alternate sulfate standard ~~established must be either the annual average sulfate concentration in the ambient water or a level of sulfate the commissioner has determined will maintain the sulfide concentrations in pore water at or below 120 micrograms per liter.~~ is determined by calculating the ratio of measured sulfide, in micrograms per liter, to 120 micrograms per liter and applying that ratio to the surface water sulfate as follows $\frac{120}{porewater\ sulfide} * surface\ water\ sulfate$.

The EPA notes that MPCA must also have supporting documentation specifying how much sulfate and sulfide data is sufficient to describe the empirical relationship between the two in the specific wild rice water. This information is contained in the methods incorporated by reference.

The MPCA believes this revision ensures the process is sufficiently repeatable and detailed to qualify as a performance based standard that does not require individual EPA review. If EPA does not agree, the rule language provides helpful additional clarity but MPCA will submit alternate standards through the EPA's site-specific standards process; MPCA does not find that language about that process is needed in the rule either in this section or in the section about the site-specific standard.

Rule Part 7050.0224, Subp. 5., E.

This rule part contains the incorporation of Sampling and Analytical Methods for Wild Rice Waters by reference. It is important to note that documents incorporated by reference have the standing of rule and should not be viewed as guidance. They are fully enforceable. EPA provided many detailed comments on the Sampling and Analytical methods. Additional detailed comments were provided by other commenters such as Mining Minnesota.

MPCA intends to review those carefully and may make changes to the methods. Some of these changes are likely needed to reflect the prior rule language change that sediment and porewater sampling and analysis must be completed in a manner "consistent with" the methods document. MPCA will be reviewing to see where the methods document can contain broader language – such as by not specifying exactly how samples are to be dried and pulverized if that is not intrinsic to the resulting calculation – to respond to comments about the methods being overly specific.

However, the MPCA believes that in many cases the level of detail that is requested by EPA or other commenters is inappropriate to include as binding language in rule, and many commenters seem to believe that parts of the methods document are already overly restrictive. EPA seems to have intended these comments to apply to a "technical guidance" document not incorporated by reference and purported to have the same standing as rule language. However, technical guidance would not have the same standing unless expressly incorporated by reference. The MPCA will also consider the need for a Standard Operating Procedure and additional detail as a useful guide for sampling, but such a detailed document would not be incorporated in rule. It would be available to others who wish to do sampling in order to help them develop their alternative sampling method or protocol as needed for approval by the MPCA.

<u>Rule Part 7050.0471, Subp. 2.</u>

This rule part sets out that MPCA will solicit information to identify new Class 4D wild rice waters in the Triennial Standards Review, and provides an illustrative example of the types of evidence that should be provided. EPA suggests that MPCA should provide additional details about how this review would be accomplished and the type of information that would be needed. MPCA agrees that additional details would be helpful, but will best be included in the public notice process for each triennial review.

Other commenters raise concerns that the types of evidence that MPCA lists is overly restrictive. A response to these comments can be found in the response to the topic “Listing of Waters”. However, in re-reading the rule language, the MPCA notes that the statement that the evidence “must demonstrate the wild rice beneficial use exists” is somewhat restrictive. It is the MPCA’s responsibility to demonstrate, based on available information, that the wild rice beneficial use exists or has existed. Furthermore. The MPCA does not intend to limit the evidence that commenters provide as part of the triennial review process, but instead to clearly lay out the demonstration that the MPCA will need to make as part of any rulemaking process to add Class 4D wild rice waters. In order to clarify this, the MPCA is proposing the following rule change:

> 11.18 Subp. 2. Triennial review<u> and future identification of wild rice waters</u>. As part of each triennial review of water-quality standards
> 11.19 conducted under Code of Federal Regulations, title 40, section 131.20, the commissioner
> 11.20 must solicit evidence that supports identifying additional wild rice waters in rule. <u>Identifying additional waters in rule must be based on</u> ~~The~~
> 11.21 evidence ~~must demonstrate~~ <u>that supports a demonstration</u> that the wild rice beneficial use exists or has existed on or after
> 11.22 November 28, 1975, in the water body, such as by showing a history of human harvest or
> 11.23 use of the grain as food for wildlife or by showing that a cumulative total of at least two
> 11.24 acres of wild rice are present. Acceptable types of evidence include:
> 12.1 A. written or oral histories that meet the criteria of validity, reliability, and
> 12.2 consistency;
> 12.3 B. written records, such as harvest records;
> 12.4 C. photographs, aerial surveys, or field surveys; or
> 12.5 D. other quantitative or qualitative information that provides a reasonable basis
> 12.6 to conclude that the wild rice beneficial use exists.

<u>Rule Part 7050.0471 – List of Waters</u>

The MPCA is proposing three changes to the proposed list of Class 4D wild rice waters. The reasons for these changes are addressed in the section of this document about specific wild rice waters. The MPCA is proposing to remove the following waters from the list of wild rice waters in Subp. 3., C.

Line 16.21 (42) Mud Lake St. Louis 69-0652-00

Line 17.1 (49) Round Lake St. Louis 69-0649-00

In addition, MPCA is proposing to split the Embarrass River WID 04010201-577 into two separate WIDs – one from Embarrass Lake through Esquagama Lake and the other from Esquagama Lake to the St. Louis River. Both stretches will receive new WID numbers to identify them. The MPCA proposes to list the WID from Embarrass Lake through Esquagama Lake as a Class 4D wild rice water. The MPCA does not have sufficient information to list the segment from Esquagama Lake to the St. Louis River as a Class 4D wild rice water and will therefore track it as an insufficient information water.

III. Detailed Rebuttal Responses

A. Scope of the Proposed Rulemaking

Many commenters have expressed concerns about the scope of the proposed rulemaking, asserting that it is too narrowly focused and therefore somehow fundamentally flawed. MPCA has responded to specific and general comments about scope in the 11/22/17 Response to Comments and elsewhere in this Rebuttal Response. It may be useful to also note here, however, that the number and volume of comments received prior to, during and after the Administrative Hearings for this rulemaking speaks to the reasonableness of the MPCA's decision to focus the scope of this rulemaking as it has. Given the complexity of the science of sulfate, sulfide and wild rice; the extensive interest in both wild rice and in the activities that may result in sulfate discharges; and the immediate need to address the difficulties in interpreting and implementing the existing wild rice sulfate standard it was reasonable for the MPCA to focus the scope of this rulemaking as it has.

Aquatic Life Standard

Some commenters (MCEA) also stated that "the SONAR generally proceeds on the assumption that if a water body or discharge does not need limits on the discharge of sulfate to protect wild rice, it does not need any limit on sulfate discharges at all. In other words, it is presumed that if there is no wild rice to be protected, that any amount of sulfate may be allowed because any amount of sulfate is presumed to be harmless to fish and other aquatic life. However, at high concentrations, sulfate is harmful to a number of aquatic uses. While probably in most cases the 10 mg/L sulfate standard is more stringent than necessary to protect uses other than wild rice, Minnesota should not throw out its only numeric sulfate standard without establishing standards to protect other uses. Doing so would have the effect of weakening protections for aquatic life from sulfate pollution."

MPCA has never made an assertion that it is not necessary to consider sulfate impacts on other beneficial uses. Rather, MPCA has explained its reasonable decision to limit the scope of this rulemaking to the effects of sulfate on the wild rice beneficial use (see Cover memorandum to the MPCA's 11/22/17 response to Comments). In fact, a sulfate standard to protect aquatic life is on the MPCA's list of potential future water quality standards development and rulemaking efforts (see https://www.pca.state.mn.us/water/mpca%E2%80%99s-proposed-water-quality-standards-work-plan-2018-2020). The SONAR does not speak to other uses because the purpose of this rulemaking was to revise and clarify the sulfate standard related to wild rice.

B. Beneficial Use Comments

Several commenters had detailed comments concerning the beneficial use and how the MPCA has designated waters. Many of the comments are addressed here, but they also overlap with comment addressed in the section discussing water body identification numbers (WIDs).

Background

Discussions related to the Clean Water Act often use three terms that include the word "use." These are – beneficial use, designated use, and existing use. It is helpful to understand these terms in order to better understand our response to comments which follow.

Beneficial use and designated use are generally used interchangeably. The MPCA refers to the wild rice "beneficial use," while EPA and other commenters might refer to the same concept as the "designated use."

According to EPA, designated uses "specify goals and expectations for how each water body is used. Typical designated uses include:

1. Protection and propagation of fish, shellfish and wildlife
2. Recreation
3. Public drinking water supply
4. Agricultural, industrial, navigational and other purposes."[2]

The terms "designated use" and "beneficial use" both refer to the goals and expectations that Minnesota has set for the use of a water body. Minnesota has identified 7 beneficial use classes which are listed in Minnesota Rules 7050.0140.

A critical goal of the CWA, as stated in section 101(a)(2) of the Act, is to ensure that all waters are fishable and swimmable. "The national goal in CWA section 101(a)(2) is water quality that provides for the protection and propagation of fish, shellfish, and wildlife and recreation in and on the water where attainable" (80 Fed. Reg. 51024, Aug.21, 2015). Thus, these fishable, swimmable goals are known as the "101(a)(2)" beneficial uses. In Minnesota, CWA section 101(a)(2) beneficial uses are protected in Class 2 of the beneficial use classes in Minnesota Rules Chapter 7050.

States may also identify beneficial uses other than 101(a)(2) beneficial uses. These other beneficial uses often include protecting water quality for drinking water, industrial use, or agriculture. Minnesota has identified 7 beneficial use classes in Minnesota Rules 7050.0140. The wild rice beneficial use of "use of the grain as food for humans and wildlife" is one of these other beneficial uses and is found in Class 4 (Minn. R. 7050.0224), which protects waters supporting agriculture and wildlife uses.

Some beneficial uses (such as Class 2) are designated to apply to all water bodies in Minnesota, while other beneficial uses are designated to apply to specific water bodies (such as the Class 1 use for drinking water, which only applies to a subset of Minnesota waters).

A single waterbody may be designated as having more than one beneficial use. For example, a single waterbody may be designated as having both Class 2 and Class 4 beneficial uses.

In 1973, the Class 4 wild rice beneficial use was initially designated to apply to "water used for production of wild rice." In a 1998 rulemaking, the MPCA specifically identified a list of 24 selected wild rice waters to which the use and the narrative standard of specifically applied. See Minn. R. 7050.0470. However, other specific waters to which this category applied were never identified. Therefore, up to this point designating the specific waters to which this beneficial use applies has been a case-by-case determination. With this rulemaking the MPCA is specifically identifying, by WID, those waters that have been designated as having the wild rice beneficial use.

[2] https://www.epa.gov/standards-water-body-health/what-are-water-quality-standards#designated

Under the CWA, the term “existing use” means that a designated beneficial use actually existed (was attained) in a water body at any time on or after November 28, 1975 (the date on which the CWA became effective). The concept of existing use is somewhat confusing because to establish an “existing use” you must consider a time period that starts in 1975 and continues to the present. If at any point in time from November 28, 1975, to the present a designated beneficial use existed in a water body, that beneficial use is an “existing use.”

Beneficial Use, Designated Use, Existing Use

Some commenters suggested that MPCA confused the idea of a designated use and an existing use. The Fond du Lac band stated “The CWA protects both “designated” and “existing” uses of water bodies…

“Designated uses” are “those uses specified in water quality standards for each water body or segment whether or not they are being attained.” 40 C.F.R. § 131.3(f). Designated uses are not dependent on whether or not conditions currently support the use.”

The MPCA has not confused the concepts of “designated use” and “existing use.” The MPCA used the existing use concept to identify waters where the Class 4D wild rice waters beneficial use would be designated (the beneficial use was previously “waters used for production of wild rice” and is now “Class 4D wild rice waters”). As stated above, the term “existing use” means that the designated beneficial use actually existed in the water on or after November 28, 1975. The MPCA is designating 1300 waters by WID as Class 4D wild rice waters where the beneficial use of wild rice has existed in the water on or after November 28, 1975. The two concepts are tied together, but are not used inappropriately by the MPCA.

When the wild rice sulfate standard was originally adopted, it was clearly intended to apply to a subset of Minnesota waters – those *used* for wild rice production -- not all Minnesota waters (SONAR, p. 20). A plain language reading of the original beneficial use description, which references use for wild rice production, supports the MPCA’s reasonable reliance on this concept in specifying the Class 4D wild rice waters. It is also reasonable for the MPCA to identify waters where the Class 4D wild rice waters beneficial use applies as those waters where the wild rice beneficial use has existed in the water on or after November 28, 1975.

Class 2 Use vs Class 4 Use

Many commenters indicated that the wild rice beneficial use was inappropriately placed in the Class 4 Agriculture and Wildlife Use Class in 1973; and should be reclassified as a Class 2 aquatic life beneficial use because they assert it is a 101(a)(2) use under the CWA. For example:

- The Fond du Lac Band of Lake Superior Chippewa commented that the MPCA should have considered tribal recommendations to “elevate the unique qualities and characteristics beyond simply ‘food.’”
- The Minnesota Center for Environmental Advocacy asserted that the wild rice beneficial use is a 101(a)(2) use because wild rice is properly seen as a form of wildlife, wild rice is closely related to propagation of wildlife, and because the collection of wild rice can be considered a form of “recreation on the water.”
- Water Legacy commented that when a “designated use” pertains to fish, shellfish, recreation or wildlife, the use has special protection under Section 101(a)(2) of the Clean Water Act.

The MPCA has repeatedly asserted and provided an affirmative demonstration in the SONAR and the Response to Comments dated November 22, 2017, that the wild rice beneficial use is appropriately retained as a Class 4 use, related to agriculture and wildlife uses; it is not a Class 2 use. The MPCA established this beneficial use through rulemaking in 1973 and rule amendments in 1997. When the Class 4A wild rice beneficial use was adopted in 1973 it clearly did not apply to all waters, which is evidence of the fact that this beneficial use is not and should not be interpreted as a CWA section 101(a)(2) use. As noted on pp. 33-35 of the SONAR, in this rulemaking the MPCA is clarifying the existing Class 4 beneficial use; the MPCA is not removing the existing Class 4 beneficial use, nor designating a new wild rice beneficial use. This effort is focused on protecting the specific wild rice beneficial use of use of the grain as a food source for humans and wildlife, not aquatic life more generally as do CWA 101(a)(2) uses. Furthermore, while wild rice is a food source for wildlife, it is not the only food source and it is therefore not reasonable to conclude that the Class 4D wild rice beneficial use is "necessary for protection and propagation of fish, shellfish and wildlife." (Fond du Lac Band, p. 24)

Identifying Waters

The MPCA also received comments that the agency was removing a designated use or existing use as part of this rulemaking when it failed to identify certain waters as wild rice waters. The comments referred to all waters listed in Appendix B of MDNR's 2008 *Natural Wild Rice in Minnesota* report and the I854 Treaty Authority's 2016 and 2017 lists of wild rice waters. The Friends of the Boundary Waters comment letter asserts that "MPCA is removing an "existing use" because MPCA has proposed a list of wild rice waters that omits many waters despite evidence that wild rice grows or has grown in them." The Fond du Lac Band's comment letter argues that the MPCA is removing a designated use when it did not include all of the waters included in Appendix B of the MDNR's 2008 report *Natural Wild Rice in Minnesota*. The Band commented that "the more than 900 excluded water bodies have the 'designated use' of wild rice waters because that use was 'specified in water quality standards' for those waters, when the state designated all surface waters in the state as Class 4A waters used for the production of wild rice." Commenters also disputed the MPCA's statement in the SONAR that the MDNR inventory in Appendix B was not developed for regulatory use. The Fond du Lac Band commented that the MPCA actually used the list for regulation of water quality when it used the list to review water discharge permits to evaluate if they discharged to wild rice waters.

The MPCA does not agree that all surface waters in the state are class 4A waters used for production of wild rice. The existing Class 4A rule has a sulfate standard that is only "applicable to water used for production of wild rice." This language is a modifier that serves to limit the scope of the waters to which the standard applies- not all Class 4A waters, but just those waters that are "used for production of wild rice." This modifier establishes a new sub-class of Class 4A, clearly demonstrating that not all Class 4A waters are wild rice waters.

The MPCA also does not agree that the presence (or evidence of past presence) of any amount of wild rice is indicative that the Class 4D wild rice beneficial use is an existing use in that water body. This topic is covered in depth in Section 6D of the SONAR and in the MPCA's Response to Comments dated November 22, 2017.

Finally, the MPCA does not agree that presence of a waterbody in the inventory found in Appendix B of MDNR's 2008 *Natural Wild Rice in Minnesota—A Wild Rice Report Study Report to the Legislature* is sufficient to demonstrate the beneficial use of the grain as a food source for wildlife and humans. The MDNR report was not developed for regulatory purposes and the MDNR is not a regulatory agency under the Clean Water Act. Although the MDNR report is the most comprehensive statewide inventory available, it has some limitations with respect to the MPCA's need to identify Class 4D wild rice waters subject to the wild rice sulfate standard. For example, the report does not consider density or acreage estimates for all the wild rice stands and it contains only limited information on streams. (see discussion in SONAR pp.42-51 and Response Exhibit N.28 e-mail from Ray Norrgard about DNR inventories). MPCA's evaluation of 1854 Treaty Authority Waters was discussed in MPCA's November 22, 2017 response to comments in Attachment 1.

The discussion cited by a commenter detailing how the MPCA conducted the permit review process to determine if waters were "water used for production of wild rice" shows that the MPCA did NOT treat the 2008 MDNR list as definitive or presumptively valid. As noted there, the MPCA reviewed multiple wild rice records and databases maintained by the MDNR (as was done to establish the list of Class 4D wild rice waters for this rulemaking), and in many cases, required permit applicants to conduct a survey of wild rice in the receiving waters. If the MDNR 2008 list was definitive, then additional surveys would not have been needed.

Other commenters (Mining Minnesota, etc.) have stated that "MPCA has elected to over-designate waters", and that "MPCA does not have statutory authority to designate waters that contain no wild rice as 'wild rice waters' subject to the requirements of Minn. R. ch. 7050." As described here, the MPCA has identified those waters where wild rice is an existing use as wild rice waters. Some of those waters may not have wild rice today, but under the CWA must be protected if the use has existed since November 28, 1975.

C. Waterbody Identification Numbers (WIDs)

Mining Minnesota commented that the application of the standard to the entire WID is inappropriate because it does not require wild rice presence within the WID, and because application of the standard to an entire WID is overly broad.

The comment letter suggests that the identification of a wild rice water should require the actual presence of rice in the waters over a defined period (4-6 years) and that an opportunity for public comment should be required before identifying wild rice waters.

The MPCA does not agree that actual presence of rice is required for identification of a Class 4D wild rice water. Class 4D wild rice waters identified in the proposed rule are the lakes, reservoirs, streams and wetlands where the MPCA has concluded that the beneficial use has existed since November 28, 1975. (November 28, 1975, is a key date in the Clean Water Act. Any beneficial use that a water body actually attained on or since that date is an existing use, and water quality should be such as to ensure that existing use is maintained.) The MPCA agrees that the public should have an opportunity for public comment when wild rice waters are identified. The current public comment period provides this opportunity for the MPCA's proposed Class 4D wild rice waters, and rulemaking is required for any future listing of wild rice waters. Rulemaking always includes an opportunity for public comment.

The commenter also raised concerns that the use of WIDs gives the agency "virtually unfettered discretion to identify and regulate 'wild rice waters' after the rulemaking process has been completed. There are no objective criteria included in the Proposed Rules for determining WIDs, and there is no public process by which interested parties can provide MPCA with information as to how to determine WIDS or their boundaries other than in the cumbersome rulemaking process."

WIDs are unique numeric identifiers assigned to surface waters that are used throughout the MPCA's permitting, water assessment and monitoring programs. This use of unique identifiers for lakes and stream reaches is well established in Minnesota. The MPCA has been using this system of unique lake and stream identifiers since 2001 for its water quality assessments and the MDNR has assigned the DOW numbers (the same as lake WIDs) for lakes since at least 1968. See SONAR Part 1D pp.39-41 for background on the reasonable scientific and hydrological bases for decisions on how WIDs are assigned. Unique numeric identifiers for lakes and stream reaches are essential in Minnesota where there may be many waters in the state with identical names.

The MPCA disagrees that the use of WIDs provides the agency with undue discretion to change where the wild rice standard applies. WIDs are an important component of the MPCA's water programs. For example, they are used to identify impaired waters for public review and reporting to EPA. (Note that for the impaired waters list they are known as assessment unit IDs or AUIDs. The MPCA is moving towards the WID nomenclature in all contexts. The AUID and WID numbers are the same.) The MPCA is committed to documenting WIDs with numeric sulfate standards on the Agency's website, and plans to provide map layers or other tools to make the geographic boundaries of WIDs more accessible. As noted in the EPA comments "EPA emphasizes that modifications to a WID number are only permissible as long as the designation of the WID as a wild rice water is not removed for the entirety of a WID or any subpart of a WID previously approved as a wild rice water". Otherwise, the modifications require rulemaking. The MPCA agrees with EPA's statement that rulemaking is required for any WID modification that may result in removal of a wild rice water from any part or subpart of a WID. Although it may be perceived by the commenter as cumbersome, this rulemaking process will provide the public process by which interested parties can provide comments.

The MPCA will address the comments about application of the standard to the entire WID in three parts: first, applicability of the standard to WIDs in lakes, wetlands and reservoirs; secondly, applicability of the standard to stream and river WIDS; and thirdly, the MPCA's plan for exceptions to the proposed approach.

1. The MPCA's decision to apply the standard to the entire WID for lakes, wetlands and reservoirs was straightforward and is reasonable because in most cases water moves and mixes throughout the entire waterbody. Therefore, discharge to any part of the WID will affect sulfide production in every other part. There are some limited cases where one part of a lake, such as a bay, may be hydrologically isolated, and will not mix with the rest of the waters of the lake. In these cases, the state has a mechanism to assign more than one WID to a lake or reservoir; and each hydrologically separate part of the water body is assigned a unique WID. In these limited cases, the MPCA will make a separate determination of whether each part of the waterbody is a wild rice water. See SONAR Part F. p.93 for further discussion and an example.

2. MPCA's decision to apply the standard to an entire WID for streams and rivers was more complex, and the MPCA considered many alternatives before deciding to apply the standard based on documented presence of the wild rice beneficial use at some point in the WID and to have the standard applicable to the entire WID. Briefly, the alternatives MPCA considered were:

   a. Applying the standard within a distance range from where the beneficial use is present or had been previously documented (MPCA at one time considered 800 meters upstream and downstream of where the rice was located). However, this proved unworkable because further investigation of sources used to identify wild rice waters showed a lack of evidence detailing the exact location of the rice. In some cases, this was due to how information was collected, but it is also because wild rice is known to move around within a water from year to year.

   b. Basing the identification of where the standard applies on the presence of suitable conditions in the wild rice water that would support wild rice. This idea was rejected as it would be very difficult to implement because of the variability of conditions for wild rice growth or the presence of other factors that could limit the growth of wild rice (e.g., wild rice will not grow where water levels vary too widely.)

   c. Establishing wild rice waters at a level smaller than a WID. This would require either subdividing existing WIDs into smaller units or establishing a wholly separate system of WIDs for wild rice waters. While it would be possible to request WID splits to better identify where wild rice might be present within an existing stream WID, it would not be reasonable to do so in every case. The WID is used by the MPCA as the main administrative designation used to assess whether a stream reach may be impaired for a variety of parameters such as dissolved oxygen, sulfate, nutrients and various toxic substances. While a series of smaller WIDs might better represent the location of wild rice, smaller WIDs would like make it more difficult for the MPCA and others to collect representative samples to characterize conditions for other parameters and would also create additional administrative and monitoring burdens. See SONAR Part 6F pp. 93-96 for further discussion.

After considering alternatives, the MPCA decided to establish wild rice waters at the WID level. This choice was reasonable because, as discussed in the SONAR at 39-41, the existing WID nomenclature provides a consistent, accessible, and reliable system to identify specific portions of streams and rivers as wild rice waters.

3. The MPCA recognizes that there may cases where the presence of wild rice within a large or very diverse WID does not justify the application of the standard to the entire WID. The MPCA had originally suggested a proposed amendment for Minn. R. Chapter 7053, which allowed the commissioner to determine that an effluent limit is not necessary under certain circumstances. These circumstances generally relate to the location of a discharge within the wild rice water; e.g., discharge from a facility only affects part of a wild rice water where there is no wild rice. Or there may be specific hydraulic or substrate conditions in the part of the WID that dischargers affects that would prevent growth of wild rice regardless of sulfate levels. Some commenters objected to this provision in the rule, and the EPA also suggested the removal of this provision. In Part IV of the Cover Memorandum to the November 22, 2017 response, MPCA proposed to remove this proposed provision from part 7053.0406, subpart 1. Even with the removal of the proposed amendment to Minn. R. Chapter 7053, there is an approach for situations where rice is not and cannot grow within part of a WID. In these situations, the MPCA can split the WID and conduct a use and value determination (see response to topic area 1.6 in Attachment 1 in MPCA's November 22, 2017 Response to Comments) to remove the wild rice beneficial use from the WID that does not support the beneficial use.

D. Future Identification of Additional Class 4D Wild Rice Waters and Triennial Standards Review

The proposed rule specifies that the sulfate standard applies only to Class 4D wild rice waters, and that those waters must be specified in rule. MPCA has proposed rule language requiring the Commissioner to solicit information about wild rice waters as part of the triennial standards review process that is mandated by the Clean Water Act. The MPCA would then, as a separate process, undertake rulemaking to add any waters to the list of Class 4D wild rice waters to which the standard applies.

Several commenters have raised concerns about the proposed rule language regarding soliciting future evidence for listing waters as Class 4D wild rice waters.

First, one commenter (Fond du Lac Band) stated that "the State admits that its methodology for identifying existing uses may fail, because it provides a process for parties to add water bodies to its list in the future by proving that a water has been used for wild rice in the past". The MPCA's acknowledgement that the list of Class 4D wild rice waters is likely to be incomplete and need to be updated does not mean that the methodology is a failure. The Clean Water Act has a rebuttable presumption that 101(a)(2) uses apply "unless states and authorized tribes show those uses are unattainable" (Water Quality Standards Regulatory Revisions, 80 Fed.

Reg. 51020 (Aug. 21, 2015).) There is no such presumption for non-101(a)(2) uses, such as wild rice, so it is not unreasonable or unexpected for states to designate such beneficial uses as they are found.

One commenter, WaterLegacy, stated that the Minn. R. 7050.041 Subp. 2 "proposed rule section requiring that the commissioner must solicit evidence that supports identifying additional wild rice waters as part of triennial review is, at best, superfluous." The MPCA agrees that we could solicit information about water bodies to add to the list of Class 4D wild rice waters without the proposed language. However, particularly given concern by Tribes and stakeholders about the lack of additions to the list of [WR] waters since their initial promulgation in 1998, the MPCA felt it was important to make our intent clear. Namely, that we are interested in gathering more information about waters that are not presently identified as proposed Class 4D wild rice waters due to a lack of information and will be specifically asking for the public to provide information for consideration in future rulemaking.

Other comments (Cleveland-Cliffs) found that the "MPCA's guidelines in proposed part 7050.0471 for how to demonstrate that the beneficial use exists in a water provide no further clarity. The proposed rule simply lists non-mandatory types of evidence that can be used to establish the beneficial use."

In this proposed rule language, the MPCA felt that it was important to give those people who wish to provide information to support future listing of waters some kind of goal or target for the information that they should be providing; therefore, the proposed rule language describes what the evidence must show in order for it to be used in development of a SONAR for a future rulemaking. The criteria and types of evidence listed mirror the process the MPCA went through to develop the proposed list of waters in this rulemaking. In developing the list of proposed wild rice waters the MPCA used not only a history of human harvest, but other evidence that rice was present in sufficient amounts (acreage, density) to support the beneficial use. The MPCA did not rely solely on human harvest history as one commenter (MCEA) implies.

Other commenters (e.g. Cleveland-Cliffs) are concerned that the criteria are insufficient because they do not require showing a history of harvest and density and acreage, which the commenter believes the legislative language requires. The MPCA responded to that concern in our November 22, 2017 Response, noting that Laws of Minn. 2011, 1st Special Session, ch. 2, article 4, section 32 states: The criteria shall include, but not be limited to, history of wild rice harvests, minimum acreage, and wild rice density. The MPCA has correctly interpreted the legislative directive to mean that all of these criteria can be considered in evaluating whether a water is a wild rice water to which the standard applies, but that the determination of a waterbody being a wild rice water does not require that the waterbody show a history of harvest and a certain acreage of rice and a certain density of rice. The usual statutory construction of the term "include" is that an illustrative example follows.

Commenters (WaterLegacy) stated that "the proposed rule adds no requirements that would increase the likelihood that additional wild rice waters would be listed in rulemaking. It would provide no benefit to citizen stakeholders or tribal rights holders who seek to protect wild rice." The MPCA believes the proposed rule does provide such benefit by providing an illustrative example of the types of evidence that parties interested in adding a water to the Class 4D wild rice waters list should be gathering.The MPCA believes the proposed rule language strikes a reasonable balance by articulating the criteria that the MPCA used to develop the list of wild rice waters proposed in this rule and setting that forth so that all interested parties know what kind of information they should be gathering to support a listing, without being overly restrictive about acceptable evidence.

Some commenters are concerned that additional Class 4D wild rice waters can only be added through rulemaking. WaterLegacy states that the MPCA's proposal of this provision "underscore[s] that – irrespective of evidence – it will not add any wild rice water prior to additional rulemaking" and implies that this is a flaw in the rulemaking.

Another commenter, Cleveland-Cliffs, states that "under the plain language of the proposed rule, a water could be regulated as a wild rice water simply on the basis of a person telling the MPCA that he or she observed a single animal (i.e., wildlife) eating some wild rice (i.e., using the grain as food). The result of MPCA's "criteria" would be either (a) that effectively *all* waters containing any amount of wild rice would be listed (because it seems likely that any water with even the smallest amount of wild rice has experienced at least one instance of an animal or human eating wild rice at some point since 1975), or (b) MPCA staff will exercise "best professional judgment" to draw the line between those waters that are "in" and those waters that are "out" of the Rule's reach, creating an inherent risk of arbitrary application of the rule."

The opposing nature of these comments demonstrates why it is reasonable, as the MPCA has proposed in the rule, to add Class 4D waters only through rulemaking. A rulemaking process, including a SONAR and public comment, will allow a full discussion of the evidence for identifying a water as a Class 4D wild rice water. The MPCA staff will exercise best professional judgement about what waters to propose as Class 4D waters, but that judgement will be subject to public review and comment, thereby preventing arbitrary application of the rule or a sulfate standard.

Some commenters are concerned about the types of evidence that the MPCA described as being needed to support the future listing of waters. Commenters were especially concerned about the two acre threshold mentioned. The MPCA believes that two acres of wild rice is sufficient, without additional corroborating evidence, to show that the beneficial use exists in the waterbody. If the MPCA is provided evidence that two acres of rice exist, or has existed since November 28, 1975, we would propose to add the waterbody to the Class 4D wild rice waters. However, if there is no evidence of two acres of wild rice, we would want to look at multiple lines of evidence to see if the beneficial use exists or has existed. A demonstration of two acres of wild rice is not required to identify a water as a Class 4D wild rice water.

Other commenters (1854 Treaty Authority) raised concerns that the list of criteria show that "[a]ny additions will undergo a more burdensome and scrutinous process than waters currently being proposed. To add waters, evidence could include meeting the minimum level of two acres of wild rice in a water, past or current human harvest, or other evidence of wild rice presence (oral histories, written records, photographs, field surveys, etc.)" The MPCA does not believe this is the case; the intent was for future criteria or evidence to be the same as the evidence that the MPCA used to propose Class 4D wild rice waters in this rulemaking. (See SONAR, pg 58 – 64).

Specific to the criteria about oral histories, WaterLegacy mentioned that "Oral histories of wild rice harvest are particularly salient to protection of tribal Treaty resources and are often referenced in tribal comments. Although the SONAR and MPCA's hearing presentations may suggest that MPCA 'recognizes the validity of written or oral histories about wild rice,' the proposed rule text belies this assertion. Written or oral histories about wild rice are only 'acceptable' as evidence if they 'meet the criteria of validity, reliability, and consistency.' No other form of evidence must meet these criteria to be considered 'acceptable.'" As stated in the SONAR (pg 62 and Exhibit 33), the MPCA drew these criteria from the way in which oral evidence was presented in the court case Zuni Tribe of New Mexico vs. United States. This strikes a reasonable balance that allows MPCA to accept important information from oral history and tradition while mitigating the potential for an erroneous listing based on hearsay.

E. Application of Wild Rice Sulfate Standard to Streams

MPCA received several comments asserting that the proposed equation should not apply to streams. The rationale stated was that sulfate does not convert to sulfide as readily in a stream as it does in a lake, because streams typically have more oxygen present in comparison to lakes (MESERB and Hall memorandum). The commenters are assuming that the greater oxygen that may occur in the surface water of streams penetrates the sediment and produces low porewater sulfide concentrations that do not conform to predictions. MPCA did investigate this question while developing the structural equation model (SEM) that was published as Pollman et al. (2017, Response Exhibit N.4). To test to see if there is a difference between the variables that control sulfide in streams and lakes, the residuals of the predictions were examined. Residuals are the difference between the observed sulfide and the predicted sulfide concentration. Residuals for both groups (lakes and streams) were normally distributed. Using a t-test to evaluate whether the mean differences between the two groups is significantly different from zero yielded a non-significant probability of $p = 0.63$. Therefore, the ability of SEM to predict sulfide was similar for lakes and streams, and there is no evidence that another variable not included in the model, such as oxygen, was influencing sulfide in stream sediment porewater differently between the two waterbody types.

If elevated oxygen were efficiently oxidizing sulfide in stream sediment, one would expect sulfide to have been consumed and not measureable. However, sulfide was measureable at all stream sites sampled during the MPCA-sponsored field work. Out of 232 sulfide measurements at lakes and streams, only three were below the lab's reporting limit of 11 micrograms per liter (i.e., near zero), and those occurred in two lakes, Carlos Avery (one measurement) and Height of Land (2 measurements, separated by a year). These low sulfide concentrations were probably the result of low availability of sulfate in the overlying water, as all sulfate concentrations from these lakes were below the lab's reporting limit of 0.5 mg/L sulfate.

Overall, these results are consistent with the premise that wild rice tends to grow at sites in waterbodies that accumulate organic matter in the sediment. Bacteria that colonize the accumulated organic matter consume all available oxygen, which allows the accumulation of sulfide.

Another commenter asserted that the "agency's field data is vastly skewed toward still water (27 streams compared to 81 lakes), and that the data has been molded into a mathematical expression that does not account for the differences between lakes and streams." (Mesabi Nugget). The assertion is immaterial, considering that the MPCA analysis (first paragraph above) found that the mathematical expression is not affected differently by lakes and streams.

Mesabi Nugget also suggested the MPCA should have collected data on water movement, and cited the repeated presence of healthy rice in Second Creek as evidence that the MPCA's equation is flawed. MPCA staff disagree with his conclusion that the equation is flawed. A detailed discussion of an alternative numeric standard approach that can apply to unique situations, such as Second Creek, can be found in the MPCA Technical Support Document (TSD) beginning on page 67.

F. Comments on Specific Waters Proposed or Not Proposed as Class 4D Wild Rice Waters

Representatives from three mining operations in northeastern Minnesota (ArcelorMittal Minorca Mine Inc. (ArcelorMittal), Cleveland-Cliffs, Inc. (Cliffs), and U. S. Steel – Minnesota Ore Operations (U.S. Steel)) submitted specific comments on individual waters proposed for inclusion in Minnesota Rules 7050.0471 as a Class 4D wild rice water. Comments on individual waters were also submitted on behalf of Northeastern Minnesotans for Wilderness and WaterLegacy. The specific proposals and MPCA's responses are summarized below.

<u>ArcelorMittal</u>

In its November 22, 2017 comment letter, ArcelorMittal provided information and recommendations on White Lake (69-0571-00) and the lower portion of the Embarrass River. ArcelorMittal requests that the MPCA:

- Remove White Lake, WID 69-0571-00 from the Proposed Rule, (Minn. R. 7050.0471, Subp. 3.C. (74)); and
- Remove the Lower Embarrass River from WID 04010201-577 (Minn. R. 7050.0471, Subp. 3.C. (17), thereby redefining the WID to only include Embarrass Lake to Esquagama Lake.

White Lake. White Lake (69-0571-00) was proposed as a wild rice water based on the initial listing of this lake in the March 24, 2016 version of the 1854 Treaty Authority's list of wild rice waters (SONAR Exhibit 24). In retrospect, the MPCA should also have included "Permittee" as a reference source applicable to this water based on the results from the December 29, 2011 wild rice survey conducted by Barr Engineering for ArcelorMittal and Figures 2 through 6 attached to the November 22, 2017 comment letter.

The background imagery of Figures 2 through 6 is of particular interest. Figure 2 background imagery is attributed to a 2010 aerial photograph from the U.S. Department of Agriculture's Farm Service Agency (FSA). In this photograph, along the northwest shore of White Lake just above the site label "60 sqft", there is a land extension that juts out into the lake. (This land extension is even more evident in another aerial photograph in the online historical aerial photographs collection from the University of Minnesota's John R. Borchert Map Library at: http://maps.dnr.state.mn.us/landview/historical_airphotos/projects/stl/y1981/stl_014_199.jpg). These two aerial photos show a more or less continuous extension of land jutting out into the lake. Comparing it to the background imagery in Figures 3 – 5 (2013) and Figure 6 (2016), one can see that the land jut becomes an island in the lake. The cause for this apparent difference is likely due to an increase in the water level of the lake. MPCA contends that the sparse number of wild rice plants observed during these surveys may have been associated with the elevated water levels that are reflected in these aerial photographs. Another possible contributing factor affecting the in-lake wild rice may have been elevated lake sulfate concentrations (two lake samples collected on August 18, 2011, each with 123 mg/L sulfate). MPCA staff do not agree with ArcelorMittal's request to remove White Lake from the proposed Class 4D wild rice waters list.

Embarrass River. The Embarrass River WID 04010201-577 is approximately 14.5 miles long with about 70 percent of its length being between Esquagama Lake and the St. Louis River. Based on the September 2017 Barr Engineering Embarrass River survey characterizing the sediment within this reach, MPCA agrees that redefining (splitting) WID 04010201-577 would be appropriate. MPCA will split this WID into two separate WIDs – one from Embarrass Lake through Esquagama Lake and the other from Esquagama Lake to the St. Louis River. The former will continue to be proposed as a Class 4D water and the latter will be added to the MPCA wild rice database as an Insufficient Information water.

Cleveland-Cliffs

Cliffs' November 22, 2017 comment letter (pages 19 – 22) questions the reasonableness of listing six individual waters as proposed Class 4D wild rice waters. A seventh waterbody noted, Dunka River, is considered an Insufficient Information water and is not being proposed as a Class 4D water. The specific concern with this water relates to the Dunka River entry in SONAR Attachment 5 that lists it as a proposed wild rice water. MPCA staff acknowledge this discrepancy and would like the hearing record reflect this acknowledgment.

MPCA's responses to the proposed Class 4D issues raised by Cliffs are summarized as follows.

Day Brook. The wild rice beneficial use of Day Brook (WID 07010103-542 in St. Louis and Itasca Counties) is discussed in MPCA's November 22, 2017 Post Hearing Response, Attachment 1 at page 17. The Permittee reference source of wild rice information came from the Barr Engineering technical memorandum with the subject heading *2011 Wild Rice Survey for Hibbing Taconite Company* dated December 22, 2011.

Mud Lake (69-0652-00) and Round Lake (69-0649-00). The primary reference source cited by the MPCA for both of these lakes is a November 9, 2011 Barr Engineering technical memorandum with the subject heading *Wild Rice Field Survey for United Taconite LLC*. Both lakes were surveyed once on August 19, 2011. The other reference source cited by MPCA for these lakes is the 1854 Treaty Authority wild rice waters list (SONAR Exhibit 24) although the 2011 Barr survey results were the primary reason these two lakes were added to the 1854 list.

At the time of the survey, a limited number of wild rice plants was observed. Field estimates of the cumulative total of wild rice plants were 65 and 95 for Mud Lake and Round Lake, respectively. The sulfate concentration in Mud Lake based on three samples averaged about 19.6 mg/L. Round Lake had sulfate concentrations less than 1 mg/L in all four of the samples that were collected.

Generally speaking, the 2011 wild rice production levels in northeast Minnesota lakes was characterized by the 1854 Treaty Authority as being "fair". The amount of wild rice on Mud and Round Lakes observed in 2011 fall way short of what would be considered as being "fair."

The nearest lake with 2011 water level records is Stone Lake (69-0686-00) which is about one-half mile south of Round Lake. For calendar year 2011, the water level in Stone Lake ranged from 0.4 to 1.1 feet below the lake's ordinary high water mark, with the lowest water levels occurring in June of that year. If lake water levels were below the ordinary high water marks for Mud and Round Lakes, water levels do not seem to be a factor influencing the limited amount of wild rice observed in these two lakes. That is not to say that 2011 was not a poor growing year in the natural wild rice cycle for these two lakes; it is difficult to say based on the one-time survey results.

Based on the above considerations, MPCA staff plan to remove Mud Lake (69-0652-00) and Round Lake (69-0649-00) from the list of proposed Class 4D waters and will maintain them in the MPCA wild rice database as insufficient Information waters pending the collection of additional wild rice information.

Perch Lake (69-0688-00). MDNR files in the St. Paul office contain a fisheries survey for Perch Lake (69-0688-00) from August 28 – 29, 1968. Wild rice density was assigned a density rating of "2". The emergent vegetation density rating scale in use at this time assigned the following numeric ratings: 4 for lush; 3 for moderate; 2 for scattered, and 1 for sparse. In addition, the survey noted "wild rice was concentrated in two areas on the northwest shoreline". The MDNR 2008 report (SONAR Exhibit 21) estimated wild rice coverage to be 32 acres. While the September 2017 Northeast Technical Services survey referenced provides useful information building upon the "wild rice story" specific to this waterbody, it does not alter MPCA's position on Perch Lake. MPCA maintains that Perch Lake (69-0688-00) should be proposed as a Class 4D water.

St. Louis River Segments. Cliffs identifies two separate entries for the St. Louis River – rule as proposed line number 58, St. Louis River WID 04010201-644 and line number 59, St. Louis River WID 04010201-631 and one entry for the St. Louis River/Estuary WID 04010201-532.

St. Louis River WID 04010201-631 is already in Minn. R. 7050.0471, subp. 1 as a wild rice water. This is the headwaters reach of the St. Louis River downstream of Seven Beaver Lake to the west side of Section 36, Twp.58, R.13. The next downstream WID, 04010201- 644, extends from the east line of Section 35, Twp. 58, R.13 to the Partridge River. There are four separate locations within this reach with wild rice identified by the 1854 Treaty Authority.

St. Louis River/Estuary WID 04010201-532 is the river reach from Mission Creek to the Oliver Bridge. In 2013 the UofM/MPCA wild rice field study had a sampling station within this reach that reported mid-summer wild rice stem counts averaging between 11.8 and 31.2 stems per square meter. Permittee wild rice surveys in this WID reach also reported wild rice. Barr Engineering conducted these permittee-sponsored surveys at the request of PolyMet Mining. These surveys were conducted in 2009, 2010, 2014, and 2016. Wild rice densities encountered within WID 04010201-532 during these surveys ranged from 1 to 5 at numerous sample site locations (see wild rice density classification description table below).

Wild Rice Density Classification	**Description**
1	<10% Wild Rice Coverage
2	10 – 25 % Wild Rive Coverage
3	25 – 50 % Wild Rice Coverage
4	50 – 75% Wild Rice Coverage
5	>75% Wild Rice Coverage

MPCA maintains the proposed Class 4D classification for these reaches of the St. Louis River and Estuary, as well a proposed Class 4D WID reach of the St. Louis Estuary (2) WID 04010201-533 (Oliver Bridge to Pokegama River).

Embarrass River. Cliffs questioned the reasonableness of proposing two Embarrass River WIDs as Class 4D waters: WID 04010201-577 (Embarrass Lake to the St. Louis River) and WID 04010201-579 (Headwaters to Embarrass Lake). [See also the discussion above regarding WID 04010201-577.]

There were a series of permittee sponsored wild rice and water quality monitoring surveys conducted by Barr Engineering for PolyMet Mining Inc. over the period 2009 – 2016 (SONAR Exhibit 30). These reports were evaluated by MPCA and the survey findings provided additional evidence supporting the Class 4D classification proposal for these two WID reaches of the Embarrass River.

Cliffs questioned whether one wild rice harvester trip on the Embarrass River was sufficient information to list the river as a wild rice water (see SONAR Exhibit 22). MPCA views one harvester trip to be more than adequate in support of the proposed Class 4D listing.

U.S. Steel.

Little Sandy Lake (69-0729-00) and Sandy Lake (69-0730-00). MPCA has provided Post Hearing response and additional exhibits concerning these two lakes (see MPCA November 22, 2017 Post Hearing Response – Attachment 1 at page 16 and MPCA Post Hearing response exhibits N. 28, N.35 – 37, and N. 39).

Little Sandy Lake and Sandy Lake are prime examples of waters where significant wild rice was present post November 28, 1975 but currently are experiencing a greatly diminished wild rice population. Since available information documents this existing use after the 1975 date, it is reasonable to propose that these two lakes be classified as Class 4D wild rice waters.

Northeastern Minnesotans for Wilderness.

The November 22, 2017 comment letter submitted by Northeastern Minnesotans for Wilderness offered support for inclusion of White Iron Lake (69-0004-00) as a wild rice water. MPCA staff acknowledge the statement of support and appreciate the comments.

WaterLegacy

Dark Lake (69-0790-00). Dark Lake is currently being maintained as an Insufficient Information water in the MPCA wild rice database. Dark Lake was not listed in MDNR's 2008 inventory of wild rice waters (SONAR Exhibit 21) but was included by the MDNR in response to the 2013 Call for Data (SONAR Exhibit 29). Dark Lake was among the waterbodies surveyed and sampled by University of Minnesota as part of the MPCA sponsored wild rice field survey.

In their comment letter, WaterLegacy provided comments on Dark Lake (page 37). MPCA's November 22, 2017 Response to Comments – Attachment 1 at page 15 discusses the reasons why Dark Lake (and Dark River) are not being proposed by the MPCA for Class 4D use classification during this rulemaking.

Upper Partridge River. WaterLegacy (at page 38) states that the portion of the Partridge River east of Colby Lake is not being proposed as a wild rice water. This is not the case. MPCA is proposing Partridge River WID 04010201-552 (Headwaters to St. Louis River) as a Class 4D wild rice water. The portion of the Partridge River east of Colby Lake is included in this WID.

G. Comments on Developing the Magnitude of the Standard

The MPCA continued to receive detailed comments relating to the development of the protective sulfide level and the resulting equation for calculating the numeric sulfate standard. Some of these comments included information on new studies, or more information on ongoing studies, while others related to data analysis and statistical approaches. Many of these comments were submitted by multiple commenters or referenced across comment letters.

1. Hydroponics Studies

   MPCA received multiple comments concerning the use of hydroponic studies in developing the proposed standard. In particularly, many commenters submitted results of a new hydroponics study conducted by Fort Environmental Laboratories in November 2017. The main discussion of this study is provided in the executive summary of the expert comments on behalf of the Iron Mining Association attached to comments submitted by a coalition of mining companies and Minnesota Power. The comments state:

   "Fort Environmental Laboratories conducted another hydroponics study in November 2017 (unpublished) in response to the MPCA speculations that the water depth was not deep enough in the previous Fort hydroponics study. The study design is substantially the same as that used in the published Fort et al 2017 study, but the water depth was increased from 1 cm to 6 cm. The study was conducted from November 3, 2017 to November 13, 2017. The study was conducted using Good Laboratory Practices, addressed all of the recommendations of the Peer Review Committee, and met all acceptability criteria. Results from the most recent study, as well as previous Fort et al studies confirmed:

   - That sulfide was not toxic to wild rice at concentrations observed in Minnesota wild rice waters;
   - That adequate oxygen was not present at sufficient levels in the test media to support detoxification based on the hypoxic environment, as speculated by the MPCA in their rejection of the 2017 Fort et al study.

- Rather complexation with Fe is the primary mitigating factor in terms of sulfide toxicity. Thus, the results suggest that detoxification of sulfide in the Fort et al. were also the result of Fe complexation rather than detoxification by the plant itself.
- The November 2017 study provides even more evidence that MPCA unreasonably rejected the published 2017 Fort et al study and should have given much more weight to its results."

The study design for the new, unpublished study, was not substantially the same as that used in the published Fort et al. 2017 study, as claimed. The study was 10 days instead of 21, was conducted in the dark, and did not include some biological endpoints such as mesocotyl (stem) length. The study does not have any bearing on whether the wild rice seedlings in Fort et al. (2017) were able to detoxify sulfide because the young seedlings in Fort et al. (2017) were afforded access to the elevated oxygen of the atmosphere. Rather, the new study repeated a similar exposure reported in Pastor et al. (2017). Both of these studies germinated seeds for 10 or 11 days in anoxic, dark conditions against a range of sulfide concentrations. Both studies showed that germination is not a growth stage that is very sensitive to elevated sulfide. The fact that the new Fort study showed that adding iron reduces the toxicity of sulfide has no bearing, despite assertions, on the reduced toxicity of sulfide when seedlings have access to the atmosphere. The new study did not even report the same biological endpoints, such as mesocotyl length, but rather just reported germination rate.

Furthermore, MPCA did not "reject" the 2017 Fort et al study. In fact, MPCA reviewed that study and included the results in the TSD (pp. 33-34, 37-38). The fact that the MPCA put less weight on that study in establishing the proposed protective sulfide concentration is not evidence that the Fort et al study was rejected or ignored. Notably, MPCA also gave less weight to some of the MPCA-sponsored studies TSD pp. 33-34, 38-39).

2. <u>Mesocosm Studies (Dr. Pastor)</u>

Multiple commenters (Water Legacy, Fond du Lac) stated that the MPCA's proposed equation would not result in defensible levels of sulfate because the equation treats iron as protective. These comments refer to research done using outdoor mesocosms by Dr. John Pastor at the University of Minnesota, Duluth; Dr. Pastor himself submitted comments and his research is discussed here based on his comments.

First, Dr. Pastor stated that "Our recent research at the University of Minnesota Duluth demonstrates that sulfide, not sulfate, is toxic to seedlings of wild rice. The MPCA proposes that iron can protect wild rice by precipitating with the sulfide. However, the addition of iron to mesocosms with high sulfate concentrations did not entirely mitigate the toxic effects of sulfide to seedlings. Our research also demonstrates that precipitation of iron sulfide on wild rice roots can inhibit nutrient uptake needed to ripen seeds, so iron sulfide can have negative effects on wild rice sustainability. Setting sulfate limits based on the level of sediment iron is premature and is not reasonable. (p. 2)…The net effect of sulfate additions to wild rice populations is to drive the populations to extinction within 4 or 5 years at high concentrations of sulfate (300 mg/l), even when iron was added to the sediments."

First, the MPCA wants to emphasize the first part of Dr. Pastor's comment. While other comments (Hansel attachment to Expert Comments) state that MPCA does not prove its hypothesis, in that there is no causal determination that sulfide in the porewater (e.g. the rooting zone) impacts the presence and density of wild rice, the hypothesis that porewater sulfide impacts the presence and density of wild rice is supported by the mesocosm results published in Pastor et al. (2017), as Dr. Pastor mentions above, and by the field data published by Myrbo et al. (2017), and the presentation of Myrbo's data on pages 51-52 of the TSD.

Turning to iron plaque formation, the only information the MPCA has on this issue is a four-page non-peer reviewed progress report (Pastor, 2017, N.34) that indicates that exposing sediment from Rice Portage Lake, which would have an equation-calculated numeric sulfate standard of about 34 mg/L (TSD, page 92). The only evidence presented by Pastor (2017) that iron plaque can inhibit nutrient uptake was performed at a treatment concentration of 300 mg/L, which is over eight times greater than the average sulfate concentration calculated for that mesocosm exposure using the equation under the proposed standard (34 mg/L). Thus, it may be true that deleterious forms of iron sulfide can form when sulfate concentrations occur that are much higher than would be allowed using the MPCA's proposed equation. Regarding the ineffectiveness of added iron: First, it is not clear how to calculate, or whether it is possible to calculate, what the equation-based standard would be after the addition of iron (the iron additions are of unstated quantity and form, and there are many chemical forms of iron). Therefore, it is unknown whether the failure of iron addition to protect wild rice is consistent or inconsistent with the equation.

Secondly, Dr. Pastor noted that "In addition, the MPCA's model assumes that concentrations of sulfide, sulfate, reactive iron and organic matter are in a steady state. This is not a reasonable assumption, especially once sulfate loading increases from various sources of pollution." (p. 2) He also commented that "the amount of reactive iron in a localized area will decline with increased sulfate loading, just as a checkbook balance declines when withdrawals increase without a matching increase in deposits. MPCA's model does not demonstrate that natural inputs of iron would replenish the reactive iron in the sediment commensurate with sulfate discharge. The model assumes, without evidence, that iron input will remain at a rate sufficient to ameliorate sulfide toxicity from the additional sulfate without creating additional adverse consequences for wild rice survival." (p.6)

This comment expresses a misunderstanding of the assumption of steady state and how an increase in sulfate in a given wild rice water will affect the prediction of the new sulfide concentration, once the water body reaches a new steady state. First, it is common and reasonable for scientists to assume that porewater sulfide is in a steady state with the controlling variables of sulfate, TOC, and iron (TSD p. 43 and Pollman et al. (Response Exhibit N.4). Because the MPCA's equation was fit to real observations in natural systems at steady state, the equation describing those relationships predicts the effect of an increase in sulfate at a particular combination of TOC and iron as modeled by waters in a steady state with similar TOC and iron, but higher sulfate. The assumption that the waters in the calibration data set are in steady state includes the assumption that there is a continuous supply of iron to the waterbody from its watershed, so that it can be assumed, contrary to Dr. Pastor's comment, that iron input will remain at a rate sufficient to ameliorate sulfide toxicity.

Finally, Dr. Pastor commented that "Both historic field data and the recent field surveys performed by the University of Minnesota as part of the Wild Rice Sulfate Standards Study demonstrate that concentrations of sulfate in surface water above 10 mg/L proposed in the MPCA's flexible standard may not adequately protect wild rice." (p. 2)

The evidence cited by Dr. Pastor for this assertion are two: (1) that most lakes with wild rice currently have low sulfate, and (2) that Sandy Lake has lost most of its wild rice even though its current sulfate concentration (cited as 95 mg/L, but actually 125 mg/L when MPCA study site Sandy-1, influenced by an incoming low-sulfate stream is not included) is only slightly higher than the average calculated standard (from 10 MPCA samplings), which is 79 mg/L.

Regarding (1), the correlation of wild rice with low sulfate does not indicate cause and effect between sulfate and wild rice, which is what the 10 mg/L standard was based on. The MPCA-sponsored research clearly demonstrated, in peer-reviewed publications, that the true cause and effect is more complicated, and that the production of porewater sulfide is primarily responsible for the presence and absence of wild rice in Minnesota (Myrbo et al. 2017, Response Exhibit N.2). As documented in Myrbo et al. there is no statistically significant relationship between sulfate concentration and wild rice occurrence, whereas there is a highly significant relationship with porewater sulfide.

Regarding (2), first, MPCA is proposing to use the lowest calculated standard, not the average. Second, sulfate concentrations declined significantly in recent years due to sulfate mitigation efforts by nearby Minntac. The wild rice was mainly lost by 2004 (according to a draft EIS titled Minntac Water Inventory Reduction) when sulfate concentrations were much higher than observed by the MPCA in 2013. The draft EIS cites a pre-Minntac sulfate concentration of 7.6 mg/L. Thus, the loss of wild rice in Sandy Lake is consistent with exceedances of equation-calculated standards, and the observations do not support Dr. Pastor's comment.

3. <u>Field Surveys and Data</u>

Many commenters raised concerns about the MPCA's use of field survey data. For example, one commenter (Hansel attachment to Expert Comments), stated that "Unlike the state-of-the-art controlled hydroponic studies, the field surveys are entirely uncontrolled. The wild rice growing in the wild rice waters (and non-wild rice waters) surveyed were subject to weather and all of the other stressors which can affect the presence and density of wild rice. MPCA acknowledges that several of these other stressors are "statistically significant", yet does nothing to separate their effects from the effects of sulfide. Instead, MPCA ascribes all ill effects on wild rice to sulfide and sulfide alone…MPCA ignores other stressors of wild rice, several of which the MPCA determined were statistically significant, in determining the sulfide and sulfide alone impacts the growth and density of wild rice."

The MPCA did not ascribe all ill effects on wild rice to sulfide and sulfide alone. On page 23 of the TSD, MPCA summarizes its investigation into the multiple factors that control wild rice:
"Performing *multiple* BLR with more than one variable demonstrated that porewater sulfide is one of three primary independent variables correlated with wild rice occurrence (Myrbo et al., in press-1): porewater sulfide, water transparency, and water temperature. The statistical analysis strongly supports the conclusion that sulfide independently affects wild rice presence and absence (p=0.001; Table 1-3), which implies that limiting sulfate availability has the potential to protect wild rice from elevated sulfide." As MPCA noted in the 11/22/17 Response to Comments (p. 3) "the fact that other factors than sulfate…also affect wild rice does not by itself negate the need for or reasonableness of a revised sulfate standard to protect wild rice from *sulfate* impacts."

This commenter continues to note that "MPCA does not resolve the inconsistencies between the results of the hydroponic studies (where only sulfide or sulfate are stressing the wild rice) and the field surveys, where multiple stressors are operating on the wild rice." MPCA finds that the data are remarkably consistent, except for the results of Fort et al. (2017), as presented on pages 33-34 of the TSD.

Some commenters were specifically concerned about the field data and the related analysis to develop the protective sulfide concentration. Comments from the Great Lakes Indian Fish and Wildlife

Commission (GLIFWC) discussed the MPCA's visual examination of the proportion of waterbodies with wild rice present, noting that "The graphical method used to identify 120 ug/L of pore water sulfide as the 'protective concentration' is conceptually flawed and cannot be used to identify a change in response of rice to sulfide concentration. The 'dip' at 120 ug/L of sulfide, identified in Figure 1-5 of the FTSD and Figure A7-3 of Appendix 7 of the FTSD, is an artifact of the number of samples with a concentration near 120 ug/L. The dip does not represent a response of rice to sulfide." (p. 3)

This commenter also stated that "The field-data based methods used to identify 120 ug/L of pore-water sulfide as the 'protective' level are either faulty (the visual examination of graphical representation) or generate highly variable results and are data-set dependent (EC10 on logistic regression and change-point analysis). The field survey data sets were not collected in a statistically rigorous manner and are not adequate to identify any particular 'protective' level of sulfide using these methods." (p. 7)

It may be true that the graphical method is conceptually flawed. Regardless, it is still a useful analysis. The MPCA relied on multiple lines of evidence from quantitative analyses of the MPCA-sponsored hydroponic, mesocosm, and field data, the central tendencies of which tend to cluster near 120 µg/l, albeit with relatively large 95% uncertainty ranges (TSD Table 1-8, page 33).

The commenter asserts that the field survey data sets were not collected in a statistically rigorous manner, without actually stating an actual problem with the data set. The easiest and most common conformance to a "statistically rigorous" dataset would be to sample sites randomly, so as to be probability-based. This issue was addressed in the MPCA June 2014 report that was peer reviewed. The MPCA wrote (p. 21):

Statisticians recommend that surveys be probability-based when the point of the survey is to characterize the population being sampled. Probability-based surveys allow survey results to be extrapolated back to a larger population. The 2012-2013 Field Survey was purposefully not probability based, in that the point was not to characterize the population of wild rice production waters, but rather to explore the effect of elevated sulfate on the chemistry of the porewater of actual and potential wild rice habitat. If wild rice habitats had been sampled probabilistically, most of the sites would have had very low sulfate concentrations and little would have been learned about the effect of elevated sulfate. To ensure that the Study included samples from waters with elevated sulfate concentrations, the survey sites were intentionally not chosen in a random manner.

After presentation and interpretation of several databases, MPCA concluded (p. 23):

In summary, the 2012-2013 Field Survey of lakes has a sulfate frequency distribution that is intermediate between the probability-based USEPA survey and the 513 sulfate values that were available for the 1,290 wild rice lakes identified by the DNR (2008). The intermediate position means that the Field Survey sampled more high-sulfate lakes than would be expected if only known wild rice lakes were sampled, but fewer than would be expected if all lakes in the state were sampled probabilistically. Given that wild rice does not occur naturally in all lakes of the state, and that a major goal of the Field Survey was to assess the effect of elevated sulfate on wild rice, the site selection approach used for the Field Survey could be just right. The intent of the sampling was to find variation in sulfate while maintaining all other parameters suitable for wild rice growth (water transparency, water depth, pH, alkalinity, hardness, etc.). If this was accomplished, then the Field Survey could be interpreted as functioning as a sampling of a natural experiment that can be used to evaluate the effect of sulfate on wild rice.

Therefore, the MPCA sampled a range of lakes that was appropriate to answering the question of the effect of sulfate (and consequently sulfide) on wild rice. The MPCA data were analyzed by Myrbo et al. 2017 (Response Exhibit N.2), in which logistic regressions were presented and used to support the conclusion that porewater sulfide is a primary controller of wild rice presence and absence. During the journal's peer review process, the representativeness of the dataset was not raised as a concern by the reviewers. It is therefore not reasonable for GLIFWC to claim that an EC10 derived from the same logistic regression is not valid. Similarly, there is no reason that change-point in wild rice density should not be analyzed on the same dataset.

Another commenter (Bock attachment to Expert Comments) raised concerns about the MPCA's use and analysis of the field data. First, this commenter stated that "An examination of the field data shows that there are a great many waterbodies in the MPCA dataset that exhibit porewater sulfide concentrations that exceed the MPCA threshold (>120 µg/l) and also possess healthy stands of wild rice. This finding calls into question the validity of MPCA threshold and suggests problems in how MPCA used the field data to derive a threshold." Dr. Bock asserts that there are many waterbodies that exceed the protective sulfide level of 120 µg /L that possess healthy stands of wild rice. The only information on the health of the stands is the density, which the MPCA has shown continuously declines above 120 µg /L (TSD, pp 50-52).

This commenter goes on to state that "the results of these analysis show that the single change point identified by MPCA is not unique and in fact does not represent a change point that can be associated with a change in wild rice density." However, Change-point analysis, when restricted to identifying the single largest reduction in wild rice density, finds a significant reduction in wild rice density at 112 micrograms per liter, from an average of 68 stems per square meter below 112, to 34 stems per square meter above 112. This analysis was independently confirmed (presented in the GLIFWC comments).

Third, this commenter says that "although MPCA does fit the field data to a dose-response curve, the data do not fit the assumptions of the statistical model and therefore any sulfide threshold derived using this method should not be used." MPCA notes that toxicologists fit dose-response data to a variety of curves, so it is incorrect to say that the data do not fit the assumptions of the statistical model.

This commenter also analyzed the field data and finds "no evidence that increasing the sulfide threshold to values 2-3 times the MPCA value would lead to a discernible decrease in the health of wild rice. There is insufficient data to reliably evaluate higher thresholds. MPCA unreasonably excludes the alternative threshold of 300 µg/l in TSD Appendix 9."The only metric available to assess the "health" of wild rice is the density of the rice in the waterbody. The MPCA demonstrated in TSD Appendix 9 that the density of rice decreases significantly above 120, so 300 µg/L would not be protective of the health of wild rice. Therefore, MPCA reasonably excluded the alternative threshold of 300 µg/L as demonstrated in TSD Appendix 9.

Finally, commenters continued to question the MPCA's use of field data from waters that are not being proposed as Class 4D wild rice waters in order to determine protective levels of sulfide and sulfide. The MPCA used procedures commonly used by conservation biologists to identify habitat requirements for species, which require the sampling of habitat that does not support the species of interest (page 8 of the TSD):

> "Binary logistic regression (BLR) is the classic method for scientists to identify environmental variables that control the suitability of habitat for a particular species of interest (Hosmer and Lemeshow, 1989; Peeters and Gardeniers, 1998; van der Heide et al., 2009). BLR is "binary" in the sense that it classifies field sites as having, or not having, the species of interest—in this approach, the density of the species is irrelevant to the classification. Conservation biologists use binary information (presence/absence) in the analysis of habitat suitability; density is rarely used because representative density data are difficult to obtain and density can be a function of factors unrelated to the long-term suitability of the habitat."

See also Attachment 1 of the MPCA's 11/22/17 Response to Comments.

4. Effect Concentration

Some commenters raised specific questions about the effect concentration chosen by the MPCA.

NCASI states that "It is unclear from the TSD why MPCA first selected the EC20 for the wild rice response effect level of interest, and later decided to use the EC10." (p. 1). This issue was discussed in detail in the TSD (pages 31-32). The choice of EC10 was a risk management decision by the MPCA.

Others (Richard, attachment to expert comments) stated that "The peer-reviewed article does not contain an EC10 so it should be noted that any EC10 based on these data were not evaluated during the peer-review process for publication. In a meta-analysis performed for MPCA, Pastor calculated an EC10 of 299 µg/L." The MPCA is not aware that Pastor calculated an EC10.

Several commenters (USFS, Fond du Lac Band, Tuominen) suggested that the MPCA should have considered using an EC5 or NOEC concentration rather than an EC10 concentration in establishing the protective sulfide level. Other commenters (NCASI) suggested that the use of an EC10 approach was overly conservative and an EC20 should have been used. The reasonableness of the EC10 approach compared to a higher EC (EC20-EC50) is discussed in detail in the TSD (pp. 31-32). This section focuses on the reasonableness of MPCA's use of EC10 concentrations rather than an EC5 or NOEC calculation.

The effect concentration concept in general is explained on pp. 31-32 of the TSD, as well as the history of MPCA's analyses of effect concentration (EC). The proposed protective sulfide concentration of 120 µ/L is based on a visual observation of the field data with corroborating evidence provided by change-point analysis of the field data and EC10 calculations from the hydroponic, mesocosm and field data.

Commenters stated that MPCA did not adequately discuss its choice to rely on an EC10 in the development of the protective sulfide level rather than EC5 calculations. The Fond du Lac band suggested an EC5 and compared it to the "extirpation coefficient" of five used by EPA in developing a benchmark conductivity standard. Fond du Lac suggests that "the EC5 or even the 'no effect' concentration (NOEC) is the reasonable protective concentration, when holistically considering the ecology of wild rice, its vastly diminished geographic range, its natural annual variability in production, and the adverse effects of other well-known stressors such as hydrologic alterations, invasive species, and climate change."

MPCA's use of EC10 calculations in the development of the protective sulfide concentration is reasonable because in a toxicological study, the tail ends of the dose-response curve are not as reliably estimated as the center of the curve (such as an EC50). The closer to the tail end of the curve (such as towards an EC0) you get, the less certain you are in the estimation. A no effect concentration is often represented as an EC5 or EC10, and these protective values were considered. The EC10 was chosen because it could be estimated more reliably than an EC5, but still represent a concentration that would elicit minimal effect.

5. <u>Sulfate/Sulfide Model</u>

Comments were received on the MPCA's model of the interactions surrounding sulfate and sulfide formation.

One commenter (Hansel) stated that "MPCA, though alerted by their own peer review panel, misconceptualized the hydrogeological conditions under which sulfate is delivered to sediment beds. This flawed conceptual model led to the following issues which pervade their analysis:

- Unreasonably assuming that chemical diffusion of sulfate from an overlying water column to the sediment porewater is a process favored in these environments; and
- Unreasonably excluding important controlling variables, such as the concentrations of iron and sulfate in groundwater, from field survey data collection."

MPCA's conceptualization of the hydrogeologic conditions is an accepted scientific approach. Diffusion of sulfate in surface water into the sediment porewater has been demonstrated in the peer-reviewed literature by the few sulfate addition experiments (both purposeful and natural) that have been made, where it has been noted that sulfide increases in the underlying sediment (Little Rock Lake, Wisconsin (Response Exhibit N.42)), a lake in the Experimental Lakes Area, north of International Falls, Minnesota (Response Exhibit N.41), and two lakes and a wetland receiving sulfate drainage from the iron range in Minnesota (Response Exhibits N.43 and N.44).

It would have not been reasonable to collect local groundwater samples from field survey sites, since installing wells is time-consuming and expensive. It was a major expense for the MPCA to install wells adjacent to Second Creek for the intensive study conducted by Ng et al. (2017). Rather than collecting empirical data, MPCA relied on the peer-reviewed scientific literature to inform its conceptual model, as noted above and in the TSD (Section 1D).

Another commenter, NCASI, found MPCA's model generally reasonable but noted that other models could be used, stating: "Finally, with respect to MPCA's reliance on the empirical sulfate model, we note that representation of the basic concepts of H2S formation (i.e. dependent upon available carbon and sulfide) in the model appears reasonable. Nonetheless, some widely used water quality computer simulation models (e.g., Water Quality Analysis Simulation Program, or WASP) predict H2S in porewaters using an approach that incorporates the underlying mechanisms that control sulfur chemistry, rather than relying on purely statistical relationships. Such a mechanistic approach could improve upon MPCA's empirical model, especially for predictions at locations not represented in the derivation of the empirical model."

The MPCA considered using a mechanistic model and determined that an empirical model would meet the needs of the state better (TSD, p. 41-43). In addition, the peer review panel recommended use of empirical modeling, in particular structural equation modeling.

6. Equation Development

Some commenters (Roberts) raised specific concerns about how the MPCA developed the probabilistic equation with the MBLR. This includes comments that "The reasons for changing from a deterministic equation to a probabilistic one are not fully explained in the TSD. The main reason given in the TSD is that it is supposed to avoid a phenomenon called re-transformation bias, sometimes also called back-transformation bias. This phenomenon occurs when a linear equation is fitted to logarithmically transformed data…The TSD provides no explanation of how the MBLR approach overcomes this bias. In fact, the claim that the MBLR approach overcomes the re-transformation bias actually is subject to serious doubt, because the derivation of the MBLR equation starts from a regression formula applied to log-transformed data. (That regression formula is presented in subsection (c) below.)" (pg 6)

The reasons for the change in equation approach are noted in the TSD as the commenter asserts, and explained in more detail in supporting information to the TSD, particularly the Pollman et. al. journal article (2017, Response Exhibit N.4). Transformation bias becomes an issue when the dependent variable is initially transformed to better fit the underlying assumption of linearity inherent in linear regression modeling. The bias is imposed on the back-transformation of predicted dependent variable values to their original (un-transformed) form because the back-transformation typically does not explicitly account for the effect of model residuals (model error) on the predicted and subsequently back-transformed value.

With MBLR, the transformation of the dependent variable is categorical and binary, with the two categories delineated by a threshold value of the original dependent variable. The MBLR model predicts the likelihood or probability that a given set of values for the independent variables will exceed the threshold value; it does not predict the threshold value. The threshold value is determined separately and external to the MBLR, and there is thus no back-transformation and associated bias relevant to the MBLR modeling.

In addition, the MBLR-calculated sulfate concentrations are more accurate than SEM-calculated numbers (16% misclassification rate for MBLR vs. 26% for SEM; TSD page 49), consistent with the elimination of back-transformation bias. Also, note that the peer-reviewed article by Pollman et al. (2017, Response Exhibit N.4) recommends the use of MBLR over SEM for predictions to avoid the back-transformation bias.

The commenter also stated that "Whether or not the decision to set p = 0.5 is protective of wild rice is much more debatable, however. Accepting it would mean that we were settling for a 50% chance of wild rice being protected at the EC10 level that was recommended by the peer review panel. This seems inadequate for protecting wild rice. Therefore a lower probability would be needed to be protective of wild rice. The TSD provides no discussion or citation to support the assumption that a 50% chance of protecting wild rice would be sufficiently protective. Absent a compelling rationale to the contrary, simple logic suggests that a lower probability would be needed to be protective of wild rice." (pg 7) The discussion that addresses the degree of protection set by p=0.5 is discussed in the TSD (p. 46) and more extensively in Appendix 8 of the TSD (pp. 123-126).

7. Error Rate

Some commenters raised questions about the error rate – particularly in how it was described and discussed. One commenter (NCASI) stated that "MPCA's error rate analysis focuses on the relationship between pore water sulfide concentration and water column sulfate concentration, rather than the relationship between sulfate (the target of criteria and management) and the wild rice response. Therefore, the error rates presented are likely underestimates of the overall false positive and false negative error rates" (p. 2)

Although it might be a worthy goal to calculate error rates that extend from sulfide to the presence or density of wild rice, it is not practical, and therefore not a reasonable goal. It is not practical because wild rice does not appear in a waterbody just because sulfide is low. Because of environmental variables that have not been studied rigorously, and therefore are poorly understood, there are many waterbodies with low porewater sulfide but no wild rice population. Beyond presence and absence, wild rice is infamous for having wild swings in density from year to year even in a well-established wild rice water. Because there are other variables aside from sulfide that control wild rice presence and density, it is not possible to calculate error rates that relate the variables that control sulfide (sulfate, TOC, and iron) to wild rice.

This commenter also notes that "As an additional consequence, the comparison made to the error rates estimated by the state of Vermont in their nutrient criteria development document, which include the relationships between nutrient concentration and biological responses (see TSD at pp. 62-63), does not seem to be an "apples-to-apples" comparison." (p. 3) Similarly, another commenter (Richards) states that "MPCA neglected to explain the Vermont process and highlight how the process was very different from the MPCA approach for the MBLR sulfate equation. In particular, specific to the implementation of the Vermont nutrient criteria, an integrated approach to implementation is also presented by Vermont. The integrated approach used by Vermont allows for compliance with nutrient criteria to be evaluated by either comparison to nutrient criteria or by comparison to nutrient response variables (e.g., macroinvertebrate community health). This integrated approach is used because of the misclassification rates of 20 to 40%. An integrated approach that might be considered is the presence and health of the wild rice in the wild rice water body and if the wild rice were present and healthy, then compliance is demonstrated. Given the amount of MPCA MBLR sulfate misclassification rate, an integrated approach is warranted."

MPCA never claimed that the Vermont approach was the same as ours, only that it was an approach used (which we then used to help evaluate our approach). The Vermont approach for lakes relates phosphorus to phytoplankton density. Vermont is able to do this because all waterbodies have phytoplankton, which will grow to greater density when more phosphorus is available. The fact that MPCA's approach to developing a standard was different than Vermont's does not mean that the use of error rate analysis as a tool to help evaluate MPCA's proposed standard is inappropriate. It is appropriate for Vermont to take an integrated approach, which allows for compliance with, say, phosphorus standards combined with the biological response, which would be the invertebrate community in a stream. If monitoring the invertebrate community shows that phosphorus is too high, the community will presumably recover fairly rapidly after phosphorus is decreased. However, it would be inappropriate to try to detect a decline in health of a wild rice population by monitoring, given the naturally chaotic fluctuations in wild rice density. By the time that wild rice is definitely harmed by elevated porewater sulfide, the sediment reactive iron would have been overwhelmed by sulfide, and recovery would take many years. Facilitating the recovery of wetlands with sulfidic sediment is problematic, and has rarely been studied (TSD, p. 100).

8. Effect of Sulfide on Wild Rice

Many comments received express general skepticism that sulfate (because of its relationship to sulfide) is an important controller of the presence of wild rice.

One commenter (Tedrow attachment to Expert comments) focuses extensively on the idea that competing vegetation in waters (particularly water lilies) and water depth control are an important factor for wild rice growth, implying that these are more important factors than sulfide. These comments seemed to be based on a misconception regarding the goal of the current rulemaking. The goal is not to manipulate the environment to encourage wild rice growth. Rather, the goal is to develop a sulfate standard so that the wild rice beneficial use is not impaired by porewater sulfide, regardless of any other factor that might be affecting wild rice. The MPCA acknowledged in the TSD that many other factors affect the success of wild rice in shallow aquatic systems (TSD, pp 23-31), and has also addressed comments related to this topic in its 11/22/17 Response to Comments. Also, regarding the commenters reference to water lilies and competition with wild rice, MPCA agrees that abundant water lilies can exclude wild rice from habitat that would otherwise be suitable for wild rice. Nevertheless, the presence of waterlilies can also be used as a sign that a site has a high probability of being suitable habitat for wild rice in the absence of water lilies.

Another commenter (Hansel) states that "the MPCA has not and cannot provide any studies, literature or other evidence that reducing sulfate in discharges to surface waters will effectively reduce sulfide in the porewater in wild rice waters. Indeed, Berndt et al. reach an entirely opposite conclusion…MPCA has not and cannot provide any studies, literature or other evidence that reducing sulfate in the water column will reduce sulfide in the porewater. This was simply not tested in any of the studies, nor in any of the literature cited by the MPCA. Yet the proposed rule explicitly says that this is what needs to happen to comply with the rule."

The reference to Berndt et al. is misleading, in that it concerns the St. Louis River, which has no wild rice habitat in the section studied. The experiments that added sulfate and showed increases in sulfide imply to the observer that decreases in the sulfate load would cause a decrease in sulfide: sulfate increases caused sulfide increases in the underlying sediment (Little Rock Lake, Wisconsin (Response Exhibit N.42)), a lake in the Experimental Lakes Area, north of International Falls, Minnesota (Response Exhibit N.41), and two lakes and a wetland receiving sulfate drainage from the iron range in Minnesota (Response Exhibits N.43 and N.44). It is highly likely that decreasing sulfate loading will decrease sulfide production. Be that as it may, the primary benefit of water quality standards is to protect waters from excessive increases.

9. Use of Conservative Assumptions

Several commenters asserted that the MPCA's standard is based on a number of overly conservative assumptions (Alexandria Lakes Sanitary District, MESERB) without providing specific detail about the assumptions. The implications are that these conservative assumptions compound through the rulemaking, resulting in a sulfate standard that will be overly stringent.

Cleveland Cliffs provided the following specific comment on MPCA assumptions associated with the standard; the substance of this comment is also largely echoed by USS.

"Furthermore, the protocol unreasonably proposes to apply the lowest sulfate standard to be the water body's sulfate standard. This introduces an additional level of conservatism for two reasons:

> 1. MPCA has not specified that only areas of the water body capable of supporting wild rice based on criteria such as water depth and sediment type be sampled. Therefore, the water body specific sulfate standard could be designed to control pore water sulfide in areas incapable of supporting wild rice and therefore wild rice would not benefit from implementation of the standard.
>
> 2. Statistically, the lowest sulfate standard approximates the 20th percentile of the distribution of possible sulfate standards. In brief, 4/5 samples, or 80% will have higher standards. We can combine the probabilities associated with the EC10 and the 20th percentile by multiplication as such: 10% x 20% is 2 %. That means that 2 % of the potential population of wild rice could be affected while 98% are predicted to be unaffected. This is much more conservative that limiting the effects to a 10% level specified by the EC10. This pattern is repeated because additional conservative inputs have been added, such as the currently recommended sulfide threshold of 120 µg/L, which is a factor of 10 lower than the NOEC from both the Fort et al. (2017) as well as the newly conducted Fort November of 2017 results. The final probability is the product of the individual probabilities. For example, if we take that 95% confidence level of the Ec10 and apply that to the 20th percentile sulfate standard for a sulfide standard that is over a factor of 100 too low. The true level of conservatism is 5% x 10% x 20% x 10% or in other words 0.01%.
>
> Conclusions: Conservatism on the order of one one-hundredth of a percent or more is not reasonable, and therefore the use of the lowest calculated protective sulfate value for a water body is not reasonable. We recommend using some type of averaging of the results. (p. 12-13)"

This comment claims that the MPCA makes three conservative (i.e., overprotective) choices and that these three choices in combination compounds the conservatism into a standard that is exceedingly overprotective. These three choices are:

1) the choice of the EC10 (as opposed to a less protective level such as the EC20);

2) the requirement that the protective sulfate standard for a waterbody will be based on the lowest calculated protective sulfate value from five samples from the waterbody; and

3) the fact that a 120 µg/L protective threshold for sulfide concentration is too low when compared to the NOEC from the Fort et al study.

The MPCA maintains that none of these three choices is overly conservative and thus there is no compounding of conservatism when these choices are made in combination. Defenses of each of these three choices as reasonable and appropriate (and not overly-conservative) – the EC10, the five sample requirement, and the 120 µg/L protective sulfide threshold – are each addressed elsewhere in these comments and in other rulemaking support documents. MPCA's choice of EC10 over EC 20 is discussed in detail in the Technical Support Document pp. 31-32. The use of the lowest calculated protective sulfate value is discussed in detail in the SONAR (p. 88) and the reasonableness of 120 µg/L is discussed in the SONAR (pp. 66-72). One other point that the commenter seems to make is that the conservatism is further compounded by using the lower bound of the 95% confidence interval around the EC10 point estimate. This, however, is not what the MPCA did. The MPCA used the EC10 point estimate itself, not the lower bound of the confidence interval around that estimate.

The MPCA has adequately demonstrated through the SONAR, TSD, and multiple responses to comment that sulfide is a factor that impacts wild rice and that the proposed rule is reasonable to protect the wild rice beneficial use from that adverse impact.

H. Duration and Related Flow Rate; Seasonality; Frequency of the Proposed Standard

Several commenters raised concerns about the duration of the standard – proposed as an annual average – and the flow rate that the MPCA proposed as the critical flow condition to evaluate in effluent limit reviews. Comments also were received about a seasonal component to the rules and the proposed one-in-ten year frequency of the standard. Most of these comments involved questions and concerns about how these elements of the rule proposal would affect the effluent limit review process and how they would allow (or not allow) higher levels of sulfate discharge from permitted facilities.

<u>Duration of the standard and related flow rate</u>

Duration: Several commenters raised concerns that the MPCA's proposed standard, by including an annual average duration and a related 365Q10 flow rate for effluent limit review, asserting that this approach would allow for high sulfate discharges that could harm wild rice. (MCEA, USFS, 1854 Treaty Authority)

Some of these comments seem to confuse a water quality standard and an effluent limit. As noted on page 96 of the SONAR and MPCA Hearing Exhibit L7, a standard applies in a water body to protect a specified beneficial use; an effluent limit applies to the discharge of a permitted facility and are an important tool in ensuring that a water quality standard is met in the receiving water(s) to which the facility discharges.

As noted on pages 15 and 79 of the SONAR, the duration and frequency of a standard are important components of understanding how a standard will be applied.

Commenters have also raised concerns that the annual average would allow some time periods of quite high sulfate discharge. For example:

- Water Legacy stated: "In practice, the MPCA would allow every sulfate discharger to use year-round dilution based on averaging of snow melt and other highest water flow conditions even if the discharge were taking place during the driest week of the year, when far less flow would be available to dilute sulfate pollution. MPCA's proposed rule would relax pollution limits based on annual average flow even in shallow streams, common natural habitats for wild rice, which may have little or no flow available to dilute pollution."

- The 1854 Treaty Authority, also raised concerns that "dischargers could potentially 'flush' their systems and release high concentrations of sulfate during certain times of the year, and attempt to reduce or stop discharges during other times" and stated that this kind of discharge regime would be a problem.
- The Fond du Lac Band expressed concern that the annual average allows high levels of sulfate to be discharged to wild rice waters while the mesocosm experiments "suggests that there actually may be a discrete time in the growing season when wild rice plants are exceptionally vulnerable to the effect of sulfate loading and reduction to sulfide." The Nature Conservancy expressed a similar concern.

Fond du Lac Band and the Nature Conservancy assertion that wild rice has periods in its life cycle during which it is exceptionally vulnerable does not change the reasonableness of the proposed annual average duration. Myrbo et al. (Exhibit 18 of rulemaking) showed that there is no significant seasonal trend in porewater sulfide over the wild rice growing season. Since porewater sulfide does not vary significantly over the growing season, then protecting for sulfide during all periods of the year is also protective of sulfide over any single period. Consequently, protecting for sulfide over an annual average period is protective of all periods of the wild rice life cycle including any period during which the wild rice may be most sensitive. This further demonstrates the reasonableness of the proposed annual duration.

Water Legacy also stated that "MPCA attempts to justify use of an annual average since sulfate is not a direct toxicant upon wild rice. However, other pollutants controlled by water quality standards are not direct toxicants. Discharge limits for mercury, for example, are set to prevent the methylation of mercury and the bioaccumulation of mercury in the aquatic food chain. Mercury monitoring and effluent limits are generally based on a daily maximum and a calculated monthly average."

MPCA does routinely interpret the duration of mercury surface water quality standard as a 30 day average during NPDES permitting in order to protect for bio-geochemical processes with multi-year effects such as mercury bioaccumulation in the aquatic food chain. An annual average standard does not imply that effluent limits will always be set on an annual basis. Water Legacy appears to be confusing effluent limits and water quality standards in this instance.

Pages 79-81 of the SONAR and 91-94 of the TSD provide extensive discussions of MPCA's conclusion that proposing an annual average duration for the wild rice sulfate standard is reasonable. Expressing the standard as an annual average does mean that at times the concentration of sulfate in the waterbody might be higher than the calculated sulfate standard, so long as the average over the year is at or below the standard. As described in the SONAR and TSD, a longer averaging time is appropriate for the wild rice sulfate standard because sulfate is not a direct toxicant, and the negative impact of elevated sulfate occurs over time, not in a matter of days or weeks. As noted in the TSD, page 94, "temporary high sulfate concentrations are not the direct cause of negative effects on wild rice". Specific to the concerns raised about elevated sulfate discharges during dry periods of the year, the TSD specifically explains how the scientific evidence supports MPCA's conclusion that short-duration increases in sulfate concentration will not impact the wild rice beneficial use, so long as the annual average is maintained.

The reasonableness of MPCA's proposed annual average frequency is bolstered by the 11/22/2017 comment letter from EPA, which states on page 5 "Based on the information provided by Minnesota as part of the public notice for these rules, the proposed criterion appears to be scientifically defensible and protective of the wild rice use."

Flow rate: The proposed rule language regarding the applicable flow rate for evaluating the need for effluent limits to ensure discharges are protective of the standard is found in two places: 7050.0224, Subp. 5D and 7053.0205, Subp. 7E, with a definition of 365Q10 at 7050.0130, Subp. 2a. The language states that "discharges of sulfate in sewage, industrial waste, or other wastes affecting class 4D waters must be controlled so that the numeric sulfate standard for wild rice is maintained at stream flows that are equal to or greater than 365Q10." This proposed rule language mirrors language elsewhere in Minnesota Rules that specify other flow rates applicable to the evaluation of potential impacts to other standards (see 7Q10 language at Minn. R. 7050.0210, Subp. 7 and 30Q10 language at 7053.0135, subp. 4 and 7053.0205, subp. 7B. Similar concepts related to 122Q10 are at 7050.0150 supp. 4A and 4BB and 7053.0255 Subp. 1A and 1G).

MPCA is proposing to use the 365Q10 flow as that protective stream flow rate to use in the effluent limit review and development. 365Q10 means the lowest average 365-day flow with a once in ten-year interval. This flow rate is calculated specific to the receiving water of concern. Built into the choice of using the 365Q10 protective flow is the assumption that high flow rates after snow melt will average out low flow rates during late summer and thus protect wild rice from sulfate over a 365 day period.

The 365Q10 flow rate is a proposed variable in the mass balance formula used to calculate effluent limits. The mass balance formula allows the MPCA to reasonably calculate the assimilative capacity of the receiving water to receive the pollutant load from the discharger and thus determine the need for effluent limits for the discharger. Pages 98 through 102 of the SONAR address the mass-balance approach and the reasonableness of the proposed 365Q10 flow rate.

EPA provided comments stating that "it is unclear whether Minnesota intends for water quality-based effluent limits (WQBELs) to apply when receiving waters flows are less than 365Q10" and recommends that proposed 7050.0224, subp. 5D be clarified. MPCA absolutely intends that once established a water quality-based effluent limit will apply to the permitted discharge as specified by the effluent limit, regardless of the receiving water flow rate at a given time. Given that this proposed rule language identically mirrors other rule parts in Chapters 7050 and 7053 regarding, MPCA will address these recommendations for enhanced clarity in a future rulemaking when the other similar rule parts can also be addressed.

Commenters also expressed concern that the use of a 365Q10 flow in setting effluent limits would not be protective of the beneficial use, and MPCA should instead use the 7Q10 analysis used to evaluate toxic pollutants. This comment is analogous to concerns expressed about the annual average duration proposed for the standard. In both cases, as explained above the MPCA's proposed approach is scientifically defensible for the wild rice sulfate standard because sulfate is not a direct toxicant. For direct toxicants, concentration at low receiving water flows is a concern because point source have the greatest impact on stream composition at those flows and short-duration exposures to direct toxicants can impact the beneficial use. This same concern is not present for sulfate and wild rice, where the impact occurs over a longer timeframe.

<u>Seasonality</u>

The concept of "seasonality" is a further consideration of the duration of the water quality standard. As noted on page 20 of the SONAR, implementation of the existing wild rice sulfate standard has at times included an interpretation of the "period when rice may be susceptible to high sulfate levels" as being the growing season.

MPCA recognized the need to examine this interpretation in light of new scientific information, and included in the SONAR a specific discussion of the seasonality concept (pp. 81-82). The 2011 legislature also referenced seasonality in their specific rulemaking charge to MPCA.

Given that sulfide can form from elevated sulfate alt any time of the year, MPCA is proposing an annual average duration for the standard rather than a duration limited to a specific season. In other words, MPCA is proposing that the standard apply in all seasons. In general, most commenters supported the MPCA's proposal to have a standard that applies year-round.

Mesabi Nugget provided the following comments about the annual duration of the standard and introducing the concept of seasonality and/or temperature dependence to the equation.

"The equation fails to account for seasonal trends in porewater sulfide...Minnesota has never had a year-round sulfate limit for the protection of wild rice. This reflects the reality that wild rice is not a perennial and only grows for less than half of the calendar year. Accordingly, it does not make sense to remove the existing seasonality language and apply the sulfate standard year-round…MPCA is claiming that wild rice is equally susceptible to sulfate at all times of the year…MPCA arbitrarily discounted the only research on this topic and proceeded as though its data supported nothing but a year-round standard, with the calculated effects of a summer discharge being treated just like a sulfate discharge in the dead of winter. In 2013 DeRocher and Johnson provided research to MPCA showing significant temperature-dependent differences in the rate of sulfide creation in sediment. Their sediment incubation study indicates that in cold water, additions of sulfate take several weeks to show any increased porewater sulfide, and then it takes only a few weeks to go back to previous sulfide levels once the sulfate additions have ended."

As noted above, the SONAR provides a discussion on the reasonableness of the annual duration and the concept of seasonality beginning on page 81; pp. 91 – 94 also address these topics. The MPCA did not discount the 2013 DeRocher and Johnson study and in fact cites this work when discussing the reasonableness of the annual duration of the standard. MPCA has acknowledged that sulfate conversion to sulfide is slower in cold temperatures. However, MPCA explained that is does not have sufficient scientific information to quantify this difference in a way that could be incorporated into a proposed water quality standard. Specifically, the SONAR (excerpted below) provides the following justification of the reasonableness of not incorporating temperature dependence into the proposed equation.

"…the MPCA lacks sufficient scientific information to quantify the lower winter diffusion rates and thereby develop a ratio or other numeric approach to allow higher sulfate levels in the winter. The MPCA also does not know if an approach that allowed higher sulfate levels in the winter would be protective over the long term. Because of this, is it reasonable to have a standard that applies all year, not just seasonally."

John Hall also provided comments interpreting the Pastor et al. 2017 study that asserted:

"These data clearly indicate that a single season exposure does not cause adverse effects, even at the highest concentrations. These results show that the duration must be greater than one year to show an effect…The criteria duration necessary to protect wild rice is at least two years."

Other commenters are clearly concerned that even an annual duration is too long, because there may be effects at shorter duration.

The SONAR provides a reasonable justification for the annual duration using data from the Pastor et al. 2017 beginning on page 79:

"In this case, it was not until the third year of the experiment that wild rice growth and reproduction was significantly affected by the 100 mg/L treatment (Pastor et al., 2017). This mesocosm experiment conducted by Pastor et al. (2017) demonstrated that porewater sulfide is directly proportional to the long-term (annual) average sulfate concentration (Myrbo et al. Exhibit 36)."

Although statistically significant effects were not observed until year 3, it is not reasonable to assume that a 3-year average would be protective, for the following reason: The mesocosm experiment was not designed to evaluate the frequency or duration of exceedances. Rather, the mesocosms evaluated the cumulative impact of sudden increases to new elevated concentrations, from a base exposure that was very low—the sediment was taken from a wild rice lake with an average sulfate concentration of less than 3 mg/L. An experiment designed to address this issue might have first exposed the sediment to a sulfate concentration closer to the calculated standard of 34, and then observed the effect of an increase above the standard. Accordingly, the MPCA made a judgements of protective frequency and duration values, partly informed by the mesocosms experiment.

Given the available data, an annual average for a standard that applies at all times, (not just seasonally), is a reasonable choice.

Frequency of the standard

The proposed sulfate water quality criterion to protect wild rice waters has an exceedance frequency of once in ten years. This means that a water body would not be considered impaired until the numeric sulfate standard is exceeded in a second year out of ten.

Some commenters (Hall) found this frequency to be excessively conservative, stating that the mesocosm experiment: "results show that wild rice has the ability to recover even when plant growth was virtually eradicated after multiple years of exposure to extremely high levels of sulfate. If wild rice can begin recovery from this extreme condition, it should be apparent that recovery would be complete within two years after an exposure that only causes slight effects…These observations support a return frequency of once in three years."

Other commenters (Fond du Lac Band) expressed concern that the proposed frequency is not protective, stating that: "Dr. Pastor's experiments were not designed to determine what that frequency might be...MPCA cannot assume that this natural resilience of wild rice will be realized if an anthropogenic disturbance such as excessive pollutant loading occurs. The only existing data that is relevant to that issue are the latest mesocosm results (Pastor progress report, June 2017), where only about half of the high sulfate treatment mesocosms rebounded when the sulfate loadings ceased."

Still others (WaterLegacy) stated that: "even if sulfate was elevated over an entire year, the proposed rules would only consider this an "exceedance" of the standard if the discharger violated the wild rice sulfate standard for more than one year out of ten."

The MPCA believes that a shorter standard frequency (one to three years) is not protective. The MPCA agrees that the objective of the mesocosm study was not to determine a protective frequency in which to express the proposed standard; however, this does not mean the MPCA's evaluation of the data from the mesocosms and other lines of evidence is not scientifically defensible. Additionally, with regards to Mr. Hall's claim that wild rice did "recover", there was a notable decrease in wild rice density after five years of elevated sulfate concentrations followed by two years of reduced exposure. This finding suggests that multiple consecutive years of increased exposure reduced the potential of the wild rice to produce viable seed heads for future plant establishment. There is not sufficient information indicating a one in three-year frequency is protective for the use and propagation of wild rice. The reasonableness of applying a one in ten year frequency is available on page 82 of the SONAR. Again, the MPCA's choice is a reasonable balance and the one in ten year frequency is reasonable and protective.

I. Comments Related to NPDES Permitting

Many commenters felt that the MPCA has not provided enough detail in the implementation sections of the proposed rule and supporting documents. For example, EPA suggests the inclusion or development of specific procedures. And, operators of permitted facilities provided comment that the lack of detail prevents them from fully understanding their future effluent limits and thus the cost implications of the rule. This is perhaps best illustrated by the comment from the Minnesota Chamber of Commerce, which states "The technical support document (TSD) and the Statement of Need and Reasonableness (SONAR) both have economic and socioeconomic impacts, but do not include all the factors that would be assembled in a complete cost analysis of the proposed rule. The MPCA estimates that, at a minimum, 130 permitted facilities will be evaluated for the possibility of requiring additional permit limits to protect wild rice under the new rule. Without an understanding of the feasibility and cost of meeting these new limits, it is difficult for these 130 facilities to plan for future development and commit capital investment into their facilities."

More general comments about the Agency's obligations around cost analyses are provided in the section of this Rebuttal Response related to procedural issues. This response section addresses the MPCA's effluent limit permitting process and why it is reasonable for the MPCA to not have specific details about effluent limits available at this time.

As noted in the November 22, 2017 Response to Comments, the MPCA understands that dischargers want clarity about how the standard will affect them, and we are sensitive to comments that the MPCA should strive to fully understand and articulate the implementation details of a rule prior to adopting the rule. In the case of water quality standards, the impact on permitted facilities comes through development of an effluent limit specific to a facility that ensures the permitted facility will not cause or contribute to a violation of the water quality standard. Effluent limit setting requires evaluating multiple factors as described beginning on page 96 of the SONAR.

There are approximately 1000 facilities in Minnesota that hold water discharge permits. Site-specific data is required to evaluate the need for an effluent limit at each facility, and these issues are addressed in an individualized permitting process. This data is not immediately available for all facilities and it takes time to gather this data.

This time and data need is inherent to the difference between water quality standards and effluent limits, and is not unique to the proposed revisions to the wild rice sulfate standard. As explained in Part 6G, pp. 96-99 of the SONAR, evaluating the need for and (as needed) determining a water quality based effluent limit requires data specific to the discharge being evaluated and the receiving water(s) being discharged to. Data needs unique to the proposed rule revisions are the sediment iron and carbon (or porewater sulfide) data.

Collecting all the data necessary to calculate all effluent limits statewide would take at least ten to fifteen years, even if the sediment data were not needed. Necessary steps such as gathering five years of effluent data to evaluate and set effluent limits combined with the 10-year surface water monitoring schedule to gather surface water data cumulatively add up to the necessary data not being available for some permitted discharges until at least ten to fifteen years after rule promulgation. The MPCA does plan to prioritize data collection based on factors such as those mentioned in the EPA comments, Appendix 2 – the likelihood of sulfate impacts (because of type and location of dischargers) and permitting schedules.

It is unreasonable to delay this rulemaking for ten to fifteen years to provide total certainty regarding future effluent limits for specific facility discharges and the exact future costs. In addition, every facility is unique and detailed engineering is needed to estimate the costs of installing any treatment system.

This is why the MPCA provided general effluent limit considerations and the range of costs detailed in the SONAR. A delay such as would be necessary to gather data and estimate the cost for all potentially affected facilities is particularly unreasonable given that while the rulemaking would be delayed the existing sulfate standard would remain in place and need to be addressed as required by the Clean Water Act and federal regulations.

NDPES Effluent Limit Expression

Commenters also raised questions about how the MPCA plans to express effluent limits, and several asked that this information to be placed in rules. For example, Mesabi Nugget made the following comment: "It appears MPCA may have committed a drafting error when preparing the rule language for public notice. The agency says that water quality-based effluent limitations (WQBELs) for sulfate will typically be expressed as a 12-month moving total mass. MPCA SONAR (July 2017), p. 105. However, the corresponding rule language does not appear to reflect this policy decision made by MPCA. The rule language should be updated to properly reflect the mass limit approach."

MPCA has not committed a drafting error. There are two general ways to express an effluent limit: as a mass limit or a concentration limit. The choice to express a limit as a mass limit or concentration is a decision that is made at the time that an effluent limit is developed for a specific discharge. The MPCA intends to fulfill its statutory responsibility to protect water quality standards and designated uses through requiring the most appropriate and protective effluent limits. At this time, based on our knowledge, the MPCA would prefer that effluent limits be expressed as 12 month moving mass totals. However, the MPCA may use other approaches as necessary to ensure protection of the water quality standard. MPCA expressly noted this intent in the sentence that follows the sentence quoted in the comment above, which reads "Concentration-based limits will also be included in the permit if need is demonstrated" (SONAR, p. 105).

More generally, it is not needed or reasonable to specify in rule the exact manner in which effluent limits must be expressed for every permitted discharge that may need a limit to protect the beneficial use. Data that the MPCA does not currently have for every facility, such as sulfate concentrations in the discharge and the receiving water(s), are key to informing the MPCA's decision on which approach is needed to protect the beneficial use in the receiving water(s).

There is extensive EPA guidance and MPCA past practices for effluent limit setting that will be evaluated and used as appropriate. This flexibility is important for setting individual facility limits, and is part of why the MPCA is not providing more detail in the rule such as the suggestion by EPA to specify a flow rate for the relatively rare situation of isolated waterbodies. MPCA may take the approach suggested by EPA, but putting detail for such a specific situation in rule is unnecessary.

It is reasonable for the agency to define key variables such as the 365Q10 in the rule and indicate the general limit-setting approach in the SONAR. It is unreasonable for the agency to know with total certainty the exact limit-setting approach for all wastewater plants, which would be needed to put exact limit-setting approaches into rule.

Sulfate Fate and Transport

Joe Mayasich provided comments on the limit-setting approach outlined in the SONAR specifically related to sulfate fate and transport in the environment. The comments criticized a lack of a discussion of specific sulfate fate decay rates in the SONAR, and provided the specific comment below on sulfate transport.

"The proposed Rules erroneously assume that 100% of the sulfate load/concentration discharged from permitted facilities' outfalls reach wild rice habitat via surface water transport, and then erroneously assert, with a simplistic equation, that the 'protective' level of biogeochemically produced Sulfide (i.e. 120 µg/L) can be achieved by reducing just the load/concentration of just the point-source-discharged, surface-water-transported Sulfate."

The MPCA has not assumed that 100% of the sulfate discharged from a facility will reach the wild rice habitat in downstream wild rice water(s). As noted in Part 6G of the SONAR, the first step in conducting an effluent limit review is determining if a discharge will cause, have the reasonable potential to cause, or contribute to an exceedance of a water quality standard (SONAR p. 97, also 40 CFR 122.44). This step is often referred to as the "reasonable potential" analysis. The MPCA effluent limit reviews of sulfate discharges from permitted facilities will consider factors such as flow dilution, water body type, water flow path, and site-specific sulfate decay rates in this "reasonable potential" analysis. Sulfate fate and transport is a complex environmental phenomenon and it is not possible to simplify sulfate fate in the environment to a singular half-life decay rate applicable statewide. The MPCA expects to treat sulfate transport in the environment conservatively during limit setting to be suitably protective and simplify the limit setting process. If quality evidence suggests sulfate is not transported conservatively then the MPCA is willing to consider that evidence in the limit setting process.

Regarding the second part of this comment, MPCA has not asserted that the protective sulfide level can only be achieved by controlling point source discharges of sulfate to surface waters. This comment again confuses key differences between water quality standards and permit effluent limits. Standards apply in the water body to protect the beneficial use. The need for and details of an effluent limit is established by first determining if a discharge has "reasonable potential" to cause or contribute to an exceedance of a standard applicable in the receiving water(s). If the discharge does have reasonable potential, the effluent limit must then be set at a level that controls the pollutant so that the facility does not cause or contribute to an exceedance. This requirement of the Clean Water Act does not assume that controlling the discharge will by itself ensure the water quality standard will be achieved, and MPCA has not made such an assertion.

Singular conservative assumptions in the implementation strategy will cumulatively result in excessive over-protection and unnecessarily low effluent limits

John Hall and other commenters provided comments on the limit-setting approach outlined in the SONAR, specifically the concept of individual conservative effluent limit setting assumptions compounding into excessively conservative assumptions when considered cumulatively. These commenters did not rigorously distinguish between the concept of compounding conservative assumptions in the science underlying the standard development and the concept of compounding conservative assumptions in the implementation of the standard. The MPCA addresses the concept of compounding conservative assumption in the science behind the standard development elsewhere in this document (Section K) and will address the concept of compounding conservative assumptions in the implementation of the standard below.

We maintain that none of the individual assumptions in the implementation section of the SONAR is overly conservative and thus there is no compounding of conservatism when these choices are made in combination. For example, the choice of the 365Q10 as the receiving water flow rate during the limit setting process is reasonable and not overly conservative. We did not choose an unnecessarily conservative receiving water flow rate such as the 7Q10 (defined in Minn. Rule 7053.0135) because choosing that extremely low receiving water flow rate would have been overprotective of the duration and frequency of the proposed standard. Since every individual implementation assumption is not overly conservative, there can be no compounding of individual conservative assumption and thus there is no cumulative compounding of conservation assumption in the implementation of the standard. We maintain that the proposed implementation strategy is reasonable, is appropriately protective of the water quality standard and will not result in unnecessarily low effluent limits.

Implementation Timeline

Commenters (Friends of the Boundary Waters) also raised concerns that high levels of sulfate would be allowed until the MPCA gathers data and sets a numeric sulfate standard – essentially leaving waters without a standard. As noted in our Response to Comments, data gathering will be needed regardless of whether MPCA moves forward with the proposed equation based rule or chose to implement a single standard. In either case, data is needed on sulfate in effluent and sulfate in surface waters in order to implement discharge limits. The addition of the need to collect sediment data to implement the equation based standard does not substantially change the timeline.

Other commenters had concerns that an increase in sulfate loading could occur prior to the setting of a numeric sulfate standard. As raised by MCEA: “MPCA has rejected the alternatives of keeping the 10 mg/L standard in place while data are collected and also the alternative of specifying that there shall be no net increase in sulfate discharges until a numeric standard is developed that can be used to set protective effluent limits…sulfate loadings cannot be relied on to stay constant until new permit limits are calculated. Dischargers are not generally discharging the full amount of pollutants that their NPDES permits allow them to discharge and, thus, there is frequently room for increasing the flow or discharges of particular pollutants without obtaining a new permit.”

The commenter is correct that most dischargers do not discharge at the full levels authorized by their NPDES permit; in MPCA’s experience, most dischargers prefer to operate with a degree of buffer between their actual and permitted discharges. The MPCA felt that the concept of “no net increase” was not implementable primarily because of very limited existing data on sulfate effluent concentrations and on how much a permittee is operating below their maximum permitted levels and how sustainable that operation is.

Implementation of a “no net increase” provision would require defensible numerical methods for defining a baseline that correctly characterizes the concentration or load the facility is currently discharging. Several methods could be used, but nearly all would result in the same outcome: a disincentive to reduce loading below maximum authorized levels. For example, the current actual discharge baseline could be defined as the average effluent concentration recorded during the previous five years. A permit condition, or limit, would then be derived from this baseline. During the next permit cycle, the permittee would strive to operate below this baseline in order to remain in compliance with permit conditions. At the subsequent permit review, the new five years of data would be used to readjust the no net increase baseline lower to comply with the previously determined no net increase baseline. In this hypothetical scenario, it would be nearly impossible to not reduce discharge during every reissuance, and as a result, permittees would be tacitly encouraged to always discharge at maximum authorized levels. Another potential result of this scenario is that effluent limits for affected facilities could ultimately be reduced to a level where violations would be frequent and unavoidable.

J. Sampling and Analytical Methods

Multiple commenters provided input on the sampling and analytical methods incorporated by reference into the rule. The goal is to set forth methods that are sufficiently clear as to result in a consistent development of a numeric sulfate standard via the equation or alternate standard, while not constraining flexibility that may be needed to adapt to the differing conditions of a given wild rice water and different lab abilities and does not affect the ultimate result.

The MPCA chose to incorporate methods by reference because the sediment or porewater sampling and analysis are fundamental to the development of a numeric sulfate standard (through either the equation or the alternate standard) and we anticipate that permittees or other parties may want to conduct sediment or porewater sampling themselves. Some commenters (MCEA) raised concerns that parties other than the MPCA should not be allowed "to do sampling that determines the applicable water quality standard under state law." Others (Water Legacy) suggested that allowing such sampling is an "invitation to mischief".

Incorporating the sampling and analytical methods by reference makes them enforceable and ensures that the MPCA is able to accept only information with results that are consistent with the results that would be received if the MPCA itself conducted all sampling and analysis. To ensure quality data, the MPCA is also requiring outside parties to submit a sampling plan if they want to collect and analyze data in a way that is consistent with but does not exactly follow the incorporated methods. The MPCA will assess data quality before any use of the data occurs. MPCA will be responsible for documenting the final numeric sulfate standard for each water and will not document or enforce a result that arises from data that does not conform to the rule's methods.

Comments on the sampling methodology generally were in the areas of clarity and flexibility. For the methods on where and how to collect sediment and porewater within wild rice waters, commenters seemed to want more clarity; for the analytical methods, commenters tended to want more flexibility.

The MPCA is considering some rule changes based on these comments; more information is provided in the section on planned and proposed rule changes. The MPCA also plans to develop detailed guidance of best practices or standard procedures that can be used for sampling and analysis in order to provide a "recipe" for those who want such details.

Sampling Methods are for Wild Rice Waters

Some comments seemed to conflate the sampling methods – particularly discussion of where to sample within the wild rice water – with the identification of the wild rice water. For instance, one commenter (Cliffs) states that "the use of water lilies as indicators of suitable wild rice habitat is scientifically flawed." Another commenter (MESERB) stated that the "The list of areas within wild rice waters that must be sampled is overly broad. Wild rice propagates through seed. The Agency should look for more than the presence of waterlilies, other plants or areas with a certain water depth to demand testing. An upstream source of seed should also be required. Similarly, if conditions that preclude establishment of wild rice are present, such as waters that are not clear or that support a population of carp, sampling should not be required." It is important to note that the sampling methods are to be deployed in waters that the MPCA has already identified as Class 4D wild rice waters. Therefore, the waters are known to demonstrate or have demonstrated the wild rice beneficial use since November 28, 1975.

The sampling methods are about getting the best characterization of sediment iron and carbon or porewater sulfide in waters that have already been determined to be wild rice waters. EPA's comments in Appendix 2, particularly comment #3, raise concerns that requiring or allowing sampling to be constrained to areas of obvious wild rice habitat within the wild rice water may bias the sampling. The MPCA will consider making changes to the method document to address this concern.

<u>Sediment and Porewater Sampling Methods</u>

Commenters (1854 Treaty Authority) rightly noted that "The design of this sampling would be crucial: where does sampling occur, how many samples are taken…it is also likely that sampling results in each water would give a range of sulfate values…under the proposed approach… However, guidelines could lead to inconsistent implementation." The goal of the methods document is to set out requirements for sampling, not guidelines, in order to have the most consistent implementation possible. As noted in the rule, the equation-based sulfate standard must be set at the lowest sulfate number obtained based on the sediment iron and carbon values found via sampling.

Similarly, commenters (MCEA) noted that "having a standard based on sampling of each site requires, at a minimum, a standard sampling protocol that rigorously controls for the spatial variability of iron and carbon in the sampled environment." Another commenter specifically mentioned the high spatial variability in iron and TOC in Twin Lakes. The TSD (Chapter 3) and Hearing Response to Comments discusses the variability of sediment TOC and iron, and the reasonableness of the methods proposed for sampling wild rice waters to collect data for use in calculating a standard for the waterbody.

The MPCA has adequately shown that the required 25 sediment samples is sufficient to characterize the spatial variability of iron and carbon, and the use of the lowest resulting sulfate value is sufficiently protective. Comments from EPA have suggested that MPCA consider providing more specificity about transects, specifically information like lengths and distances, and the MPCA will consider this and may make changes to the sampling methods. In particular, EPA Appendix 1 comments number 3, 4, 6, 11, and 13 suggest additional clarity that the MPCA will consider.

There was also some confusion among the commenters about the relationship between sampling for sediment iron and carbon, and porewater sulfide. Some stated that the sampling methods do not include a clear description of the purpose of the porewater sampling and others seemed to believe that all of these parameters would be collected at all times. To be clear (this is also discussed in the portion of this document on proposed and planned rule changes), the MPCA envisions that the vast majority of the sampling will be only for sediment iron and carbon. Porewater sulfide will only be collected if there is a reason to believe that using the alternate standard approach to developing a numeric sulfate standard would be appropriate. Other commenters (GLIFWC) noted that "The procedures do not make it clear how the porewater sampling effort can occur in conjunction with the sediment core sampling. The document states that the sediment sampling must be done before the porewater sampling. It then states that the porewater sampling must be done no later than 4 hours after the sediment cores are taken. Given that the sediment sampling is done first, how will the MPCA determine what is an undisturbed sediment for the purpose of porewater sampling?" The MPCA will review the methods document and add clarity as needed.

Commenters (Mining Minnesota) also stated that "[i]t is also unclear how to interpret porewater sulfide data. The MPCA Sampling Methods include direction that two porewater samples be collected at each of five transects used for the previous sediment sampling for a total of ten porewater samples per 'wild rice water.' It is unclear, however, which porewater sulfide value will be considered relevant for compliance. Is it the lowest of the ten values in the dataset, an average, or some other value? If sulfide values in the same location differ by hundreds of micrograms per liter or more, how will that data be evaluated and for what purpose? How will results be interpreted if they differ from the calculated sulfate standard based on sediment iron and total organic carbon data?" Porewater sulfide data would only be used to establish a numeric sulfate standard via the alternate standard procedures. Once that numeric sulfate standard is set, that sulfate standard would be used to determine attainment of the standard and in effluent limit review. However, MPCA does agree that the rule and method do not adequately explain how to use the multiple porewater sample values to develop a sulfide level for use in the alternate standard. The MPCA will clarify.

Use of Sediment Data to Develop Sulfate Level

The rule language directs that "the calculated sulfate standard is the lowest sulfate value resulting from the application of the equation to each pair of organic carbon and iron values collected and analyzed" consistent with the methods document. Several commenters state that it is not appropriate to use the lowest calculated sulfate level rather than an average. The Technical Support Document discusses the detailed reasonableness of using the lowest calculated value of sulfate derived from the analysis of five composite sediment samples. (See page 87 of the TSD). Briefly, though each of the five values that are calculated from the five paired data sets of sediment TOC and iron is protective of wild rice, the lowest value represents the most sensitive condition for the wild rice in that waterbody. It is reasonable to protect for the beneficial use based on applying that lowest calculated sulfate value.

Analytical Methods

The document incorporated by reference also includes methods for analyzing the collected sediment to determine the iron and carbon levels and analyzing the collected porewater to determine the sulfide level. Commenters provided some very detailed and technical comments on the analytical methods in particular. These issues are more detailed than MPCA can fully investigate and respond to in the time allotted for the post-hearing comment and rebuttal periods. In addition, EPA posed some detailed questions concerning the analytical methods. MPCA is therefore responding broadly here. We will continue to consider the comments on the methods and the need for changes to the methods document prior to adoption of a final rule and will work to provide additional information to EPA and others as needed.

In general, comments about the analytical methods seemed to focus around the need for more flexibility – allowing for analytical methods that would provide comparable results while not requiring certain steps that are not consistently available at every analytical lab. The MPCA believes that the proposed rule language change to require analysis be conduct "consistent with" rather than "using" the specified methods will provide an appropriate level of flexibility and will be reviewing the analytical methods for similar types of revisions.

Many comments were received about the availability and need to follow specific procedures for drying sediment samples, sieving samples, method blanks and various other specifics of sediment sample preparation and analysis. The MPCA will review these comments and consider revisions to the methods as needed.

Comments (Mining Minnesota) were also received about the availability of the methods. "Because MPCA is specifying an analytical method that must be used under the Proposed Rule for porewater sampling, the MPCA should also consider whether commercial laboratories are willing to perform the specified method, and if laboratories become available, whether they are able to conduct the testing within the required detection limits and QA/QC standards."

Particular concerns were raised about the method for porewater sulfide analysis. Mining Minnesota noted that two methods have been used in the past; the two methods have a different distillation step; they state that "MPCA has incorporated Method E as the sole approved porewater sampling methodology without regard to its historical purpose or commercial availability… approximately 30 separate laboratories in the United States and

Canada were contacted, and none were able to conduct a Method E analysis." They note that most labs could analyze sulfide using a third method, which has higher reporting limits. Another commenter states that "MPCA does list acceptable analytical performance but neglects to identify the required MDL. My opinion is given MPCA's use of a porewater sulfide threshold of 120 µg/L, the MDL should be at least 3 to 5 µg/L and the RL 10 to 15 µg/L to have confidence in using the data to derive an enforceable sulfate standard." The MPCA will consider the need to specify a method detection limit in the incorporate document; the MPCA envisions that if a MDL is specified, multiple methods able to meet that limit could be used.

Ramboll also notes that they have "reached out to over 10 reputable certified (e.g., NELAC) commercial water testing laboratories and none of them either are set-up to run this method or routinely run this method to be confident in the quality of their results at a RL of 10 to 15 ug/L sulfide. One commercial lab who has been a leader in AVS and sulfide analytical method development, Alpha Analytical, noted that colorimetric methods have a high potential for false positives due to naturally colored water. It is concerning that dischargers have limited knowledge on the accuracy and precision of the state laboratory execution of Method 4500-S2- E Sulfide and has no information on what to expect for interlaboratory variability." In analyzing samples for the MPCA, the Minnesota Department Health (MDH) and the Science Museum of Minnesota labs both avoided the problem mentioned here--the potential for false positives due to naturally colored water--by separating the sulfide from the water sample prior to quantification. Standard Method 4500--S2-E, used by MDH, first separates the sulfide from the sample via gas dialysis, and only then quantifies the sulfide via colorimetric methods. The Standard Methods book states, "The automated methylene blue method (E) is similar to Method D. A gas dialysis technique separates the sulfide from the sample matrix. Gas dialysis eliminates most interferences, including turbidity and color." Standard Methods notes that this method can accurately quantify sulfide as low as 2 µg/L sulfide, lower than the MDH reporting limit of 11 µg/L sulfide.

K. Procedural Concerns

Several comment letters include assertions regarding purported failures of the MPCA to meet legal/procedural requirements of the Administrative procedures Act, SONAR content requirements, and Minnesota Statutes Section 116.07, subd. 6. The comments allege that MPCA failed to:

- Adequately cite its statutory authority to adopt rules
- Include economic information in the SONAR
- Give due consideration to economic factors
- Consider feasibility and practicability
- Properly assess alternatives

The following paragraphs address each comment in turn.

<u>Statutory Authority:</u> U.S. Steel has commented that the MPCA could have cited additional statutory provisions to demonstrate its authority for the present rulemaking. The agency appreciates that U.S. Steel acknowledges and identifies that the rulemaking is also authorized under other authorities in addition to those specifically cited in the SONAR. Minn. Stat. 14.131 establishes the requirement for a statement of need and reasonableness and delineates general content requirements. Additionally, Minn. R. 1400.2070 (not 1400.0270) presents additional content requirements, providing specifically that the statement must include:

D. a citation to the agency's grant of statutory authority to adopt the rule and, if the grant of authority was made after January 1, 1996, the effective date of the agency's statutory authority to adopt the rule;

Minn. R. 1400.2070, subp. 1.D. This is to assure that agencies have the necessary statutory authority to promulgate a rule and that the rule is lawful. Subpart 2.D. of the rule refers to information required by other law to be included in a SONAR. The agency complied with the requirements of both the statute and the rule. Neither requires an exhaustive listing of all agency rulemaking authorities nor is specific mention of the rule, Minn. R. 1400.2070, required SONAR content. The MPCA demonstrated that it has the necessary authority for the present rule amendment and cited sufficient statutory authority for the rulemaking.

Economic information included in the SONAR and used to inform development of the standard: In its November 22, 2017 Response to Comments the MPCA responds to the multiple comments about how and to what extent MPCA included economic information in the rule development and SONAR. This included whether the separate study MPCA has underway, funded by the Legislative Citizen Commission on Minnesota Resources, provided information to inform development of the standard.

Due consideration given to economic factors: A number of comments (USS, Cleveland-Cliffs, ArcelorMittal) suggest that the MPCA failed to consider cost and economic factors as required by 14.131 or that the analysis was insufficient. While it is true that MPCA did not title a section of the SONAR as "Consideration of Economic Factors," it is also true that the MPCA gave due consideration to economic factors as required by statute. In fact, the specific SONAR citations provided on page 9 of the USS comments demonstrate that cost considerations were part of MPCA's thinking in developing the proposed rule and SONAR.

USS on pp. 8-10 of its comments also cites recently completed examples of MPCA rulemaking as evidence that MPCA has recognized its obligation to consider economic impacts, and implies that these are in contrast to the rulemaking at hand. The SONAR's content readilyrefutes this assertion. The cost and enhanced economic analysis components of the SONAR for this rulemaking span pages 145-195 and 209-216; and the full regulatory Analysis section spans pages 143 - 218. Due to differences in economic impacts, formats and changes in statutory requirements direct comparisons of SONARs cannot provide a meaningful measure of whether costs were appropriately considered in any individual rulemaking. However, an examination of the SONARs mentioned by for the earlier rulemakings shows that:

- The Regulatory Analysis for the Tiered Aquatic Life Use rulemaking was 17 pages, and the "consideration of economic factors" spanned eight pages.

- The Regulatory Analysis for the Variance rulemaking was six pages, and the "consideration of economic factors" is three paragraphs.

- The "consideration of economic factors" section for the 1997-98 Great Lakes Initiative rulemaking was two pages.

The number of pages in SONAR for the present rule containing discussion of costs and economics exceeds the combined total of the above-identified SONARs. MPCA has fully met the requirements of Minn. Stat. § § 14.131 and 116.07, subd. 6. The fact that MPCA integrated its consideration of economic impacts throughout the Regulatory Analysis for this SONAR rather than limiting them to a section titled "consideration of economic factors" is not evidence that the requirement of due consideration was not met.

ArcelorMittal and USS also claim that MPCA has not met the statutory requirements under Minn. Stat. 14.131 and 115.43 to illustrate the benefits of implementing the proposed rules and that MPCA must directly compare economic costs to benefits. Minn. Stat. 115.43 does require the agency to give due consideration to economic factors and take into account any taxes on municipalities. As demonstrated above, the MPCA has done this for this rulemaking. The APA does not require an explicit balancing of costs and benefits; in fact, Minn. Stat. 14.131 never explicitly mentions the idea of the benefits of a proposed rule (merely the costs of not implementing a rule). In addition, the Tribes in particular would note (as they have in consultation with the MPCA) that it is nearly impossible to quantify the benefits of wild rice and that this results in an uneven balance between easily monetized financial costs and difficult to monetize but very real benefits

Cliffs also claims that the CWA does not prohibit MPCA from evaluating the cost of compliance and references the agency's statements regarding the role of economics in determining water quality standards. The MPCA is on record as stating that the cost of compliance is not a determining factor in *setting* a water quality standard. The content of pages 143-218 of the SONAR demonstrate that the MPCA has considered costs as required by law. The MPCA cannot and should not act as many commenters suggested and simply determine the standard is unreasonable because it is expensive to implement.

A number of commenters have suggested that the MPCA can and should simply delete the existing wild rice standard, that the proposed rule amendment is solely a policy decision, and that the MPCA would be authorized to delete the existing standard without adopting a replacement. . Both the MPCA's response to Comments and the EPA's November 22, 2017 comment letter address this. EPA's comments directly contradicts assertions that MPCA can simply delete the existing wild rice sulfate standard without a replacement and meet its obligations under the CWA Section 303(c) and 40 CFR 131.11(a), and that the proposed revisions to the wild rice sulfate standard are in some way a "policy decision" and not a legal obligation.

<u>Consideration of Feasibility and Practicality:</u> USS asserts that MPCA has not given due consideration to the feasibility and practicability of the proposed rules, and references Section 404 of the Clean Water Act, Webster's Dictionary and the variance discussion in the SONAR as evidence of this lack of consideration. MPCA disagrees with these comments. Consideration of feasibility and practicality is about the proposed rule revisions, not the original adoption of a wild rice sulfate standard. As noted in the Response to Comments and above, MPCA cannot demonstrate that removing the existing wild rice sulfate standard, without a replacement approach, would be protective of the wild rice beneficial use. Therefore the consideration becomes the feasibility and practicality of the proposed revisions as compared to the existing rule.

In citing definitions of "practicable," the commenter references Section 404 of the Clean Water Act. This reference is misguided, since this proposed rulemaking involves the requirements and authorities of Section 303(c) of the Clean Water Act (see EPA comment letter); Section 404 is not relevant to this particular rulemaking.

Finally, the comments note that a condition for granting a variance is a finding "that attaining the designated use and criterion is not feasible" and suggests that MPCA's acknowledgment of the likely need for an applicability of variances therefore proves the rule is not feasible. This argument conflates two separate concepts: the feasibility and practicality of the rule revisions themselves and the feasibility of imposing specific permit conditions as needed to be protective of the adopted standard. These are not the same thing, as MPCA has repeatedly demonstrated throughout the SONAR and rulemaking record. In fact, the availability of variances as a tool to address economic impacts to permitted facilities is evidence that the proposed rule revisions are feasible and practical even though sulfate treatment technologies are currently limited and costly.

<u>Minnesota Statutes 14.127:</u> Mesabi Nugget's submittal includes a request for a statement from the MPCA acknowledging that Minn. Stat. 14.127 protections apply to them and that the Proposed Rule will not apply to

Mesabi Nugget until the rules are approved by law enacted after the agency determination or disapproval by the Administrative Law Judge. Such a statement is not required. The MPCA made the determination required by Minn. Stat. 14.127 in the SONAR as is noted in Mesabi Nugget's comment. The statute does not require the agency to make the requested acknowledgement and the statute speaks for itself as to its applicability and effect. Further, the statute requires that a business or city submit a statement claiming a temporary exemption from the rules before protections under 14.127 are triggered.

AGU PUBLICATIONS

JGR

Journal of Geophysical Research: Biogeosciences

RESEARCH ARTICLE

10.1002/2017JG003787

This article is a companion to Myrbo et al. (2017), https://doi.org/10.1002/2017JG003788 and Pollman et al. (2017), https://doi.org/10.1002/2017JG003785.

Key Points:

- Sulfate loading to freshwater ecosystems may alter aquatic plant communities when sulfate is reduced to sulfide in the anoxic rooting zone
- The occurrence of self-sustaining wild rice populations is mainly controlled by pore water sulfide concentrations
- Even if pore water sulfide is low, wild rice is less likely to be found if the surface water is turbid or warm

Supporting Information:

- Table S1
- Table S2
- Table S3
- Data Set S1
- Figure S1

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Sulfide Generated by Sulfate Reduction is a Primary Controller of the Occurrence of Wild Rice (*Zizania palustris*) in Shallow Aquatic Ecosystems

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Abstract Field observations suggest that surface water sulfate concentrations control the distribution of wild rice, an aquatic grass (*Zizania palustris*). However, hydroponic studies show that sulfate is not toxic to wild rice at even unrealistically high concentrations. To determine how sulfate might directly or indirectly affect wild rice, potential wild rice habitat was characterized for 64 chemical and physical variables in over 100 sites spanning a relatively steep climatic and geological gradient in Minnesota. Habitat suitability was assessed by comparing the occurrence of wild rice with the field variables, through binary logistic regression. This analysis demonstrated that sulfide in sediment pore water, generated by the microbial reduction of sulfate that diffuses or advects into the sediment, is the primary control of wild rice occurrence. Water temperature and water transparency independently control the suitability of habitat for wild rice. In addition to generating phytotoxic sulfide, sulfate reduction also supports anaerobic decomposition of organic matter, releasing nutrients that can compound the harm of direct sulfide toxicity. These results are important because they show that increases in sulfate loading to surface water can have multiple negative consequences for ecosystems, even though sulfate itself is relatively benign.

Plain Language Summary Research in the 1940s and 1950s found that wild rice grew best in low-sulfate Minnesota lakes, but it was not known why. The correlation was a puzzle, since sulfate is not very toxic to plants or animals. This study found that the problem is sulfide, not sulfate. Sulfate can be converted into toxic levels of sulfide in the soil in which wild rice germinates and roots. Wild rice is an annual plant that must sprout each spring from seed that was dropped the previous fall into wet soil. Anaerobic microbes in the soil make sulfide from sulfate in the overlying water. Lakes, streams, and wetlands that have high concentrations of dissolved sulfide in the sediment therefore have a low probability of hosting wild rice. The study also found that wild rice prefers high-transparency water and cold winters.

1. Introduction

Minnesota is unique among U.S. states and Canadian provinces in having a water quality standard that regulates sulfate (SO_4) to protect wild rice, *Zizania palustris* and *Zizania aquatica*. The more common wild rice species in Minnesota, *Z. palustris* (northern wild rice), is an annual emergent aquatic grass that forms monocultures in shallow freshwaters (wetlands, lakes, and rivers) in the area of the Laurentian Great Lakes (Minnesota, Wisconsin, Michigan, Ontario, and Manitoba). Wild rice is culturally important to multiple groups in Minnesota, especially Ojibwe, Dakota, and other Native Americans, and also provides habitat and food for waterfowl and other wildlife (Vennum, 1988). In 1977, the Minnesota legislature voted to make wild rice the Minnesota state grain. Minnesota Rule 7050.0224, promulgated in 1973, seeks to limit the exposure of wild rice to SO_4 concentrations exceeding 10 mg L^{-1} (0.1 mmol L^{-1}). This value was based on empirical research that correlated water chemistry to aquatic plant assemblages and included the observations that no large populations of *Z. palustris* occur in waters exceeding 10 mg L^{-1} SO_4 and that stands are uncommon where SO_4 concentrations exceed 50 mg L^{-1} (Moyle, 1944, 1945). In addition, Moyle (1956) noted that plantings of wild rice seed in high-SO_4 regions generally failed. A larger unpublished Minnesota Department of Natural Resources data set also shows that sites with reported wild rice presence (DNR, 2008) are generally correlated with surface water SO_4 below 10 mg L^{-1} (Figure S1 in the supporting information).

We report here on a multiyear field survey that was part of a larger study (Myrbo et al., 2017; Pastor et al., 2017; Pollman et al., 2017) designed to reevaluate the 10 mg L^{-1} SO_4 standard by testing potential mechanisms by which SO_4 might be harmful to wild rice. SO_4 is a relatively nontoxic and unreactive compound under aerobic conditions. Pastor et al. (2017) and Fort et al. (2014) have shown that SO_4 is not directly toxic to wild rice at concentrations up to 1,600 mg L^{-1}, which exceeds concentrations in virtually all natural surface waters of the upper Midwest (Gorham, Dean, & Sanger, 1983). The U.S. Environmental Protection Agency's nonmandatory drinking water standard of 250 mg L^{-1} SO_4 (2.6 mmol L^{-1}) is based on taste rather than toxicity (EPA, 2010).

1.1. Potential Effects of Elevated Sulfate and Sulfide in Freshwater Systems

SO_4 concentrations in most freshwaters are less than a few percent of the mean concentration in seawater (2,800 mg L^{-1} (29.1 mmol L^{-1})). We surveyed 108 different lakes, streams, and wetlands across Minnesota, where the median SO_4 concentration in lakes is 10 mg L^{-1} (10th and 90th percentiles of 0.2 and 285 mg L^{-1} (MPCA, 2016)). In the much higher SO_4 concentrations of marine waters, it is well established that SO_4 can diffuse into sediment and be converted by microbial sulfate reduction (MSR) to potentially toxic sulfide that influences the presence and absence of rooted macrophytes, such as seagrasses (Borum et al., 2005; Ingold & Havill, 1984; Koch & Erskine, 2001; Lamers et al., 2013).

Despite a long-standing assumption that SO_4 is benign (Pester et al., 2012; Schindler, 1986; Urban et al., 1994) and plays a negligible role in freshwater biogeochemistry (e.g., Capone & Kiene, 1988), there is evidence that SO_4 availability in freshwaters can control the concentration and therefore the toxicity of hydrogen sulfide (H_2S) in sediment pore water to plants and animals (Bagarinao, 1992; Kinsman-Costello, O'Brien, & Hamilton, 2015; Lamers et al., 2013; Wang & Chapman, 1999). The chemical species of H_2S varies with pH; below pH 7, H_2S dominates, and above pH 7, the bisulfide ion (HS^-) dominates. For simplicity in this discussion we refer to the sum of the two species as sulfide.

1.1.1. Sulfide Toxicity to Freshwater Plants

Remarkably little attention has been given to the potential toxicity of sulfide in sediment pore water, even after Bagarinao (1992) concluded in a major review that sulfide had been "largely overlooked as an environmental factor for aquatic organisms." In a discussion of sediment toxicity testing, Wang and Chapman (1999) also observed that the biological implications of sulfide in sediments are poorly understood and "all too often ignored." They suggested that sulfide may be more important than ammonia in determining sediment toxicity to organisms and made a suite of recommendations to fill the knowledge gap, including the measurement of sulfide in undisturbed sediments. Kinsman-Costello et al. (2015) measured sulfide in undisturbed sediments and concluded that the potential toxicity of pore water sulfide is likely shaping the plant and animal communities of freshwater ecosystems. Lamers et al. (2013), in a review of sulfide toxicity to aquatic plants, pointed out that traditional toxicity testing generally neglects the chemistry of the rooting zone. Simkin, Bedford, and Weathers (2013) showed that pore water sulfide in a wetland controlled the distribution of plants more than did nutrients.

The toxicity of elevated sulfide to freshwater plants was first recognized in paddy-grown white rice (*Oryza sativa*) in the 1950s (Lamers et al., 2013; Pearsall, 1950). Rice paddies and other water-saturated soils present a profound challenge for rooted plants because of the chemical changes caused by the absence of oxygen and resulting potential toxicity of the pore water (Ponnamperuma, 1972). Anaerobic decomposition of organic matter results in elevated pore water concentrations of ammonia, organic acids, and variable concentrations of sulfide and ferrous Fe, depending on the availability of SO_4 and Fe. The interaction of Fe and the S cycle is complicated (Hansel et al., 2015), but because under anoxic conditions sulfide forms an insoluble precipitate with Fe, elevated pore water sulfide concentrations occur when Fe availability is relatively low (Ponnamperuma, 1972; van der Welle et al., 2006). It is thought that the iron sulfide precipitates are relatively inert and that only sulfide dissolved in pore water is potentially toxic. The concentration of sulfide in pore water is the balance between production and competing fates of sulfide, including precipitation with metals such as Fe, oxidation by oxygen introduced by bioturbation or by release from the roots of macrophytes (Armstrong & Armstrong, 2005), and by downward advection of surface water due to groundwater movement or transpiration by dense macrophyte stands (Bachand et al., 2014).

1.1.2. Geochemical Consequences of Enhanced Microbial Sulfate Reduction

Increased SO_4 availability can allow increased anaerobic decomposition of organic matter, releasing the inorganic nutrients that generally limit growth of higher plants (N, P, and K) (Lamers, Tomassen, & Roelofs, 1998; Myrbo et al., 2017; Weston et al., 2006, 2011). Enhanced decomposition breaks down particulate and dissolved organic carbon (DOC) in the sediment, which can increase DOC and dissolved inorganic carbon (DIC) in the overlying water (Myrbo et al., 2017).

In addition to supporting organic matter mineralization, MSR production of sulfide causes a cascade of reactions that can alter ecosystem functioning independent of any toxicity to plants and animals. First, sulfide can participate in redox reactions, chemically reducing Fe, which converts Fe from solid phase Fe(III) oxyhydroxides to water-soluble Fe(II) (Hansel et al., 2015). The dissolution of the Fe oxyhydroxides releases sorbed ions into solution, including phosphate and trace metals (Caraco, Cole, & Likens, 1993; Davranche & Bollinger, 2000; Søndergaard, Jensen, & Jeppesen, 2003). Second, sulfide can precipitate dissolved metals, including essential plant nutrients Fe, Cu, and Zn, decreasing their bioavailability and leading to nutrient deficiency (Kirk, 2004; Lamers et al., 1998; Neue & Bloom, 1989; Neue & Lantin, 1994). In systems unpolluted with heavy metals, the sulfide precipitate is overwhelmingly dominated by iron sulfide compounds, consisting of a range of stoichiometries and minerals (Schoonen, 2004), which we here term "FeS compounds." Third, the conversion of SO_4 to sulfide entails the production of DIC, or alkalinity, an effect not fully appreciated in freshwater systems until the mechanistic consequences of acid rain were investigated in the 1980s (Baker, Brezonik, & Pollman, 1986; Cook et al., 1986; Schindler, 1986). Alkalinity is thought to be a major factor influencing the distribution of aquatic species, including macrophyte species (Moyle, 1945; Vestergaard & Sand-Jensen, 2000). In addition, elevated alkalinity may further enhance decomposition, producing a positive feedback to the effects of SO_4-driven mineralization (Geurts et al., 2009; Roelofs, 1991).

1.2. Multiple Plausible Negative Effects of Elevated Sulfate and Sulfide Production on Wild Rice

The purpose of this study was to examine the multiple ways that increases in SO_4 concentration and sulfide production can change the biogeochemical functioning of freshwater ecosystems and potentially negatively affect the growth and reproduction of wild rice populations. Before any field data were collected for this study, alternative hypotheses regarding the most likely negative effects were identified (MPCA, 2011), so that appropriate data would be available to test them. The primary hypotheses of how increases in surface water concentrations of SO_4 could harm wild rice populations include direct toxicity by elevated pore water sulfide; reduced bioavailability of Fe, Cu, or Zn; and increased P bioavailability promoting the growth of phytoplankton and macrophytes that compete for light and space. Additional variables were quantified so that exploratory data analysis could be pursued in addition to evaluation of the primary hypotheses. Surface water, pore water, and sediment physical and chemical properties were collected from 108 different sites, both with and without wild rice present, to inform evaluation of these multiple interrelated hypotheses.

2. Methods

2.1. Study Area

2.1.1. Physical Environment

SO_4 concentrations in surface water vary with geology and climate (Gorham et al., 1983) in a northeast-southwest gradient across Minnesota. Bedrock and bedrock-derived glacial deposits of northeastern Minnesota (the "arrowhead") comprise slowly weathered crystalline materials, generally low in S, and surface waters are dilute (specific conductance of $<$140 and often $<$30 μmho cm^{-1}; Gorham et al., 1983). Within this area of naturally low SO_4, iron-mining activities in the "Iron Range" district of northeastern Minnesota have created an "island" of lakes and streams elevated in SO_4 (Figure 1), a result of the weathering of sulfide minerals in waste rock piles and tailing basins. The surficial geology of southwestern Minnesota, in contrast, is derived from marine shales and carbonates that are relatively S-rich and readily weathered: surface waters often exceed 500 μmho cm^{-1} and may exceed 7,000 μmho cm^{-1} (Gorham et al., 1983). SO_4 concentration is positively correlated with conductivity above about 200 μmho cm^{-1} and 10 mg L^{-1} or 0.1 mmol L^{-1} SO_4 (Figure 7B in Gorham et al., 1983). Overprinting this geological pattern is a strong climatic gradient with warmer, drier conditions toward the southwest (toward the northern Great Plains) and colder, more humid conditions to the northeast (toward the Laurentian Great Lakes), which enhances the conductivity gradient: more evaporative conditions in the southwest serve to concentrate surface waters and further increase ionic

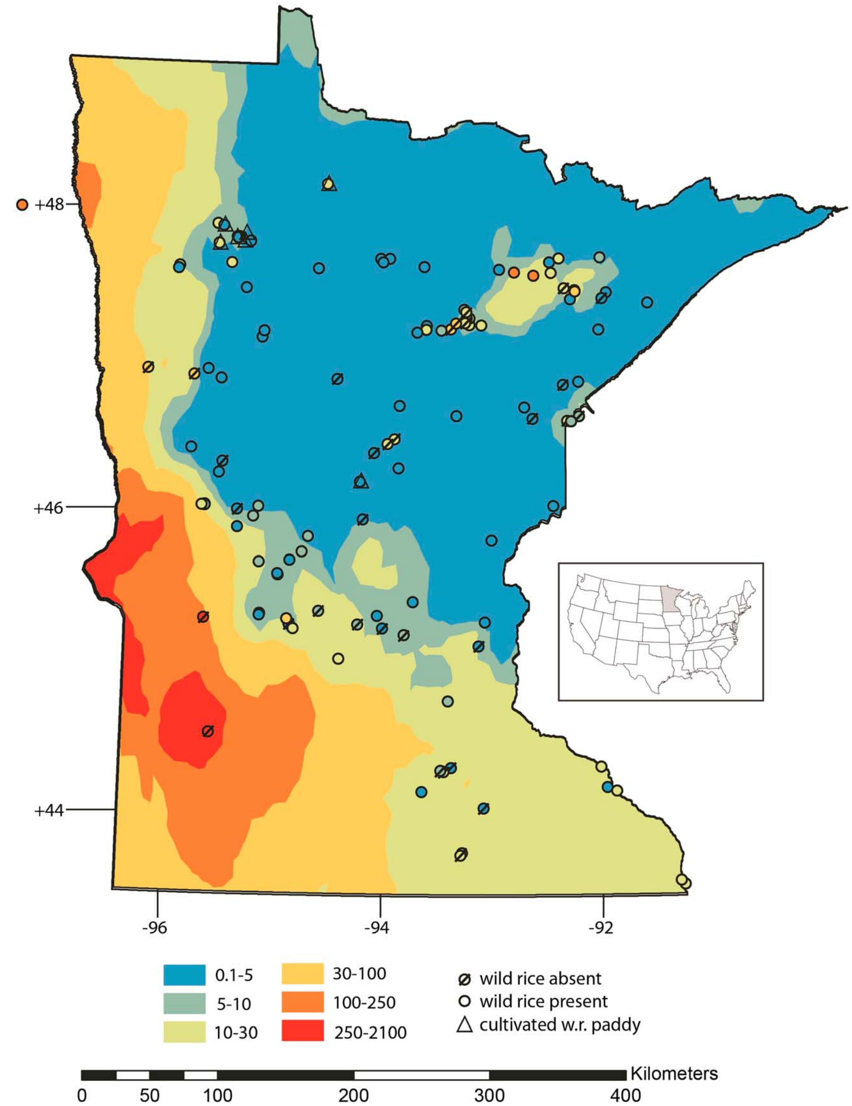

Figure 1. Map of Minnesota showing field sites overlain on kriged contours of average surface water SO_4 concentrations from 4,998 waterbodies (data from MPCA and DNR databases). The symbols are filled with the color corresponding to the site's surface water sulfate concentration. Site to the northwest of the Minnesota map is within the state of North Dakota, 40 km west of the border with Minnesota (see text). Sites where wild rice was not found have a diagonal line through the symbol.

strength, while moister conditions in the northeast maintain low ionic strength in surface waters (Gorham et al., 1983).

2.1.2. Habitat Preferences of Wild Rice

Although the scientific literature contains many assertions concerning the environmental preferences of wild rice regarding water and sediment quality (e.g., DNR, 2008, 2016; Lee, 2002; Moyle, 1944; Moyle & Krueger, 1964; Pillsbury & McGuire, 2009), sometimes little evidence was presented to support the putative preferences. The shallow freshwaters in which wild rice is found are usually relatively transparent because wild rice and other rooted macrophytes do best if they can photosynthesize as they grow each spring from the sediment to the water surface (Scheffer, 1998). Otherwise, any particular habitat preference of wild rice, such as specific chemical ranges of the sediment or surface water, is challenging to identify. Since wild rice is an opportunistic annual plant, a primary habitat requirement is periodic environmental disturbance (Grime, 1977) that keeps perennial plants such as water lilies from controlling the space and light of the shallow waters in which these species cooccur (Pillsbury & McGuire, 2009). Wild rice does not seem to have specific sediment requirements, as it has been observed growing in a variety of substrates (Aiken et al., 1988; Lee,

1986) within its range. Annual plants are adapted to exploit environments intermittently favorable for rapid plant growth and to maximize seed production (Grime, 1977). Wild rice produces between 25 and 150 relatively large seeds per stem (Eule-Nashoba, Biesboer, & Newman, 2012). Seeds buried in the sediment can survive for up to several decades until conditions are again favorable for germination and growth (DNR, 2008). *Zizania palustris* seeds germinate at low rates unless they have been exposed to near-freezing temperatures for at least 3 months (Kovach & Bradford, 1992), although the environmental cues for subsequent germination are poorly understood, aside from elevated temperature.

Because *Z. palustris* does not normally self-pollinate and is wind-pollinated (which implies that the pollen source must be relatively nearby; Friedman & Barrett, 2009), does not reproduce asexually, and has an annual life cycle (Aiken et al., 1988), in this analysis the presence of wild rice plants is taken to mean that the waterbody hosts a successfully reproducing and self-sustaining population. A few of the sites in this study may have experienced recent watershed changes such that steady state has not yet been reached among environmental variables and wild rice reproduction, but the balance of the 108 sites should have been in steady state at the time of sampling. The population of wild rice in a given lake can exhibit large fluctuations from year to year, which has been attributed to disturbances such as abrupt increases in water level (DNR, 2008) and to cyclical changes in N availability (Walker et al., 2010). Wild rice fills a unique ecological niche, in that there are virtually no other annual aquatic macrophytes across the Great Lakes region (Eggers & Reed, 2011).

2.1.3. Site Selection

The goal of the field survey was to identify and sample potential wild rice habitat across a gradient of SO_4 concentrations. Potential wild rice habitat was defined simply as shallow water (30–120 cm deep, though some sampled sites had water as shallow as 5 cm) that was sufficiently transparent to support rooted aquatic macrophytes. Turbidity from dense phytoplankton blooms or suspended solids may effectively exclude rooted macrophytes due to light limitation (Scheffer, 1998).

Most Minnesota lakes that host wild rice populations have low SO_4 concentrations; the median concentration of wild rice lakes is 1.8 mg L^{-1}, and the 75th percentile is 3.6 mg L^{-1} (MPCA, 2014). If only those waters hosting abundant wild rice were sampled, most of those would be low in SO_4, and little would be learned about how elevated SO_4 concentrations (or other important variables) might affect wild rice. Conservation biologists commonly identify important habitat variables through binary (i.e., is the species present or absent at a given site?) logistic regression, which requires the sampling of sites that do not support the species of interest (e.g., Carroll, Zielinski, & Noss, 1999; Peeters & Gardeniers, 1998; van der Heide et al., 2009). Consequently, potential wild rice habitats with a range in SO_4 concentrations were sampled without regard to whether the waterbody hosted or was known to host wild rice. An effort was made to sample waterbodies that covered the range of SO_4 concentrations across Minnesota and especially to sample sites in high-SO_4 regions that had reports of recent or historical presence of wild rice. This strategy also resulted in the sampling of a high-SO_4 wild rice site in the North Branch of the Turtle River (198 mg SO_4 L^{-1}), 40 km into North Dakota from northwestern Minnesota (Figure 1). A gradient of SO_4 concentrations was sampled by identifying potential wild rice habitat in two areas of elevated SO_4, the "island" of elevated SO_4 in the Iron Range region of northeastern Minnesota and waters naturally elevated in SO_4 to the west and south of the known range of wild rice (Figures 1 and S1). Nutrient (N and P) availability (reflecting natural soil fertility as well as agricultural runoff) also increases to the west and south, potentially supporting phytoplankton growth sufficient to exclude macrophytes, including wild rice. Consequently, in western and southern Minnesota, DNR lake databases were screened for the presence of water lilies (*Nuphar variegata* or *Nymphaea odorata*), the occurrence of which indicates transparency sufficient to support rooted macrophytes that also often cooccur with wild rice. In an analysis of DNR aquatic plant surveys from 1,753 shallow lakes, we found that the odds of finding wild rice where there are water lilies are 26 times the odds of finding wild rice where there are no water lilies, with a 95% confidence interval of 20–36 times (neither wild rice nor water lilies = 968; wild rice but not water lilies = 60; no wild rice but water lilies = 272; both wild rice and water lilies = 453).

With these considerations, water bodies were selected for sampling based on preliminary data including average water depth, presence of water lilies, conductivity or SO_4 concentration, and geographic distribution (i.e., to sample widely across the state). Both rivers and lakes were sampled, as were seven different cultivated wild rice paddies. Within a given water body, the field team chose a location for sampling based on a decision tree (Table S1 in the supporting information).

2.2. Field Methods

Sampling occurred in August–September 2011 and June–September 2012 and 2013. Sampling efforts were focused in late summer to capture physical and chemical conditions when wild rice plants were maturing and when identification of wild rice is most certain; voucher specimens of wild rice were always taken. Samples were collected from an anchored canoe or small boat, except in the cultivated wild rice paddies when the water was too shallow to float a canoe, and samples were collected on foot. A Hach model HQ40d or Hydrolab Quanta sonde, calibrated daily, was used to measure temperature, specific conductance, dissolved oxygen, and pH in the surface water. Water transparency was determined with a 1 m long Secchi-tube (Water Monitoring Equipment & Supply, USA), and apparent color was measured using a Hach model CO-1 color test kit. Surface water samples (later split into separate subsamples; see below) were collected by a technician wearing long nitrile gloves in two 2 L amber Nalgene bottles that had been previously triple rinsed with deionized water and rinsed 3 times with water from the site before filling. Water samples were stored on ice.

Short (~50 cm) sediment cores with ~10–20 cm of overlying water were collected at eight undisturbed locations at least 1 m apart around the boat using an HTH corer (Pylonex, Sweden) with a 7 cm diameter polycarbonate barrel. A piston was inserted in the bottom end of each core as it was retrieved. Cores were kept upright and shaded prior to sample processing.

Aquatic macrophytes were identified and percent cover estimated within a plastic hoop 1 m in diameter placed at 4 locations around the boat. In 2012 and 2013, the number of stems of wild rice inside each hoop was also quantified.

Pore water samples were obtained from cores processed on shore using 10 cm Rhizon™ filters (pore size 0.12–0.18 μm) (Rhizosphere.com, Netherlands; Shotbolt, 2010) inserted vertically into the core tops, following extrusion of overlying water, and connected to evacuated serum bottles with PVC/polyethylene tubing and a stainless steel needle. Three separate cores were sampled, one for nutrients (nitrate + nitrite, TP, and TN) and DOC (70 mL), a second for metals (50 mL), and a third for dissolved silica, Cl, and SO_4 (30 mL). A fourth core was sampled for pore water sulfide, but in this case, the serum bottle was preloaded with 0.2 mL of 2.0 N zinc acetate, 0.5 mL of 15 M sodium hydroxide, and a stir bar, flushed with a nitrogen atmosphere, evacuated, and preweighed. Air was flushed from the Rhizon-tubing assembly with sample pore water using a second evacuated bottle before the needle was inserted into the sulfide sample bottle. In 2011 only pore water samples for sulfide and metals were collected. Pore water pH was measured on a fifth core by inserting the probe of a Hach model HQ40d pH meter into the sediment to a depth of 5 cm and allowing the reading to stabilize.

A composite sediment sample was collected from the uppermost 10 cm of the sixth, seventh, and eighth cores, placed into a stainless steel bowl, and stirred under nitrogen atmosphere to homogenize. A 50-mL subsample was placed in a polypropylene sample bottle along with 1.0 mL of 1.0 N zinc acetate for analysis of acid-volatile sulfide (AVS). The headspace of the AVS sample bottle was flushed with N_2 and the bottle capped; that bottle was placed in a larger glass jar and that jar flushed with N_2 and tightly sealed. The sample was immediately placed in a cooler with dry ice to freeze. The remaining composited sediment was placed into a polycarbonate container and stored on ice for later analysis.

Water subsamples were taken from the large amber Nalgene bottles by a technician wearing nitrile gloves. Sulfuric acid (5 mL of 10%) was immediately added to subsamples for the analysis of P, TKN (total Kjeldahl nitrogen), ammonia, and nitrate + nitrite in 250 mL polyethylene bottles. Nitric acid (2.5 mL of 20%, to acidify to pH < 2) was immediately added to subsamples for the analysis of total metals in 250 mL polyethylene bottles. Samples for dissolved metals were subsampled in 250 polyethylene bottles and subsequently filtered using a 0.45 μm filter and preserved with nitric acid in the laboratory. Samples were stored on ice.

2.3. Laboratory Methods

Surface water, pore water, and most sediment analyses were conducted by the Minnesota Department of Health Environmental Laboratory (MDHEL) in 2012 and 2013, following standard methods. In 2011 other laboratories conducted the analyses (University of Minnesota Soils Laboratory (UMNSL), St. Croix Watershed Research Station (SCWRS), and Gustavus Adolphus College (GAC)); methodological differences are noted, and the laboratory is identified where relevant.

Surface and pore water samples were analyzed for anions (Cl and SO_4) by ion chromatography on a Dionex ICS-3000 (MDHEL), Fe, Ca, Na, Mg, and K by inductively coupled optical emission spectrometry on a Varian 715-ES (MDHEL), Mn, Cu, Zn, Co, Ni, Al, As, and Se by inductively coupled mass spectrometry on a Perkin Elmer Elan DRCE (MDHEL), and DOC by UV-persulfate oxidation on a Tekmar-Dohrmann Phoenix 8000 (SCWRS and MDHEL). N and P were measured by colorimetric methods (on a Lachat Quikchem Flow-Injection Autoanalyzer) at SCWRS and MDHEL following cadmium-reduction (nitrate and ammonia) or dual alkaline-persulfate digestions (TP and TN). Silica was measured colorimetrically at SCWRS on the Lachat Autoanalyzer and at MDHEL on a Beckman Coulter DU 800 UV/VIS spectrophotometer. Pore water sulfide was analyzed colorimetrically on each lab's Lachat Autoanalyzer following in-line acid distillation and NaOH trapping (SM 4500-S2). Alkalinity was measured by potentiometric acid titration (MDHEL) or as DIC by acid digestion and IR detection (SCWRS). DIC was converted to alkalinity using pH, temperature, and specific conductance of the surface water.

Sediment samples from 2011 were analyzed by combustion for total carbon (TC), total nitrogen (TN), and total sulfur (TS) using, respectively, a Tekmar Phoenix 8000 CO_2 analyzer, an Elementar Vario Max N analyzer, and a LECO sulfur analyzer (UMNSL). Samples from 2012 and 2013 were analyzed for CHN on a Costech 4010 Elemental Analyzer (UMN Stable Isotope Laboratory). Total inorganic carbon (carbonate) was analyzed by coulometric titration on a UIC CM5015 CO_2 coulometer, while water and organic matter content were determined by loss-on-ignition methods (Heiri, Lotter, & Lemcke, 2001) in the UMN LacCore facilities. Sediment AVS was analyzed colorimetrically, as above for pore water sulfide, following acid-distillation and in-line alkaline trapping (SM 4500-S2; Hsieh & Shieh, 1997).

Sediment phosphorus was extracted from freeze-dried sediments following methods of Engstrom and Wright (1984) for total-P and Hieltjes and Lijklema (1980) for P fractions (NH_4Cl-extractable, NaOH-extractable, HCl-extractable, and residual (organic)-P). The P extracts were measured colorimetrically by flow-injection autoanalyzer (SCWRS). Extractable iron and trace metals were quantified from a 0.25 g homogenized freeze-dried sediment subsample incubated in 0.5 M HCl for 30 min at 80°C. The samples were centrifuged, decanted, and analyzed by ICP-MS at GAC. This extraction releases metal oxyhydroxides, sulfides, and loosely bound phases from the sediment without appreciably attacking the silicate matrix (Balogh et al., 2009).

2.4. Data Subsets and Statistical Analysis

From 2011 to 2013, 260 site visits were conducted in 108 different natural waterbodies, including lakes, small streams, backwaters of the Mississippi River, and wetlands, plus 7 different cultivated wild rice paddies. For a variety of logistical reasons, the full suite of samples could not be collected on some site visits. Three subsets of the field data were identified for the analyses reported here. A subset that consists of all of the samples from natural waterbodies (excluding the cultivated paddies) with virtually complete analyses (surface water, pore water, and bulk sediment; $n = 194$) was termed for internal purposes Class D. Pollman et al. (2017) used Class D to develop a structural equation model to elucidate key variables that govern the concentration of sulfide in sediment pore water. A second subset, Class S, of 51 samples from 7 stream and 8 lake sites was each sampled 3 to 5 times from 27 May to 19 September 2013, to provide a data set to assess seasonality in variables. A third subset, Class B, was used for conducting probabilistic analyses to identify the most likely parameters controlling the presence and absence of wild rice and to examine Spearman nonparametric correlations among field variables. Class B consists of one sample from each site ($n = 108$) and excludes samples collected in 2011, which were analyzed with slightly different lab methods. Although Class B was not created as a random sample of Minnesota waterbodies, the frequency distribution of SO_4 concentrations is intermediate between a probability-based survey conducted by USEPA (MPCA, 2016) and a list of known wild rice water bodies, which are overwhelmingly low-SO_4 lakes (MPCA, 2014). Therefore, the Class B data set is reasonably representative of potential wild rice habitat, and binary logistic regressions can be used to approximate the probability of wild rice occurrence as a function of field variables such as pore water sulfide. The Class B data set is used in all analyses presented here, with two exceptions: (1) Figures 3a–3c present the full Class D data set, plus for comparison, data from the cultivated wild rice paddies; (2) Statistical analysis was performed with the software package R version 3.2.3.

To identify variables associated with the presence and absence of wild rice, we relied on binary logistic regressions (BLR), using the glm function in R. BLR does not require normally distributed data, but

Table 1
Field Variable Correlation With the Presence-Absence of Wild Rice, Assessed Through Binary Logistic Regression (BLR), Plus Spearman Correlations Between Variables[a]

	Binary logistic regression (BLR) correlation with field variable			Spearman correlation with field variable (rho)				
Field variable	Log transformed?	*p* value	Correlation direction	Wild rice density (only wild rice sites) *n* = 67	Pore water sulfide	Sediment AVS	Water transparency	Water temperature
pw K	Y	0.0008***	Negative	−0.27*	0.46***	0.11	−0.10	0.33***
pw sulfide	Y	0.0012***	Negative	−0.31**	1.00	0.29**	−0.07	0.17
Water depth (m)	N	0.0028***	Negative	0.07	0.11	0.08	0.22*	0.19*
Transparency (cm)	N	0.0031***	Positive	0.11	−0.07	−0.13	1.00	−0.08
sw TN	Y	0.0054**	Negative	−0.12	0.22*	0.08	−0.61***	0.23*
sed Se % dry	N	0.0059**	Negative	0.12	0.08	0.27**	−0.21*	0.13
sw Temp	N	0.0077**	Negative	0.08	0.17	0.11	−0.08	1.00
pw Fe	Y	0.0109*	Positive	0.20	−0.58***	0.00	0.04	0.09
sw pH	N	0.0200*	Negative	−0.14	0.28**	0.08	−0.05	0.35***
sw TP	Y	0.0353*	Negative	0.15	0.05	0.29**	−0.58***	0.27**
Latitude	N	0.0376*	Positive	−0.04	−0.06	−0.09	0.13	−0.51***
sed TS % dry	Y	0.0483*	Negative	0.20	0.40***	0.42***	0.03	−0.08
sw K	Y	0.0922		−0.03	0.29**	0.21*	−0.18	−0.08
sed AVS % dry	Y	0.1317		0.02	0.29**	1.00	−0.13	0.11
sw sulfate	Y	0.1475		−0.10	0.44***	0.45***	−0.07	0.04
sed TP % dry	N	0.2697		−010	0.07	0.30**	−0.14	0.14
sw alkalinity	Y	0.2786		0.25*	0.22*	0.26**	0.11	0.17
pw TN	Y	0.2963		−0.30	0.31***	0.14	−0.20*	0.34***
pw NH4	Y	0.4505		−0.33**	0.33***	0.22*	−0.17	0.26**
sed Fe % dry	Y	0.4795		0.16	−0.35***	0.38***	−0.10	−0.06
pw DOC	Y	0.4865		0.08	−0.05	−0.1	−0.21*	0.09
pw Si	N	0.5548		0.03	0.33***	0.18	0.07	0.29**
pw TP	Y	0.6341		0.02	0.12	0.30**	−0.26**	0.26**
sed TN % dry	N	0.6807		−0.06	0.14	0.04	0.06	−0.06
sed water content	N	0.7274		−0.07	0.15	0.10	0.10	0.02
sed TOC % dry	N	0.7854		−0.10	0.10	0.02	0.10	−0.06

[a]Note. The variables are ordered by the significance of the BLR. The first 12 variables have BLR significance of $p < 0.05$. The additional 14 variables are listed because of their correlation with pore water sulfide, sediment AVS, or surface water transparency or temperature—or their notable lack of correlation with wild rice presence-absence (pw = pore water; sw = surface water; sed = sediment).
*$p < 0.05$. **$p < 0.01$. ***$p < 0.001$.

nevertheless, we transformed some variables (Table 1) to achieve approximately normal distributions. BLR also yields the probability of occurrence at a given value of the variable. Spearman nonparametric correlations (rho) between field variables in Class B were examined as part of the effort to identify the major biogeochemical interactions in these shallow-water systems. Seasonality in a variable was assessed using linear mixed effects models, with time (fraction of a year) as a fixed variable and site as a random factor (to account for multiple samples per site). In the model developed for each field variable, we accounted for the seasonal cycle using the following equation (Crawley, 2007), where *A*, *B*, and *C* are fitted model coefficients:

$$y = A + B\ \sin(2\pi\ \text{time}) + C\ \cos(2\pi\ \text{time}) \quad (1)$$

3. Results and Discussion

3.1. Field Variables Associated With Wild Rice Presence and Absence

Of the 64 field quantified variables, BLR identified 12 that are associated with the presence/absence of wild rice at the 0.05 probability level or better (Table 1): pore water sulfide, K, and Fe (Figures 2a, 2b, and 2f); surface water temperature, TP, TN, and pH (Figures 2d, 2m, 2n, and 2o); sediment Se and TS (Figures 2c and 2p); water depth and transparency (not shown; Figure 2e); and latitude of the site (Figure 2g). These variables may be important in controlling the presence or absence of wild rice or may merely be correlated with one or more actual causative factors. Because we are primarily interested in factors that control presence or absence of wild rice, in contrast to the density of wild rice, we place primacy on the BLR results and use the Spearman

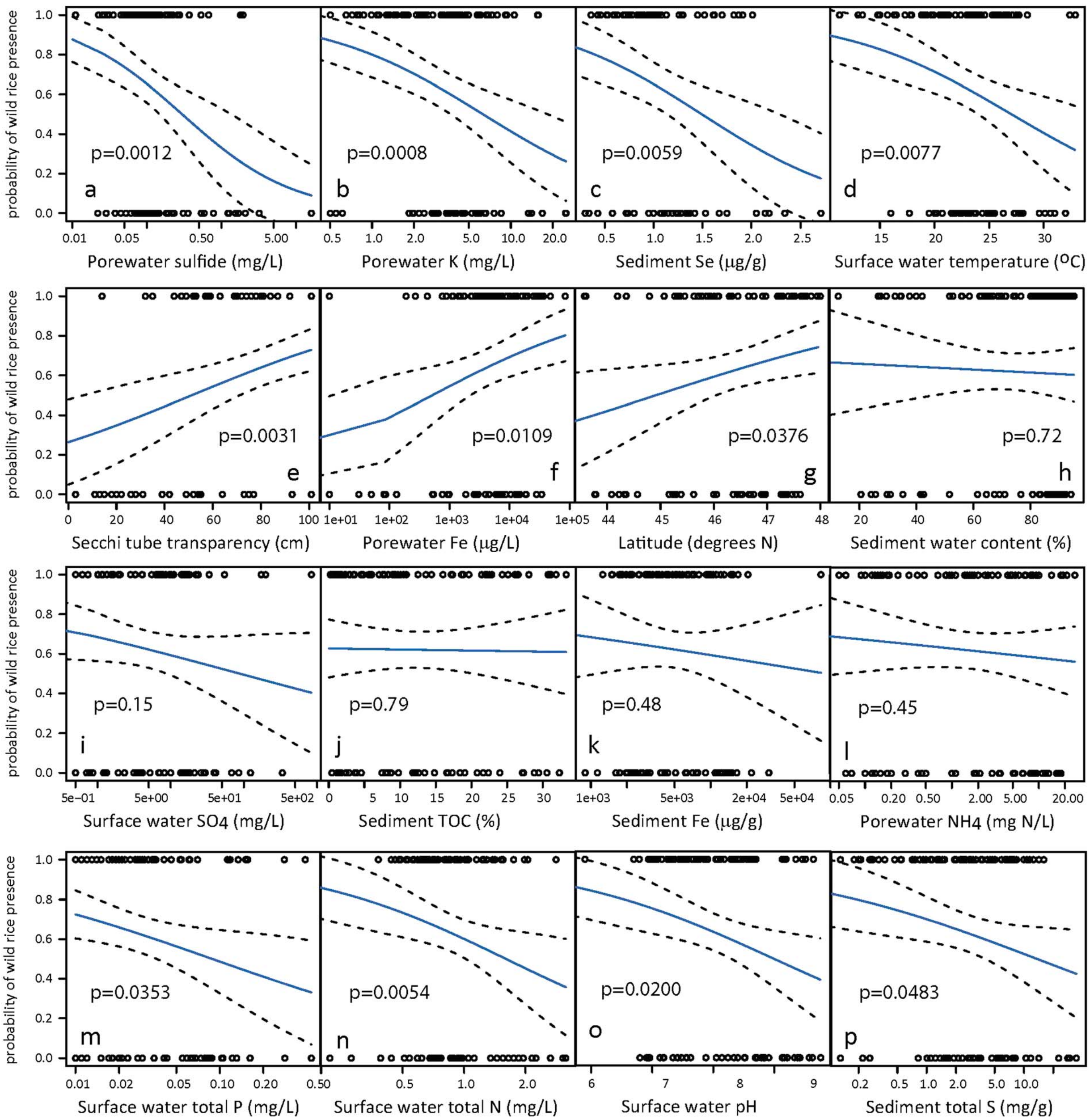

Figure 2. Binary logistic regressions for 16 variables found to be statistically significant in this study or indicated in the literature as important for wild rice habitat. The open circles indicate the value for a given parameter of each site used in the analysis; the circles at the top of a plot indicate sites with wild rice present; the circles at the bottom of a plot indicate sites with wild rice absent. The span of the dashed lines around the solid line indicates the 95% confidence interval.

correlations to help understand the relationships between environmental factors of interest. Wild rice density is negatively correlated with pore water sulfide, potassium (K), and NH_4 and positively correlated with surface water alkalinity (Table 1). There are likely factors controlling the density of wild rice at any particular location in addition to the variables measured, such as herbivory and hydrological disturbances.

One should be cautious in the interpretation of statistically significant associations between wild rice and field variables, in that true cause and effect are not necessarily obvious. For instance, is the toxic quality of pore water sulfide sufficient explanation for its negative associations with both the presence and density of wild rice? Do sites with greater density of wild rice have lower pore water sulfide because low sulfide allows wild rice to grow, or because plants release oxygen from their roots, oxidizing sulfide? The true explanation is likely a combination of the two mechanisms: elevated pore water sulfide can eventually extirpate a wild rice

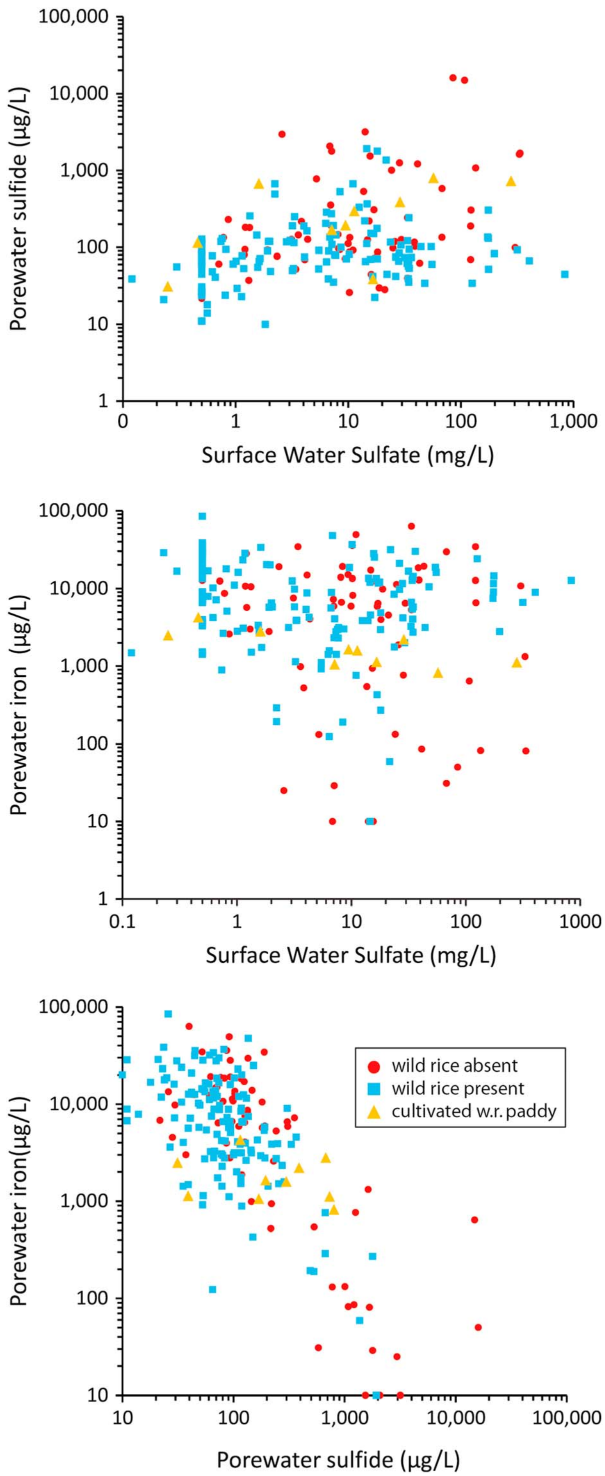

Figure 3. Class D data plus cultivated wild rice paddies (yellow triangles) showing sites with wild rice present (blue squares) and absent (red circles). Note that (a) pore water sulfide is not linearly related to surface water SO_4, indicating that additional factors besides SO_4 concentration contribute to the sulfide concentration in pore water; (b) wild rice can occur in sites over a wide range of surface water SO_4 values as long as pore water Fe is relatively high; and (c) pore water Fe and sulfide have a strong negative relationship, due to the energetically favorable formation of FeS compounds, and that wild rice mainly occurs where pore water sulfide is $<$1,000 μg L^{-1}.

population by reducing seedling survival and seed production, weight, and viability (Pastor et al., 2017), but oxygen release from roots when sulfide concentrations are low enough to allow wild rice to successfully reproduce drives sulfide to even lower concentrations than would have occurred without the plants (Myrbo et al., 2017). Although the negative correlation between pore water sulfide and wild rice density (rho = -0.31, $p < 0.01$, Table 1) could be interpreted to mean that lower sulfide allows a larger population to grow, it is also possible the correlation is partly caused by oxygen release from the wild rice roots, decreasing sulfide concentrations. This hypothesis is supported by the observation from a controlled experiment that acid-volatile sulfide (AVS) sediment concentrations were 30% lower when wild rice was present (Myrbo et al., 2017).

Of the 12 variables significantly associated with the occurrence of wild rice, we propose that nine are noncausal and merely related to one or more of three truly causative factors: (1) pore water sulfide, (2) water transparency, and (3) water temperature. These three variables are not significantly correlated with one another (Table 1), and there are plausible mechanisms for each to independently exclude wild rice from otherwise suitable habitat: (1) elevated sulfide reduces the growth of wild rice (Pastor et al., 2017); (2) low water transparency plausibly constrains the ability of a germinated wild rice seed to reach sufficient light before it runs out of endosperm energy (Aiken et al., 1988; DNR, 2008); and (3) warmer winter water temperature at lower latitudes may limit seed germination, as the seeds of *Z. palustris* must experience at least 3 months in cold water to break seed dormancy (Kovach & Bradford, 1992) (although summer temperatures were measured in this study, winter and summer temperatures would be correlated).

3.2. Pore Water Sulfide as a Causal Variable and Associated Correlated Variables

Our primary a priori hypothesis was that elevated surface water SO_4 can produce elevated pore water sulfide concentrations which, in turn, negatively affect potential wild rice habitat. A plot of pore water sulfide against SO_4, with wild rice presence noted (Figure 3a), suggests that wild rice is generally not found at sites with elevated sulfide. Of the sites with pore water sulfide greater than 1,000 μg L^{-1}, wild rice was present in 23% (3 of 13, with only a few plants found at 2 of those 3 sites). In contrast, wild rice was present at 74% of the sites where sulfide was less than 1,000 μg L^{-1}. Despite historical reports of *Zizania aquatica* in Minnesota, inspection of voucher specimens, following the taxonomy of Terrell et al. (1997), found only *Z. palustris* at all sites sampled. *Zizania aquatica* (Southern wild rice) is rare in Minnesota, but its range extends east through Wisconsin and the southern part of the Great Lakes region to New England and occurs in freshwater tidal marshes south to Florida and west to Louisiana (Terrell et al., 1997). The findings of this study, especially those related to temperature, may not apply to *Z. aquatica*.

Despite a strong relationship between sulfide and wild rice, the relationship between SO_4 and pore water sulfide among the 108 field sites was not a simple linear function. High surface water SO_4 did not always result in high pore water sulfide (above 1,000 μg L^{-1}), and some samples with surface water SO_4 less than 10 mg L^{-1} had pore water sulfide greater than 1,000 μg L^{-1} (Figure 3a). The 33 samples with surface water SO_4 below 1.0 mg L^{-1} all had pore water sulfide less than 200 μg L^{-1}, suggesting that surface water SO_4 might limit maximum sulfide production.

Wild rice was present at high and low SO_4 concentrations as long as pore water Fe was high and sulfide was low (Figures 3b and 3c): pore water Fe and sulfide each exert antipathetic control over the concentration of the other (Figure 3c; Pollman et al., 2017), and wild rice mainly persists in sites where pore waters are low in sulfide and high in Fe. Pollman et al. (2017) developed a structural equation model showing that variations in three variables (SO_4, sediment TOC, and sediment extractable Fe) contribute nearly equally to the observed variations in pore water sulfide among the sites in this study. Sulfate-reducing bacteria are simultaneously limited in their production of pore water sulfide by surface water SO_4 and sediment TOC (which are roughly proportional to available SO_4 and labile organic matter, respectively). Concentrations of sulfide in pore water are then constrained by the availability of pore water Fe, which is in turn controlled by the overall supply of Fe in the sediment (Pollman et al., 2017).

If pore water sulfide concentration is a causative factor controlling the presence of wild rice, as hypothesized, then other variables may be statistically significant because they either vary with the process of SO_4 reduction or with the sulfide itself. Pastor et al. (2017) showed that wild rice growth declines in proportion to sulfide concentrations in both hydroponic and outdoor mesocosm experiments. In a study of the Pastor et al. mesocosms, Myrbo et al. (2017) showed that the enhanced mineralization of plant litter associated with SO_4 reduction produced increases in surface water P and N, and increases in pore water sulfide caused decreases in pore water Fe. These effects from the controlled mesocosm experiment are consistent with correlations observed among sites in the field data between pore water sulfide and surface water N and pore water Fe (Table 1). Surface water P is not significantly correlated with pore water sulfide in the field data, despite dual mechanisms of P mobilization from sediment, (1) the interaction between sulfide and Fe (Caraco et al., 1993; Maynard, Dahlgren, & O'Geen, 2011; Smolders & Roelofs, 1993) and (2) mineralization of organic matter. The lack of correlation of surface water P with pore water sulfide in this field study is not surprising because given the wide variety of landscapes sampled, there is no reason that pore water sulfide would be proportional to the mass of Fe that has reacted with sulfide and released sorbed P. In SO_4 addition experiments where the P and Fe content of the sediment is held constant, there is often a significant correlation between pore water sulfide and mobilized P (Myrbo et al., 2017). In contrast to the lack of correlation of pore water sulfide with surface water P in this field study, AVS is significantly correlated with surface water P (rho = 0.30, $p < 0.01$, Table 1), presumably because AVS is proportional to the iron that has reacted with sulfide.

Elevated pore water sulfide is a product of SO_4 reduction-driven mineralization of sediment organic matter, which also releases the constituents of the decaying plant material, N, P, K, silica, and C (either as DIC, which increases alkalinity, or DOC) into sediment pore water and the overlying surface water (Myrbo et al., 2017). Consequently, the occurrence of wild rice is negatively associated not only with pore water sulfide ($p = 0.001$) but also with elevated pore water K ($p = 0.0008$) and surface water TN ($p = 0.005$, Table 1). Median concentrations of these variables are lower in wild rice waters compared to waters with no observed wild rice (88 versus 126 μg L^{-1} sulfide, 2.4 versus 4.3 mg L^{-1} pore water K, and 0.74 versus 0.95 mg L^{-1} TN, Table S3). Pore water sulfide is itself positively correlated with pore water K, TN, NH_4, and silica, surface water K, alkalinity, and pH, and sediment TS and AVS (Tables 1 and S4).

The strong evidence for the association of elevated pore water K with the absence of wild rice (Table 1) is interesting, as K is an essential plant nutrient, and therefore, it is unlikely that the association is based on toxicity to wild rice. Rather, it is likely that the association is a result of the simultaneous mobilization of K with the production of sulfide as plant matter is mineralized. Potassium does not bond covalently with organic compounds and is readily leached out of dead organic matter (Troeh & Thompson, 2005). Silica phytoliths dissolve as plant matter is mineralized, allowing additional K that had been trapped within the phytoliths to be released into sediment pore water (Nguyen et al., 2015). Wild rice and other wetland macrophytes develop abundant phytoliths that release dissolved silica upon decomposition (Struyf & Conley, 2009). Additional dissolved silica is likely released to pore water as epiphytic diatoms are mineralized. Pore water silica, K, and sulfide are all significantly correlated with each other (Tables 1 and S5). The negative correlation of pore water K with wild rice may be magnified by its additional positive correlation with elevated water temperature (Table 1), which plausibly accelerates dissolution of silica in organic matter (Gudasz et al., 2010; Kamatani, 1982).

AVS largely consists of solid-phase sulfide, which is not available to plants and therefore is not significantly associated with wild rice presence/absence ($p > 0.10$, Table 1). AVS is a measure of cumulative sulfide production, which is proportional to past mineralization of organic matter, consistent with significant positive correlations between AVS and pore water TP and NH_4, and surface water TP and alkalinity ($p < 0.01$, 0.05, 0.01, and 0.01, respectively, Table 1).

The negative association of sediment total-S (TS) with wild rice presence (BLR $p = 0.048$, Table 1) is likely the result of both TS and wild rice being controlled by sulfide production; the median TS concentration at sites with wild rice is 2.6 mg g^{-1}, compared to 4.1 mg g^{-1} at sites without wild rice (Table S3). Sediment TS is correlated with both pore water sulfide and AVS. The negative association of sediment Se with wild rice (BLR $p = 0.006$) is surprising, given that median Se concentrations are very low (0.9 and 1.2 μg g^{-1} in sites with and without wild rice, respectively). The slightly higher Se at sites without wild rice may be caused by the coprecipitation of Se and S by SRB, as shown by Hockin and Gadd (2003). Selenium is correlated with sediment total S (rho = 0.35; $p < 0.001$).

3.3. Water Transparency as a Causal Variable and Associated Correlated Variables

Lower water transparency is associated with a lower probability of wild rice occurrence (BLR $p = 0.003$). Transparency is not related to wild rice density (rho = 0.11, $p > 0.20$, Table 1); however, low transparency can apparently exclude wild rice (11 of the 12 sites with transparency <30 cm had no wild rice), but above that threshold, other variables control wild rice density. Low water transparency decreases photosynthesis of wild rice seedlings while growing to the water surface, which (a) decreases oxygen production that could otherwise be used to detoxify sulfide internally (Krüssel et al., 2014), or externally if released into pore water from the roots (Colmer, 2003); and (b) decreases the energy available for root development, enhancing vulnerability to a sudden increase in water depth, which can uproot an entire year's cohort (DNR, 2008). Wild rice is unusual among grasses in that the stem develops before the root, probably because the seedling may have to grow over 50 cm before reaching the water surface, at which time floating leaves are developed that can supply energy for root development (Aiken, 1986). If transparency is too low, or the water too deep, the energy stored in the seed can be insufficient for the seedling to reach the water surface.

Water transparency can be controlled by the density of phytoplankton, which was not measured in this study. However, transparency is highly correlated with the nutrient concentrations that control phytoplankton growth, total phosphorus (rho = −0.58, $p < 0.001$), and total nitrogen (rho = −0.61, $p < 0.001$). Transparency can also be controlled by colored dissolved organic matter, consistent with the observed significant correlation between transparency and water color (rho = −0.68, $p < 0.001$, Table S4).

3.4. Temperature as a Causal Variable and Associated Correlated Variables

Wild rice germinates at higher rates following longer exposure at temperatures closer to freezing (Kovach & Bradford, 1992), consistent with the significant association of wild rice absence with lower latitudes (BLR $p = 0.04$) and warmer summer water temperature (BLR $p = 0.008$; medians of 21.9° and 23.7°C with and without wild rice, respectively). Sites with warmer summer water temperatures generally also have warmer winter temperatures. Warmer and shorter winters would cause lower germination rates, ultimately reducing the probability that a population could persist over the long term. For this reason, the Minnesota Department of Natural Resources hypothesizes that climate change may push the range of wild rice farther north (DNR, 2008, 2016). However, the temperature control of wild rice germination has not been adequately investigated to rigorously assess this hypothesis. The observed association of wild rice with lower pH surface waters (BLR $p = 0.04$; median pH values of 7.8 and 8.5 at sites with and without wild rice, respectively) may be due simply to the correlation of wild rice with cooler surface waters: the solubility of CO_2 is higher in colder water, leading to lower pH (Spearman correlation between temperature and pH = 0.35, $p < 0.0001$).

Lower latitude sites are negatively associated with wild rice presence and density (Table 1). Lower latitude sites are correlated with higher water temperature (rho = −0.51, $p < 0.001$). Geological and land use gradients also correlate with latitude, producing correlations with surface water N and P (rho = −0.25 and −0.31, $p < 0.01$). Despite these correlations with nutrients, latitude is not significantly correlated with water transparency (rho = 0.13), so the general unsuitability of lower latitudes for wild rice may be a combination of warmer winters and some reduced transparency as a result of nutrient enrichment. Latitude is not significantly correlated with pore water sulfide (rho = −0.06).

3.5. Synergy Among the Three Causal Variables of Sulfide, Temperature, and Transparency

While temperature may control wild rice presence/absence through winter temperatures too warm to achieve high rates of seed germination in the spring, higher summer temperatures may act synergistically on variables correlated with pore water sulfide. Elevated summer temperatures likely enhance microbial activity, no matter which electron acceptor is respired by the dominant microbes (Gudasz et al., 2010). Water temperature is indeed correlated with pore water concentrations of the plant nutrients N, P, and K released by decomposition, which are also significantly correlated with either pore water sulfide or AVS (Table 1). Although sulfide production may be enhanced by elevated temperature, the correlation between sulfide and temperature is weak (rho = 0.17; $p > 0.05$).

The production of sulfide plausibly contributes to the significant correlation of six of the nine variables with wild rice occurrence: P and N in surface water, Fe and K in pore water, and S and Se in sediment. Water temperature is significantly correlated with three of these variables (P, N, and K), and therefore, synergistically reinforces their associations with the absence of wild rice. Elevated surface water P and N are further synergistically associated with the absence of wild rice because their release via MSR-driven mineralization also enhances phytoplankton growth, reducing light available to wild rice seedlings; P and N are highly correlated with reduced transparency ($p < 0.001$, Table 1).

In this data set greater water depth is negatively associated with the occurrence of wild rice, not because wild rice grows better in shallower water, which it may, but because of where field crews took samples when wild rice was not present. Following a decision tree (Table S1), when wild rice was not present, field crews usually sampled among water lilies, which, on average, were observed in slightly deeper water than wild rice (67 cm compared to 52 cm).

Finally, *multiple* BLR was employed to investigate the question of whether any of the correlated variables provided additional explanatory power for the occurrence of wild rice beyond the models with sulfide, transparency, or temperature as base predictors. Surface water temperature is predictive of wild rice presence independent of sulfide ($p = 0.03$). Pore water K improves models based on sulfide ($p = 0.02$) or temperature ($p = 0.004$) alone but provides no significant additional explanatory power beyond a model built on both sulfide and temperature ($p = 0.07$). Overall, multiple BLR analysis confirms that other variables provide no additional explanatory power and that the three base predictors are independent of each other.

Multiple BLR was used to model the probability of wild rice occurrence (WR presence) as a function of pore water sulfide (pw sulfide, in mg L^{-1}), water transparency as measured by the Secchi tube (trans, in cm), and water temperature (Temp, in °C):

$$\text{Logit}\ (\text{WR presence}) = 0.532 + 0.0183\ (\text{trans}) - 1.169\ (\log 10\ \text{pw sulfide}) - 0.107\ (\text{Temp}) \tag{2}$$

where odds = exp(logit) and probability = (odds/(1 + odds)).

Pore water sulfide and water transparency are significant variables in the multiple BLR ($p = 0.012$ and $p = 0.016$, respectively), whereas water temperature is only marginally significant ($p = 0.056$). To visualize the interaction of the variables, a 3-D plot was constructed that predicts the probability of wild rice occurrence as a function of sulfide and transparency, while holding constant the marginally significant variable, temperature, at the median value of the Class B data set (23.2 C; Figure 4). Within the range of variables in Class B, modeled probabilities of wild rice occurrence range from a high of 89.8% (trans = 100 cm, which was the maximum of the measurement device, and pw sulfide = 11 μg L^{-1}, which was the reporting limit) to a low of 9.6% (trans = 3 cm, which was the minimum observed, and pw sulfide = 2,000 μg L^{-1}). Modeling was cut off at a sulfide concentration of 2,000 μg L^{-1} because only three Class B sites had pore water sulfide greater than 2,000 μg L^{-1} and none of the three hosted wild rice.

3.6. Field Variables not Evidently Associated With Wild Rice Presence and Absence

Some variables included among the initial hypotheses, or in the past cited as important attributes of wild rice habitat, were not found to be significantly associated with wild rice presence and absence. These include sediment TOC ($p = 0.79$, Figure 2j; DNR, 2008; Lee, 1986; Moyle & Krueger, 1964), flocculent sediment (quantified here as the sediment water content; $p = 0.72$, Figure 2h; DNR, 2008; Lee, 1986; Moyle & Krueger, 1964), sediment N ($p = 0.68$, Table 1; Carson, 2002; Walker et al., 2010), sediment P ($p = 0.27$, Table 1; Carson, 2002; DNR, 2008), and surface water alkalinity ($p = 0.28$, Table 1; Moyle, 1944).

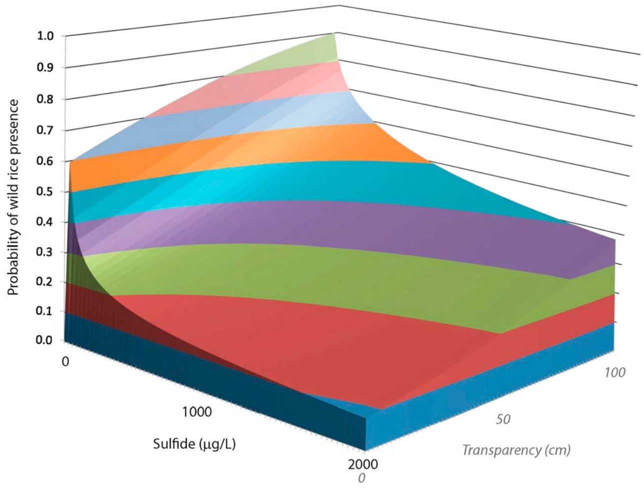

Figure 4. Visualization of the relationship, determined by multiple binary logistic regression, between water transparency and pore water sulfide in controlling the probability of wild rice occurrence at 23.2°C, the median temperature for all sites in the class B data set.

Reduced sediments are generally regarded as producing pore water constituents that are potentially toxic to rooted plants; potentially toxic agents, in addition to sulfide, include ammonia and Fe (Pezeshki & DeLaune, 2012). Analysis of the binary logistic regressions showed no evidence for ammonia toxicity (BLR $p = 0.45$, Figure 2l) or Fe toxicity (wild rice presence is positively correlated with pore water Fe, BLR $p = 0.01$, Figure 2f). As a product of decomposition, ammonia is correlated with pore water sulfide, K, and silica (Spearman correlations $p < 0.001$, Table S4).

The field data provide little evidence that elevated sulfide production excludes wild rice by producing Fe, Cu, or Zn deficiency (Table S3). The possibility that *low* pore water Fe limits wild rice growth is difficult to distinguish from sulfide toxicity because of the strong negative correlation between pore water Fe and pore water sulfide (rho = −0.58, $p < 0.0001$, Table 1). Hydroponic studies using chelated Fe in combination with elevated sulfide (Pastor et al., 2017) show reduced growth, implying that the mechanism is sulfide toxicity, rather than Fe limitation, assuming that the chelated Fe remains bioavailable in the presence of sulfide (Li et al., 2009). The median pore water Fe levels at sites with and without wild rice are similar, 5.7 and 5.9 mg L^{-1}, respectively; average levels are 11.0 and 7.0 mg L^{-1}, respectively, which produced the significant BLR positive correlation between pore water Fe and wild rice presence. On balance, there is little evidence to support the hypothesis that elevated sulfide reduces wild rice growth through Fe deficiency rather than by direct sulfide toxicity. Pore water Cu concentrations were often below the detection limit in the field sites sampled, precluding analysis of their correlation with wild rice presence and absence. The BLR for pore water Zn concentrations with wild rice presence and absence was not statistically significant (data not shown). Neither Cu nor Zn had a significant Spearman correlation with pore water sulfide (data not shown), unlike Fe.

3.7. Seasonality in Field Variables

Fifteen natural wild rice sites were sampled 3 to 5 times in 2013 to determine which field variables exhibit statistically significant seasonal trends that might be important to consider in the overall analysis, given that different sites were sampled in different months. Some variables conformed to expected seasonal trends, such as water temperature ($p = 0.001$), which increased in early summer, peaked about 1 August, and then declined. Some of the surface water variables exhibited monotonic increased concentrations over the summer (alkalinity, Na, Mg, and SO_4; $p = 0.0009$, 0.008, 0.021, and 0.05, respectively). One hypothesis that explains this observation is that waterbodies in Minnesota, after being diluted by spring snowmelt, in general become more concentrated as the summer progresses due to evaporation and, for waterbodies with shorter residence times, greater influence of groundwater flux. Cl and Ca had nonsignificant positive slopes ($p = 0.29$ and 0.37, respectively), whereas K exhibited no trend ($p = 0.48$). As expected, none of the solid-phase variables of the homogenized 10 cm long sediment cores showed any significant seasonal trends (e.g., sediment extractable Fe $p = 0.93$, sediment TOC $p = 0.96$). Among the pore water variables, only K and pH exhibited significant trends. Pore water K values decreased over the summer ($p = 0.006$), likely as a result of diffusion into surface water or uptake by growing rooted macrophytes. Pore water pH generally increased over the summer ($p = 0.003$), which may reflect loss of CO_2 as the sediment warmed over the summer, reducing the solubility of gases. The lack of seasonality in pore water sulfide ($p = 0.62$) indicates that sulfide concentrations were in steady state with the variables that exert primary control over its concentration, surface water SO_4, extractable Fe, and sediment TOC (Pollman et al., 2017). Of the variables controlling pore water sulfide, only SO_4 exhibited even marginally significant seasonal trends ($p = 0.05$, 0.93, and 0.97, for SO_4, extractable Fe, and sediment TOC, respectively). Despite the finding of seasonal variation in SO_4, Pollman et al. (2017) found that SO_4 is one of the primary variables that control pore water sulfide concentrations. Seasonal variation in SO_4 concentrations undoubtedly contributes to noise in the statistical relationship documented by Pollman et al. (2017). Myrbo et al. (2017) found that the microbial production of pore water sulfide in a wild rice sediment is proportional to the long-term average SO_4 surface water concentration.

3.8. Cultivated Wild Rice Paddies

Commercial wild rice paddies have been reported with healthy stands of wild rice growing under surface water SO_4 levels as high as 170 mg L^{-1} (Aiken et al., 1988). Our limited measurements in seven different paddies ranged from 0.3 mg L^{-1} to 279 mg L^{-1} SO_4, with a median of 8.3 mg L^{-1} (n = 7, Table S3). Natural wild rice waters in our study had a median SO_4 concentration of 4.1 mg L^{-1}. Surprisingly, median pore water sulfide in paddies was 182 μg L^{-1}, greater than the medians of natural wild rice waters (88 μg L^{-1}; n = 67) and waters without wild rice (126 μg L^{-1}; n = 41). The median sediment extractable Fe concentration of paddies (4.5 mg g^{-1}) is similar to that of natural wild rice waters (4.8 mg g^{-1}). In contrast, median sediment TOC is much higher in paddies (25.2%) than natural wild rice waters (9.1%). It thus appears that the greater TOC driving enhanced SO_4 reduction (Pollman et al., 2017) and driving median pore water Fe lower than in natural wild rice sediments (1.6 and 5.7 mg L^{-1}, respectively), despite the similar reservoirs of Fe in the sediment. Elevated production of sulfide coupled with the consumption of the available Fe may put some paddies on the brink of sulfide toxicity to wild rice.

However, the physical setting of cultivated wild rice paddies differs from that of natural lakes and streams in a number of important ways. Often paddies and their surface sediments are dewatered during the growing season through use of buried drainage tiles, allowing tillage after harvesting and enhanced aerobic decomposition of rice straw and roots, and possibly reoxidation of sulfide and reduced Fe. Prior to drainage tile installation in the 1980s, failure of wild rice crops was sometimes attributed to elevated sulfide (Grava & Rose, 1975; Gunvalson, personal communication, 2016). Water depth in paddies is also typically shallower (median of 30 cm) than wild rice habitat in natural lakes and rivers (median of 52 cm), allowing seedlings to emerge above water with less energy expended, photosynthesize sooner, and release oxygen from roots to oxidize sulfide. The use of nitrogen fertilizers may further enable seedlings to elongate more quickly through the water and into the air. Fertilized plants have been shown to be more resistant to sulfide toxicity than are control plants (Geurts et al., 2009). The production of sulfide would be inhibited if N fertilizers were applied as nitrate—but N fertilizers are applied as ammonia or urea (Oelke et al., 1997).

3.9. Conclusions and Implications

Analysis of an extensive suite of physical and chemical parameters from 108 different sites with potential wild rice habitat shows that pore water sulfide toxicity is a primary biogeochemical factor controlling the occurrence of wild rice populations in otherwise favorable habitat. High concentrations of pore water sulfide greatly decrease the probability that a wild rice population will be found in a waterbody. When pore water sulfide is low enough to support reproducing wild rice populations, however, it is likely that the relationship between sulfide and wild rice becomes more complicated and analysis of cause and effect more ambiguous. The variation in sulfide concentration is correlated to the density of wild rice, at least partially as a result of oxygen release from roots, and thus, not only does sulfide affect wild rice but wild rice affects sulfide.

Aside from low pore water sulfide, favorable wild rice habitat has long, cold winters and transparent surface water in the ice-free season. *Zizania palustris* seeds germinate at low rates if the winter is too warm or too short. The probability that wild rice seedlings successfully grow to maturity is reduced if photosynthesis is inhibited by low water clarity. Thus, pore water sulfide (itself a function of surface water SO_4, sediment Fe, and sediment organic matter (Pollman et al., 2017)), water temperature, and water transparency together largely determine wild rice presence and absence. These three factors are independent of one another but may act synergistically on other related processes.

In addition to generating sulfide, SO_4 reduction supports organic matter mineralization that releases nutrients and alkalinity to the surface water, which has the potential to change plant community structure even if Fe is high enough to keep pore water sulfide from reaching phytotoxic levels (Myrbo et al., 2017). Natural and anthropogenic SO_4 loading to freshwaters may thus strongly affect ecosystem composition and function, despite the low direct toxicity of SO_4 under oxic conditions.

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Wild Rice Monitoring Handbook

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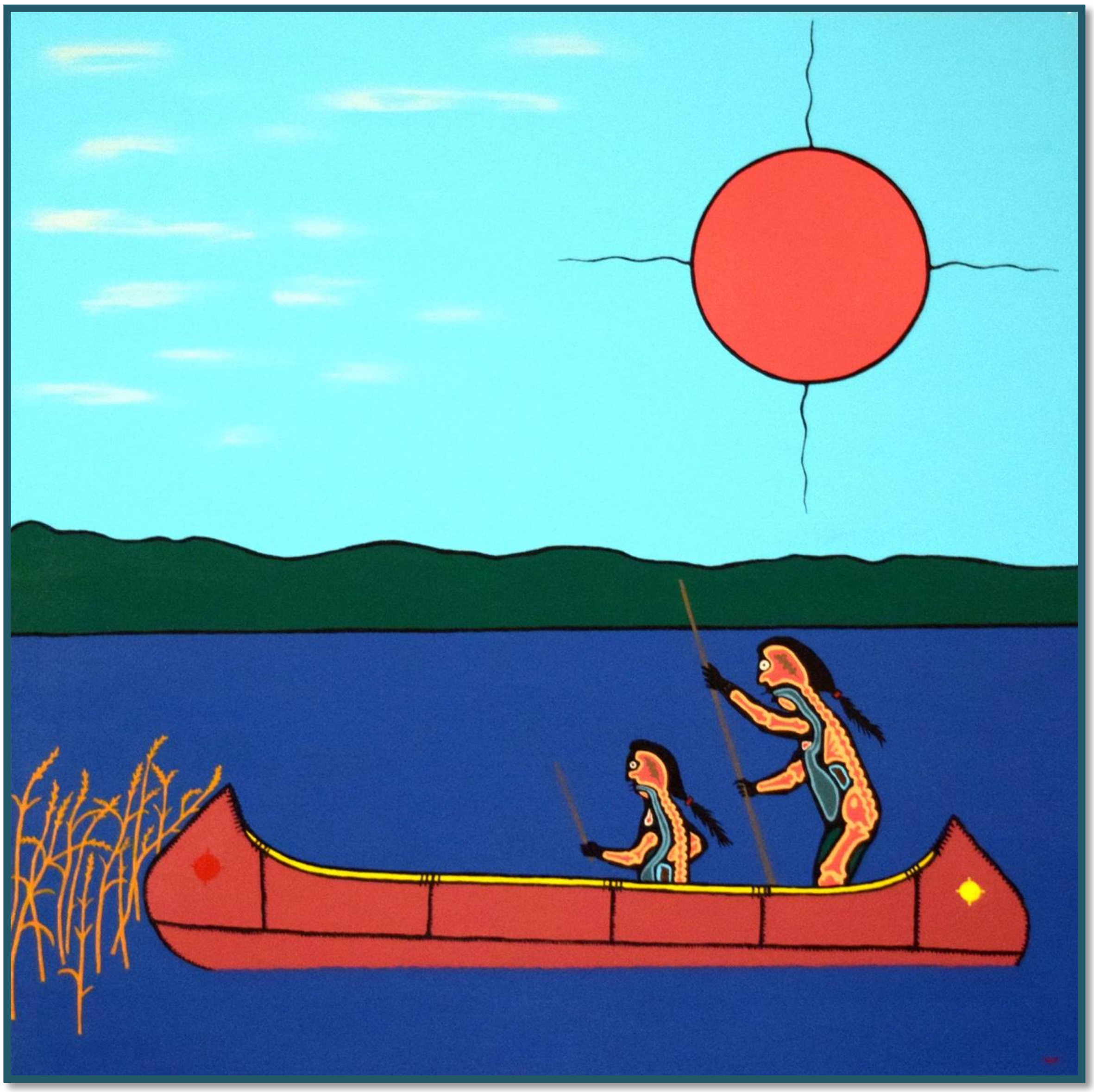
Wild Rice Monitoring Handbook

By Tonya Kjerland



Wild Rice Monitoring Handbook

Companion to *Wild Rice Monitoring Field Guide*

Electronic copies of this document and the *Wild Rice Monitoring Field Guide* are available at: www.seagrant.umn.edu/coastal_communities/wildrice

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Wild Rice Monitoring Handbook

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"Because we can't speak the same language, our work as scientists is to piece the story together as best we can. We can't ask the salmon directly what they need, so we ask them with experiments and listen carefully to the answers. We stay up half the night at the microscope looking at the annual rings in fish ear bones in order to know how the fish react to water temperatures. So we can fix it. We run experiments on the effects of salinity on the growth of invasive grasses. So we can fix it. We measure and record and analyze in ways that might seem lifeless but to us are the conduits to understanding the inscrutable lives of species not our own. Doing science with awe and humility is a powerful act of reciprocity with the more-than-human world."

~ From "Braiding Sweetgrass" by Robin Kimmerer

Preface

The methods described in the Wild Rice Monitoring Handbook have been designed to respect Native American, First Nation, and like-minded peoples' views on the sacred nature of wild rice.

The Handbook establishes a standardized method for measuring wild rice biomass and productivity. It is a comprehensive reference for designing wild rice surveys. The Handbook is a companion to the Wild Rice Monitoring Field Guide, which supports crews working to monitor wild rice populations. The Field Guide describes how to collect "core wild rice variables" and offers aid in identifying common aquatic plants that often occur with wild rice. The Handbook includes the field sampling protocols from the Field Guide, as well as generic wild rice biomass equations, information about the spiritual and cultural significance of wild rice, and a review of the biology of wild rice. It also presents a case study illustrating how data collected using these methods may be applied. It includes guidelines for setting up a monitoring plan, instructions for determining the number and location of sample points, instructions for creating site- or area-specific biomass equations, and blank field and lab data sheets. The Handbook also provides decision trees and tables to guide managers with decisions necessary to quantifying wild rice abundance and distribution.

The measurements recommended in the Field Guide and the Handbook will be most useful when taken over a series of years and used to assess trends on a given water body. These methods are not intended to establish relative condition or productivity between (or across) waters where wild rice grows. These are also not methods for identifying productive or unproductive waters with reference to wild rice.

These methods are designed to be flexible enough to allow for applicability in a range of situations and across a broad geographic range. For example, they may be used in different types and sizes of water bodies and also, with different species or varieties of wild rice.[1] Two species of annual wild rice are known to grow in Minnesota, Wisconsin, and Michigan, with hybrids occuring where their ranges overlap—*Zizania palustris* and *Zizania aquatica*. There is debate about whether these are two distinct species or varieties of the same species. One treatment of wild rice taxonomy further subdivided each species into two varieties (Aiken et al., 1988). *Zizania palustris* var. *palustris* is the variety most commonly found in the northern parts of the states and Canada where wild rice is harvested for food and commercial purposes.

The generic biomass equations are based on *Zizania palustris* var. *palustris* (northern wild rice). The core wild rice variables may be used with any species or variety of wild rice. If concerned about the accuracy of using generic wild rice biomass equations, consider developing site- or area-specific equations according to the instructions provided.

Aquatic vegetation survey manuals were consulted in order to create this Handbook, and these are listed in the References. The scope of this Handbook is principally wild rice, a unique emergent annual plant. The scope of other manuals usually is much broader, for example: surveys to identify a list of aquatic

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[1] References for wild rice taxonomy: Aiken, et.al. (1988, pp. 21-38); Dore (1969, pp. 16-23); Meeker (1993, Ch. 3 in Ph.D. Dissertation).

plant species in addition to other organisms present in a lake, measurements of biodiversity, or locations of specific species (i.e. rare/endangered plants or plants considered a nuisance for recreational purposes). Another common purpose of aquatic vegetation survey manuals is to assess overall lake or wetland conditions and status, all of which are beyond the scope of this Handbook. The Field Guide offers a basic plant identification key for common plants that occur with wild rice.

The methods described in this Handbook would be relatively easy to adapt for use with aquatic plant manuals that have a broader scope by adding two parameters: a count of wild rice stalks in quadrats plus plant height of one sample plant per plot. By using Biomass Equation 1 and plugging in plant height, a measure of biomass would be obtained. The number of recommended sample points per water body (40) is in keeping with recommendations from most manuals reviewed or in some cases, considerably lower (some recommended up to 100 points).

Variables such as estimating wild rice stand area take more time to collect but enable computation of important variables for wild rice persistence including biomass per area, number of stalks per area and number of stalks per water body. Area of wild rice is straightforward to compute in shallow lakes where the entire lake is potentially wild rice habitat. In a study comparing emergent plant mapping of bulrush stands on five "deep" lakes (91 to 587 ha in surface area), Radomski et al. (2011) found that the time to carefully map bulrush on study lakes was about two to three 8-hour days per lake. Mapping wild rice would be expected to take less time because it usually grows in large contiguous stands.

Monitoring of lakes and rivers is an ongoing process and various agencies are measuring a range of parameters. Many agencies may already be collecting data related to water quality and sediment through existing agreements. Therefore, this Handbook does not attempt to define methods for collecting this type of data, which are well documented elsewhere. Instead, it provides recommendations for which parameters might be most important to measure if concerned about wild rice. How these parameters relate to the ecology of wild rice is unknown, but by establishing a standardized method for estimating wild rice growth, there is hope that new discoveries will emerge.

Overview

This Handbook establishes a standardized method for measuring wild rice biomass and productivity. These methods may be adapted to measure productivity for an entire lake, stream reach, or flowage.

Applications include:

- ✓ Monitoring wild rice productivity trends
- ✓ Relating trends to harvest, water quality, or weather
- ✓ Evaluating outcomes of management actions
- ✓ Informing adaptations to stressors such as climate change
- ✓ Evaluating success of restoration projects

This is a comprehensive reference for use in designing wild rice monitoring surveys and inventories, for analyzing data, and for communicating with others via a shared set of protocols. The Field Guide is a more portable version that focuses on field data collection.

GLOSSARY

Standardized method. A standardized method is one that defines procedures for collecting data in a statistically valid manner that can be easily reproduced and will provide consistent, accurate measurements each time, allowing trend analysis across years and locations.

This Handbook provides guidance about decisions that need to be made in order to quantify wild rice abundance and distribution. Use the "decision tree" charts and tables to choose which portions to incorporate. For example, the number of plots to sample is based on the amount of statistical precision you require and estimated biomass each year. Field and lab methods are explained in the Standard Operating Procedures. The Case Study illustrates some potential uses for the data collected. Helpful solutions for common concerns are included in the section, "Problems Faced When Doing Wild Rice Inventories and How to Solve Them." Appendix A includes data sheets for use in field and lab data collection.

These methods have been designed to respect Native American, First Nation, and like-minded peoples' views on the sacred nature of wild rice. Supporting the sustainability of natural wild rice populations is a primary goal of this project.

Summary of the Field Methods

- Stalk density with the quadrat frame.
- Water depth within the quadrat frame, or as close as possible.
- Sample plant height, measured one of two ways: either ABOVE WATER or TOTAL.
- Seed heads from the sample plant so the pedicels can be counted back in the lab.
- The names of other plant species within the quadrat frame.
- If creating a site- or area-specific biomass equation, collect whole wild rice plant (optional).
- Field notes.
- Related environmental variables (optional): sediment and water quality.

Cultural and Spiritual Significance

CONTEXT FOR BUILDING A COMMON GROUND

A valuable resource for all. Wild rice is significant to communities in northern Minnesota, Wisconsin, and Michigan. Historically, wild rice has been an important food source for thousands of years in these areas, and continues to be today. Wild rice is the only North American wild grain that produces substantial amounts of food for humans. Early European immigrants to the north country valued wild rice as a vital part of their food supply, and many non-Indians harvest wild rice. It is hoped that with more research, education, and outreach, the public will become more aware of this valuable resource and realize the importance of preserving natural stands of wild rice for future generations.

For Native American communities. Wild rice is as vital a cultural resource today as it was in the past. Wild rice is essential to many Native American communities - culturally, spiritually, socially, and economically. Many tribes of the region have long traditions of harvesting wild rice – Ojibwe, Lakota, Potawatomi, Menomonie, and Ho Chunk, among others.

Harvesting wild rice is a very important family and community activity. It provides a significant amount of food, and it is also a tradition that has been passed down through hundreds of generations. Passing along this traditional way of living is a way to connect people across time to their grandparents; a way to educate and strengthen young people in their awareness of who they are and where they come from.

For Ojibwe. Wild rice is featured prominently in the origin stories and traditions of one of the largest tribes in North America, the Ojibwe, also known as Chippewa, or Anishinabeg. Ojibwe nations are prominent in the states of Michigan, Wisconsin, and Minnesota. There are also many Anishinabe nations and related tribes in the Canadian provinces of Manitoba, Ontario, and Quebec.

The Ojibwe migration story tells of a time when Ojibwe ancestors lived in the east next to the ocean in the areas that are now called Maine and Nova Scotia. People of the Abenaki tribe in present day Maine still remember the ancient connections with Ojibwe people and have prophecies and stories that correlate with the Ojibwe stories. Both speak Algonquian-based languages.

Some say that prior to the Ojibwe migration, the Anishinabeg ("the people" in Ojibwe language) received a prophecy to move westward, where they would find "the food that grows on the water." Over many generations, the Ojibwe migrated west, where they found wild rice, or *manoomin*.

Contributing to community resilience. A cornerstone of social unity, the gathering and processing of wild rice during the early fall plays an important role in maintaining family and community ties. Wild rice harvesting is part of the traditional life ways of Anishinabeg that still follow the seasonal patterns of food availability. Another example is maple syrup, which is harvested by many in the early spring. Ricing is such an important activity that one of the months is named “manoominike-giizis”, or wild rice moon, which occurs in either August or September. Many people living in urban areas return to the reservation to help with wild rice harvesting and processing. Extended families and friends work together, and children learn from their elders. This provides a means of strengthening ties and passing along wisdom of all kinds, including how to rice and how to preserve the rice.

Economic benefits. Wild rice is also significant economically for tribes because sustainably harvested food constitutes a major portion of the diet. Numerous people still rely heavily on natural foods that they can harvest themselves such as wild rice, maple syrup, fish, deer, and moose. In addition, tribal governments gain financially through programs to harvest and sell wild rice. Each year families who are able to harvest wild rice are also able to supplement their income from its sale or trade, if they so choose.

In these ways, wild rice feeds the people, heals the people, and reunites the people. The preservation of wild rice for generations to come will have lasting benefits for everyone.

How to Respect Native Traditions When Conducting Wild Rice Studies

In order to be respectful of the cultural and spiritual significance of wild rice, there are important protocols to follow.

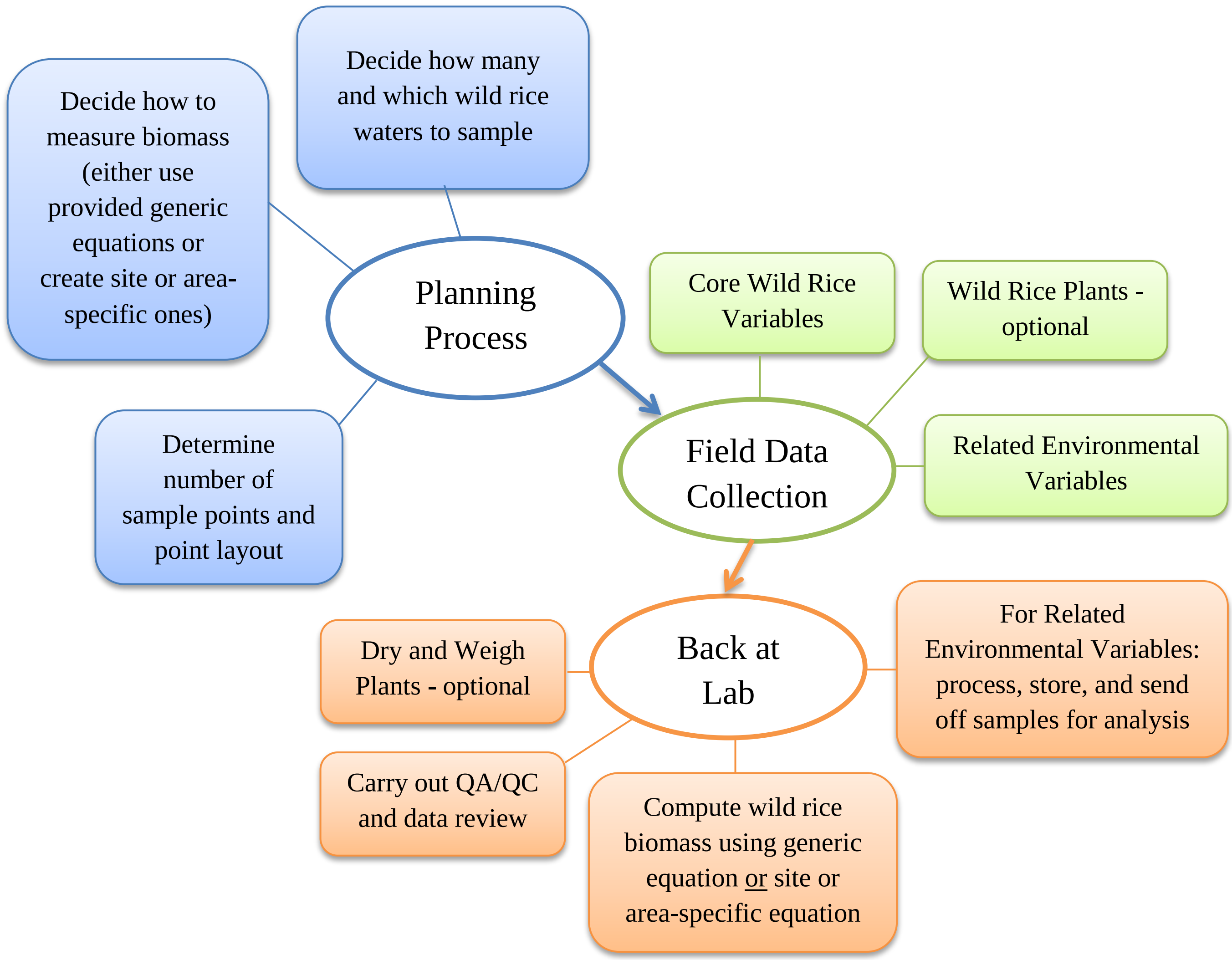
- ❖ Obtain appropriate permissions and know the cultural boundaries for research with wild rice
- ❖ Put down tobacco in the water before taking samples or collecting data
- ❖ Offer a prayer of gratitude and statement of your good intentions

The prayer can take many forms. Speak in your own words and according to your own religious traditions.

Sampling Design

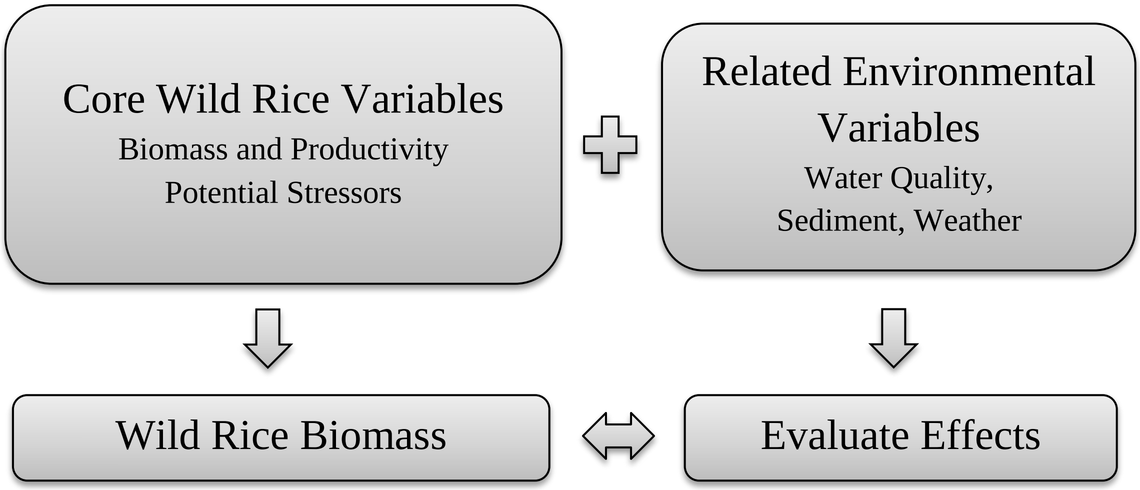
This overview recommends data to collect and provides guidance for designing the sampling plan. The main decisions to be made are: 1) how many and which wild rice waters to sample; 2) how to measure biomass; and 3) the number of sample points and point layout (see Figure 16).

Figure 1. Mental map of events in sampling process



Regulations pertaining to wild rice. Rules and protections for wild rice exist in many areas. If you are considering physically collecting wild rice plants, think carefully about whether this is necessary and then check into tribal, state, and other laws to determine if you need a permit to collect plants. Permits may also be required for collecting seeds and seed heads.

The sampling design includes two categories of variables, "Core" and "Related Environmental." The Core Variables are designed to accurately and objectively measure wild rice productivity (See **Table 1**). Measuring the related environmental variables will aid in evaluating trends and diagnosing problems.



CORE WILD RICE VARIABLES

The core wild rice variables are a set of carefully selected parameters that, taken as a whole, provide useful information to assess the health of wild rice populations. In addition, either plant height or seed number can be used to compute plant biomass by using a generic model.

GLOSSARY
Biomass is another name for the "weight" of an individual or group of organisms. This Handbook uses grams per square meter (g/m^2) as the measuring unit for wild rice biomass. If desired, whole lake production can be estimated by measuring or estimating the wild rice area.

Biomass is a commonly used measure of plant productivity that relates directly to important variables for wild rice, including plant health and number of seeds produced. Biomass estimates may be used to compare productivity for a single lake, flowage, or river reach from year-to-year; and, to compare general trends between different locations (increasing, decreasing, no change).

Collect the information listed in the first two columns of variables listed in Table 1 to adequately monitor wild rice populations. The last optional column requires collecting wild rice plants. Do this if you want to create a site-specific biomass equation. A chart comparing these two options is shown in Figure 2. A decision tree for deciding how to measure biomass is provided in Figure 3.

Table 1. Core wild rice variables

Core Wild Rice Variables		Optional
Biomass & Productivity (Annual Yield)	**Potential Stressors (Field Notes)**	**Plant weight measured directly**
Density (number of stalks per area)	Observed shoreline use	Plant dry weight
Average Stem Height	Observed water use	Number of viable (filled hulls) and non-viable seeds collected
Water depth	Brown spot fungal presence and severity index	Calculate new site-specific biomass equation
Number of potential seeds (# pedicels per stalk)	Animals, birds, pests, pathogens presence	Presence of worm holes in seeds (observed in the lab)
Presence of other plants co-occurring with wild rice (List)	Weather (current and past 2-3 days)	
Estimate of wild rice stand area	Other possible concerns for wild rice growth (i.e. pollutants)	

Estimating wild rice stand area. It is useful to create an approximation of the outline of areas where wild rice is found growing each year. Knowing this area is essential to computing overall biomass and for mapping challenges, such as interpolating values between sample points. Because using GPS to outline wild rice beds is subjective; the accuracy of area measurements may vary between surveyors. Areas may move considerably year to year due to the variability of wild rice growth. In order to standardize these approximations, it is recommended that whoever does the work be given clear instructions, make notes on what criteria they used to determine where to map and that the same crew assess each area each year. Because of GPS inaccuracy and field technician subjectivity associated with collecting this type of data, it should only be used as an estimate for comparing year-to-year variability *within* a specific waterbody. It is not intended to provide a mechanism for assessing relative condition or productivity *between* (or *across*) wild rice waterbodies.

Multiple methods for estimating the area of wild rice stands are described in Appendix B. The two methods recommended in these field sampling protocols and in the Field Guide were chosen due to their ease of implementation.

BIOMASS EQUATIONS

Generic equations. One way to measure biomass involves collecting wild rice plants, drying, and weighing them. However, this Handbook presents a short-cut way to approximate biomass that requires simple, non-destructive field methods and generic equations developed by collecting plants from a variety of different sources.[2] Generic biomass equations were created from pooled data of *Zizania palustris* var. *palustris* plants derived from six wild rice waters in Minnesota and Wisconsin (data

[2] See SOP #4 for details about how these biomass equations were created.

collected in 2011 and 2014.[3]) There are two generic equations. One relates biomass to plant height and the other relates biomass to seed number. Measure plant height and stem density in the field and collect seed heads and count number of potential seeds per unit area. By measuring these plant characteristics, and then plugging in the results to either of the two possible equations, a reasonably good estimate of biomass is obtained in a non-destructive way. Some managers may wish to develop their own biomass equations, and the Handbook also describes how to do this. Points to consider in making this determination are elaborated upon below.

Site- or area-specific equations. If resources are available, the most accurate biomass equation would be based on an individual water body. If not, it is suggested to use the generic equations presented in this Handbook. In order to develop a site- or area-specific biomass equation, it is necessary to collect wild rice plants, dry, and weigh them. This process involves collecting roots, stems, and seeds of one sample plant per quadrat; then drying and weighing the materials in order to determine their actual biomass, or dry weight. The sample plant is chosen by selecting the plant in each quadrat closest or close to a pre-marked corner. Number of stalks on this plant must be counted in the field. Ideally, plants would be collected from a minimum of 40 quadrats spanning a range of plant sizes from short to tall. This would allow the final equation to be useful over a range of different years. The data are then used to compute site-specific biomass equations according to instructions described in SOP #5.

When to Use Generic Biomass Equations and When to Create a New One

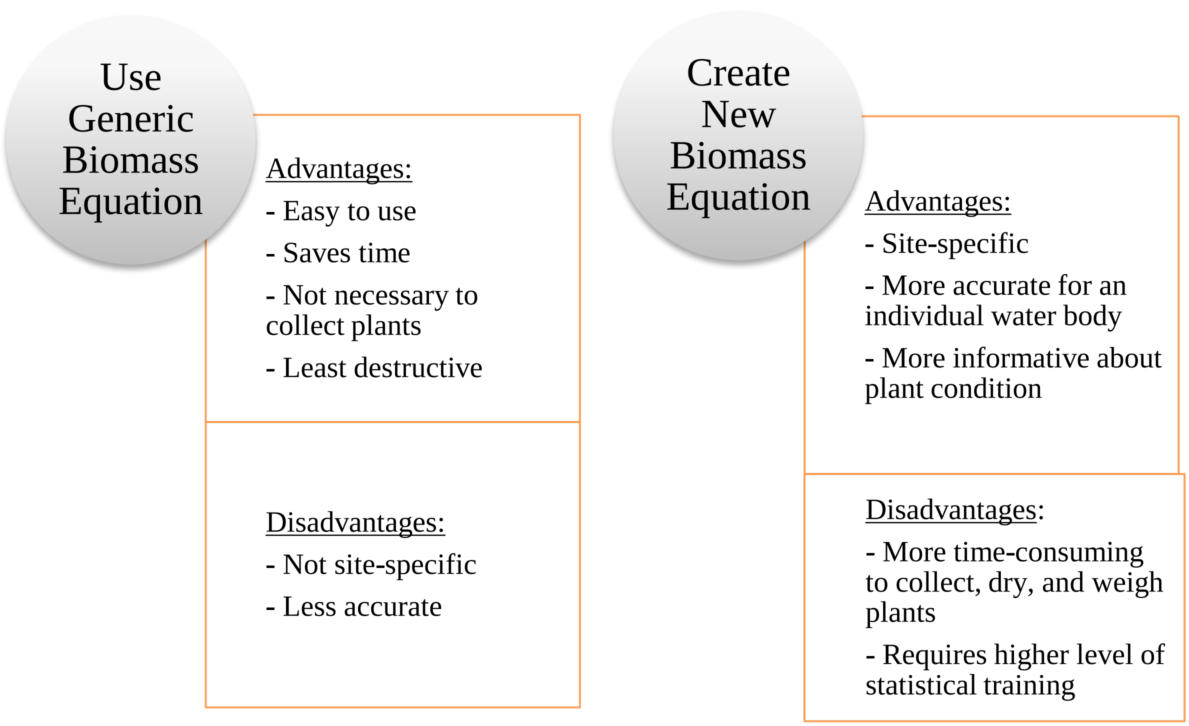


Figure 2. Advantages of creating site-specific biomass equations or using generic ones

[3] T. Kjerland analysis of data collected by Darren Vogt (2011) and Melissa Lewis (2014.)

Points to consider:

- Purpose of the study
- What levels of accuracy and precision are required
- Differences between wild rice stands and water bodies
- Alternative way to measure biomass
- Regulations and permitting

Purpose of the study. Clearly stating the study's purpose may help clarify which method to use:

- If the purpose is to look at changes over time on a coarse-level, such as "increasing," "decreasing," or "no change," then using generic equations will suffice.
- If the purpose is to explore what factors regulate year-to-year differences, such as water quality, use the generic equations.
- If data collection might inform regulatory decisions, think about collecting whole wild rice plants and creating a site-specific or area-specific equation.
- If the purpose is to accurately measure and compare biomass of wild rice plants in different water bodies, then it may make sense to create separate equations for each water body.

What levels of precision and accuracy are required? For most management studies, using the generic equations should be fine. But for more advanced studies, more accuracy may be required. The more accurate you are hoping to be with your estimate of biomass, the more you should be thinking about creating your own site-specific equation. In most cases, an equation should only need to be created once, and can be re-used in following years. The changes in morphological features of wild rice that are reflected in the generic biomass equations are expected to change slowly, but the rate is unknown and more research is needed in this area.

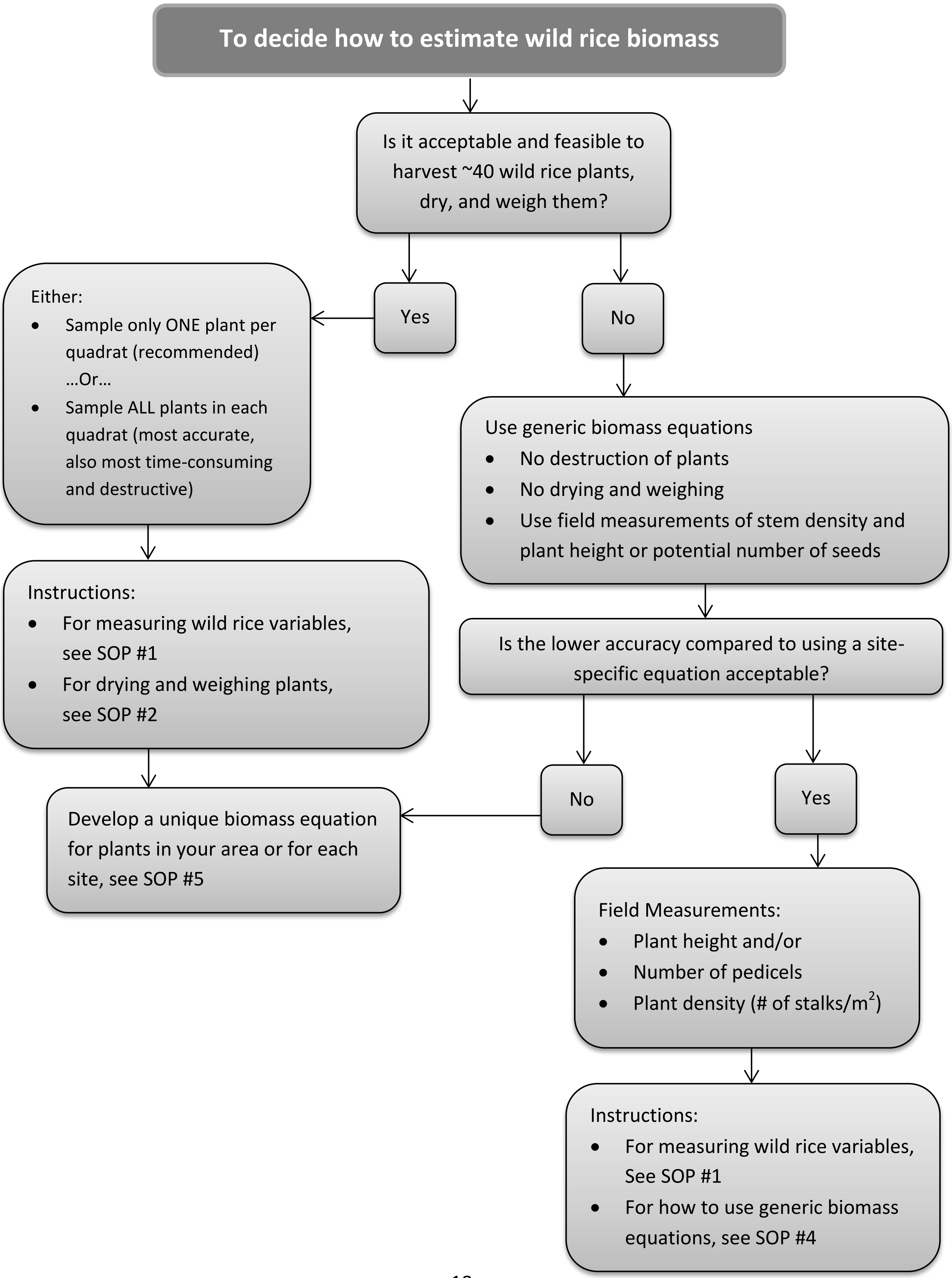
Differences between wild rice stands and water bodies. If it is not clear whether or not you need to develop your own biomass equations, one approach would be to conduct a pilot study of the wild rice in the water body you are measuring and compare results to the characteristics of the wild rice and associated water bodies used to create the generic biomass equations.

Data from the lakes used to create the biomass equations are provided in *Appendix C*.

Alternative way to measure biomass. The most accurate way to measure biomass would be to collect all of the wild rice plants within an area (e.g. quadrat) for drying and weighing. This method works well with some plant species and for scientific studies that demand high accuracy. In most situations for wild rice, this would be considered too destructive and time-consuming. For this reason, the methods in this Handbook recommend subsampling by selecting one plant per quadrat to measure.

Regulations and permitting. Rules and protections for wild rice exist in many areas. If you are considering physically collecting wild rice plants, think carefully about whether this is necessary and then check into tribal, state, and other laws to determine if you need a permit. Permits may also be required for collecting seeds and seed heads.

Figure 3. Decision tree for deciding how to estimate biomass



Related Environmental Variables

The "Related Environmental Variables" include additional laboratory measurements, water chemistry and sediment characteristics. Their purpose is to better understand the factors regulating wild rice growth. In order to link these two sets of parameters, it is important to sample them at the same locations and at the same time of year. The frequency of concurrent sampling of related environmental variables and core wild rice variables should occur at least every few years at a minimum of five (5) sampling points in each wild rice bed.

Standardized methods for measuring the related environmental variables are well established, and are not detailed in this manual (e.g. Elias et. al., 2008; see also Resources and Appendix D). Below is a list of the most important water quality and sediment parameters to consider for routine sampling in wild rice waters. This list is by no means exhaustive, but it is intended as a guide in cases where resources and/or time preclude comprehensive sampling.

Helpful Tip: A more complete list of variables to measure, rationale, estimated costs, and standardized protocols is provided in Appendix D.

Water Quality and Sediment Parameters

1. Parameters measured using electronic sensors (Temperature, dissolved oxygen, pH, specific electrical conductivity [EC25])
2. Alkalinity – Measure of acid-neutralizing capacity (ANC)
3. Transparency (secchi disk or transparency/secchi tube) – Trophic state indicator; proxy for color
4. Sulfate – Surface water concentrations can be biologically converted to toxic H_2S (hydrogen sulfide) gas in anoxic bottom water and in the sediment root zone.
5. Dominate Substrate Type - See Appendix D (Minnesota DNR, 2012, 1993).
6. Total Nitrogen (TKN) and Dissolved Inorganic Nitrogen (NH_4-N, $NO_{3/2}$-N) – Most likely limiting nutrient for wild rice
7. Total Phosphorus (TP) and Soluble Reactive Phosphorus (SRP) – Second most likely limiting nutrient for wild rice
8. Chlorophyll-a in open water

How to locate sample sites for related environmental variables. Reference (or "least impacted") sites located near wild rice sampling sites can help determine whether potential land use stressors or specific sources of pollution may be cause for concern. For this reason, the study plan might also include measurements of the related environmental variables at "reference sites" in addition to the places where concerns about negative impacts exist. In some cases, the reference sites may need to be located on a different water body, for example, when the whole lake is considered to be influenced by the potential cause for concern (i.e. entire lake surrounded by agriculture, residential development, etc)..

Suggested sites for measuring related environmental variables:

- Areas where **a major change in wild rice density** is noticed (to assess causes)
- **Stream inlets** (potential sources of nutrients and pollutants). In this case, also consider measuring in the middle of the lake and at an outlet site for comparison purposes.
- Land or water uses that could negatively impact wild rice stands, such as:
  - **Industrial discharges** (i.e. mining, power generation, etc.) – pollutant sources
  - **Waste water treatment facilities and sewage pond** discharges (leaching of phosphorus into water)
  - **Agricultural land** adjacent to water (nutrient, sediment, pesticide runoff)
  - **Roads and parking lots** (stormwater runoff, increased flashiness of storm water)
  - **Boating and jet skiing** (wakes uprooting wild rice plants, causing shoreline erosion, long tail boat blades chopping up wild rice and other plants, wave action re-suspending bottom sediments)
  - **Concentrations of homes** (lawn runoff, wakes from boats, herbicide use, clearing of plants for opening up water ways, leaching of nutrients from individual onsite sewage treatment systems, removal of shoreline vegetation that acts as a buffer strip)
- **Reference, or "least impacted" sites** for comparison

TIME AND LEVEL OF EFFORT INVOLVED

Allow more time the first year, and expect the time to lessen as field crews gain experience. The decision tree in Figure 4 illustrates a process for thinking about how many and which wild rice waters to sample based on the level of effort and time involved.

Many factors affect the time and effort involved, but as an example, the 1854 Treaty Authority reports that crews take 2-3 hours to measure the core wild rice variables for approximately 20 sample plots on 60 to 100-acre lakes. The estimated time to sample per point for these variables is about 3-5 minutes using a 0.5 m^2 quadrat. Assuming an additional 2 minutes to collect seed heads or whole plants and 2-3 minutes to travel between points, measuring 40 sample points should be completed in about 5-7 hours. Travel time to the water body and time to collect water or sediment samples (if part of the monitoring plan) should be added to estimate the total time required.

Helpful Tips
1) Try doing a dry run or pilot study of 5 points to determine the feasibility, number of sample points needed, and number of lakes to sample.
2) Take it slowly. Start in year 1 by only collecting the core wild rice variables on one lake. Add more variables and water bodies over time.
3) Practice using the GPS unit ahead of time on land and water.

Factors that may affect the time to complete sampling

- **Number of variables collected**. Sampling only the core wild rice variables takes 3-5 minutes per point.

- **Distance between points.** Distance may be adjusted in the initial setup of the sampling scheme; and should ideally be at least 30 m apart (MN DNR, 2012, Uzarski et al. 2014). See box, "Two-points-per-stop method" below for an exception to this rule, based on a sampling scheme of taking one set of measurements in a quadrat at the front of the boat, and one at the back.
- **Arrangement of quadrats.** Grid method is quickest because it involves following a straight line to navigate to points. Randomly-located points take longer to find.
- **Time to navigate to sample points.** The ability of the navigator to use the handheld GPS unit can be improved by practicing ahead of time.
- **Size of lake or river.** Affects the time to paddle from access point to sample points and the time to travel between points if they are spread further apart
- **Density of wild rice.** More dense rice takes more time to paddle through and more time to count rice stalks. In sparse areas, counting none to a few plants goes quickly (these type of sample points probably only take about 30 seconds).

TWO-POINTS-PER-STOP METHOD

Example from Fond du Lac Band of Lake Superior Chippewa:

If taking measurements at many GPS points is not feasible, consider halving the number of points and taking two measurements at each point or canoe stop. For example, rather than stopping at 40 different points, stop at 20 points and measure 2 quadrats. One measurement is taken by the person sitting at the front of the boat, and one in back.

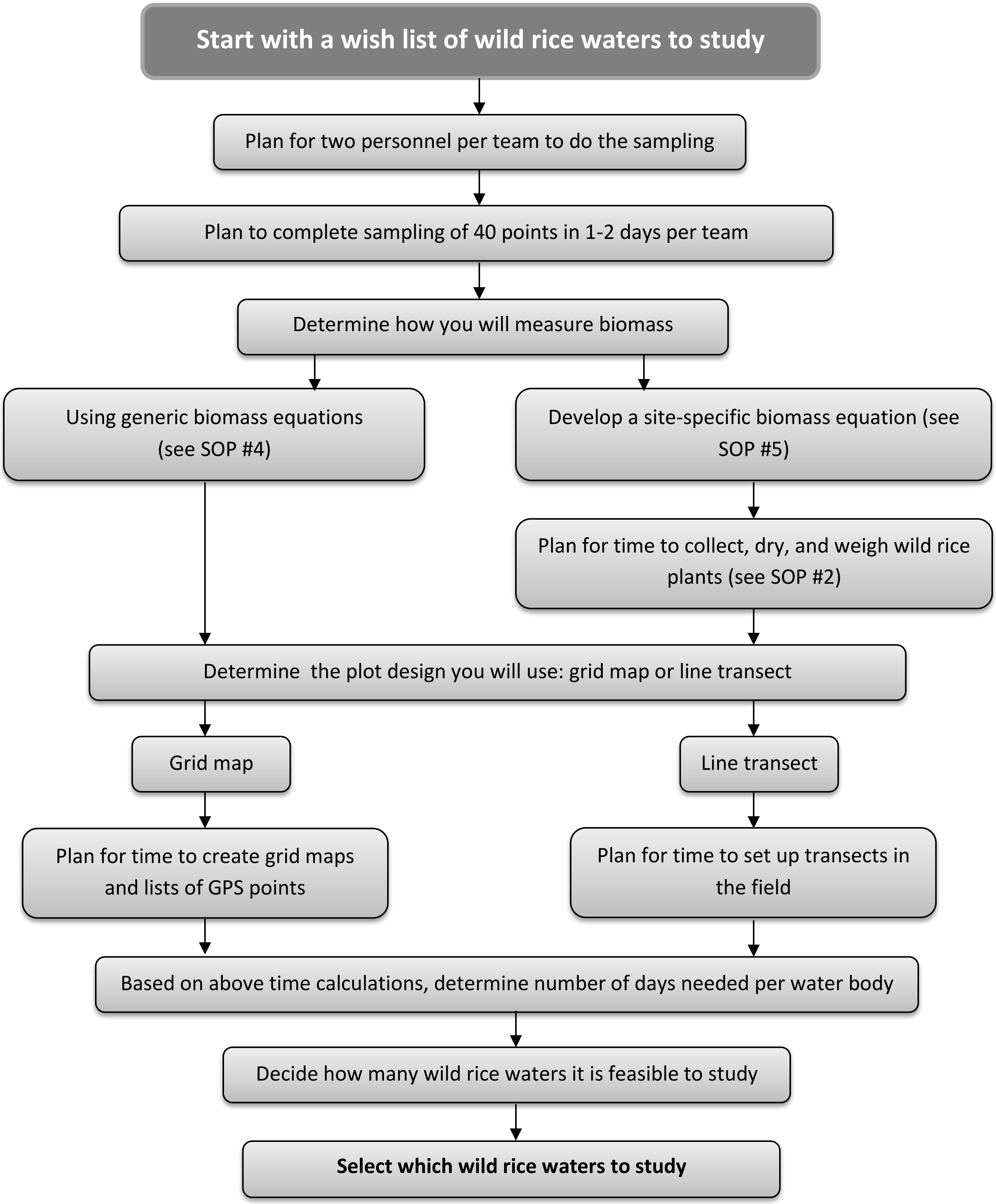
Be sure to be consistent about which side of the boat you take the measurements on (left or right each time.) This will avoid bias based in deciding which side looks "better."

By taking two measurements per stop, more data can be gathered in a relatively shorter period of time. This method may be a good choice if you are time limited, such as when also collecting data on related environmental variables.

The advantage of saving time should be weighed against the disadvantage that these two points are likely to be strongly correlated with one another due to proximity. The results will be more precise than if only 20 measurements were taken, but not as robust statistically as taking 40 samples that are the required distance apart. Analysis of the data collected by Fond du Lac Band of Lake Superior Chippewa in 2014 on Mud Lake showed positive correlations between two points collected per stop of 0.69 for plant height and 0.77 for stalk density.

Due to this strong correlation of paired quadrat points, the proper way to analyze paired points is to take their average and use this result as if it were one point for further analysis, such as for developing a new biomass equation. These averaged sample points will result in a lower variance compared to only sampling 20 points.

Figure 4. Decision tree for determining how many and which wild rice waters to sample



How to Determine the `Number of Sample Points

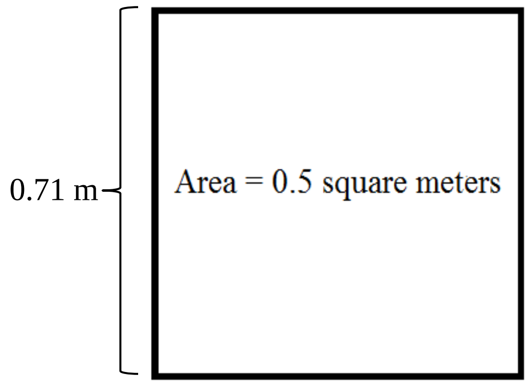
Three primary factors affect the number of sample points:

- ✓ Density of standing biomass
- ✓ Quadrat size
- ✓ Statistical precision desired

Size of area is a secondary consideration that may apply in some situations.

Density of standing biomass. The amount of sample points needed depends in part on the current year's biomass (units per area). More sample sites are needed in years when the rice is sparse to achieve the same level of accuracy as when rice is abundant.

Quadrat size. For reasons of efficiency, accuracy, and safety, the recommended quadrat is square, with a size of 0.5 m^2, which is 71 cm per side. A square-shaped quadrat is recommended because this is the shape used in many aquatic biomass studies and is easiest to construct and transport. See Appendix E for instructions on how to build a quadrat frame.



A 0.5 m^2 quadrat provides an efficient tradeoff between field
convenience and number of stems sampled in the typical range of stand densities in natural waters. This smaller size is also safest to prevent tipping when stalks are being counted from a canoe that is not equipped with anchors or outriggers.

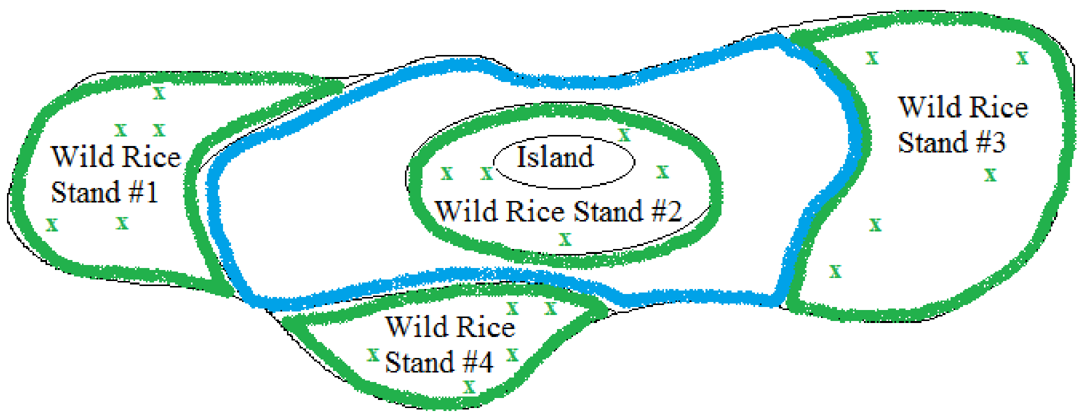
Statistical Precision Desired. The level of statistical precision recommended is a standard error less than or equal to 20% of the mean. The number of sample points required under different sampling conditions and with different levels of precision are shown in Table 2. The shaded grey column is the recommended configuration. For more information, see Appendix F.

Size of area. The same number of sample points should be used regardless of resource size. This recommendation is based on research showing size of a water body is not a factor in determining the number of sample points required for determining the amount of biomass or frequency of species occurrence (Downing and Anderson, 1985; Newman et al, 1998; MN DNR, 2012). However, for other reasons it may make sense to consider the area of wild rice, such as for mapping, for computing densities in different bays or separate wild rice beds, or for estimating overall amount of wild rice available. It is important to note that some scientists would argue that the level of sampling effort should be based upon size of the area sampled, and that this is a meaningful scientific debate.

Conduct A Pilot Study

For any size wild rice bed, consider using a pilot study to determine the number of points required. For example, for small areas (<10 acres) it may be that due to the homogeneity of the site, there is less variability among sample points, and therefore fewer points will be required to achieve the same level of statistical precision.

Zone technique for determining number of sample points. For large acreage wild rice waters with scattered beds of rice or deep lakes, consider using a zone technique for determining the total number of points to sample. Estimate the area of each wild rice stand (See Appendix B). Divide the water body into zones based on wild rice distribution. Sub-sample from the grid five points in each zone.



x = Sample points for pilot study based on subsampling grid map of points, 5 points per zone

Figure 5. Zone technique for determining number of sample points using a pilot study

Use the average of the five points to determine the total number of points required that year for each stand based on Table 2. Below is an example showing the number of sample points required for each stand given hypothetical estimated averages for wild rice found during the pilot study.

Wild rice stand (zone)	Estimated average wild rice biomass (g/m^2) based on the pilot study samples	Number of sample points for each stand (zone)
1	116	20
2	80	24
3	125	20
4	25	40
		Total sample points = 104

Determine the number of sample points

The effect of quadrat size and statistical precision on the number of samples needed is shown in Table 2. The primary input for deciding number of sample points required is density of standing wild rice biomass. The number of sample points required to achieve the same level of precision will vary from year-to-year. While it may seem counterintuitive to estimate what you are trying to measure exactly, it's necessary because in low productivity years, there are more open water and low density areas. When there are more open water areas, it's necessary to sample more points to get an accurate measurement.

GLOSSARY

Density of standing biomass is the average wild rice biomass per area at the time of sampling.

Precision desired means the level of agreement of a set of measurements made on the same variable of interest. A high precision measurement will be very reproducible. Accuracy relates to the real life, "true" value of a variable. For example, your data for standing biomass may all be similar (very precise), but if you used an inaccurate lab balance to weigh your plants, or used wet weight instead of dry weight, your accuracy will be poor.

Standard error is a measure of the variability of the data; it is an estimate of the standard deviation.

STEP 1. Estimate wild rice biomass in the current year.

a) **Option 1: Use a pilot study.** A good way to estimate the current year's biomass is to do a pilot study of five points prior to sampling the entire water body to come up with a rough estimate. Use the methods described in this Handbook to measure the core wild rice variables and use one of the generic biomass equations from SOP #4 to compute biomass (See page 60 or page 61). . Use the generic equations to compute weight per stalk and multiply by the stalk density to get g/m^2. Use this rough estimate (average of 5 plots) and Table 2 to determine the number of sample points required for a particular year. Time to do the pilot study is well spent. Sample points from a pilot study can be part of the final data analysis and count toward the number of points needed in that year.

b) **Option 2: Use past experience.** Estimate the level of the current year's biomass based on past experience or existing data.

STEP 2. Find your estimated amount of wild rice biomass in Column 1 of Table 2.

STEP 3. Move across the corresponding row to find the number of sample points required to achieve the desired level of statistical precision.[4]

[4] A standard error no greater than 20% of the mean is recommended. This level of precision is built into this handbook's recommendations for the number of sampling points because it is an acceptable level of variability for aquatic plant biomass studies (Minnesota DNR, 2012; Downing and Anderson, 1985).

Decision Table: Connecting Biomass and Number of Sample Points

Table 2 demonstrates how the required sample size varies with quadrat size, wild rice biomass, and level of statistical precision. The recommendations from this Handbook's methods are shaded grey. The statistical basis for this table is explained in Appendix F.

Table 2. Number of Sample Points

	Quadrat area = 0.5 m^2			Quadrat area = 1.0 m^2		
Wild Rice Biomass (g/m^2)	Required sample size (25% error)	Required sample size (20% error)	Required sample size (15% error)	Required sample size (25% error)	Required sample size (20% error)	Required sample size (15% error)
10	38	59	105	34	53	94
20	28	44	78	23	39	70
25	25	40*	71	25	36	63
30	24	37	65	21	33	59
40	21	32	58	19	29	52
50	19	29	52	17	26	47
60	17	27	48	16	24	43
70	16	25	45	15	23	41
80	15	24	43	14	22	38
90	15	23	41	13	20	36
100	14	22	39	13	20	35
200	10	16	29	9	14	26

*Recommended number of sample points

Recommendations. Use a 0.5 m^2 quadrat to sample 40 points per water body for most situations. Analysis of wild rice historical data showed that sampling 40 points would achieve the recommended statistical precision in 80% of the years[5]. On larger lakes with multiple wild rice stands of differing densities it may be more efficient and accurate to use a zone technique to determine the number of sample points (See Figure 5). Using a larger quadrat size will result in more time to count stalks. Aiming for greater level of statistical precision will require sampling a greater number of points.

In a nutshell: When using a 0.5 m^2 quadrat, 40 points will give you good precision ~80% of the time. In sparse years, you will need to add more points (T. Kjerland analysis of data collected by Vogt, 2014).

Plan for extra sample points. For example, if sampling 40 points, identify up to 60 possible points. Why? Because: 1) there will be times when plots will be eliminated from sampling in the field upon discovery that those plots are not within suitable wild rice habitat in that year (i.e. water is too deep, plot is on shore, there is some obstruction, etc.); and, 2) 60 is the maximum number of plots recommended, even during sparse years (~15 g/m^2). For consistency across years, there is value in sampling the same points year-to-year, even when they contain no wild rice, as long as they remain in suitable wild rice habitat.

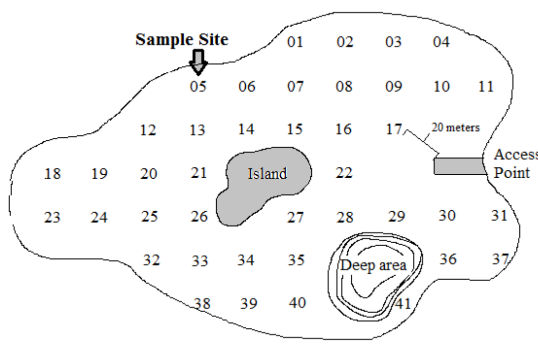
[5] T. Kjerland analysis of data collected by Vogt, 2014

How to Select Sample Point Locations

Two options are presented for designing the location of sample points: grid map and line transect. A third possibility is a variation on the grid map, which is to randomly subsample points from the grid. Related environmental variables should be located at the same points as wild rice, and/or in areas where potential stressors or pollutants are a concern. Several "reference" or "least-impacted" points should also be included for comparison purposes. See "related environmental variables" for details.

Recommended method: Grid map

Use mapping software (i.e. ArcGIS) to create a grid map of coordinates.



Advantages:

- Easy to set up
- Covers entire spatial area of interest
- Pre-selecting points avoids bias in the field
- Points can be re-sampled annually to monitor trends
- Simple to explain
- Easy to sample points in the field systematically
- Faster navigation to points along straight line

Disadvantages:

- If the variable of interest varies in a systematic way along lines of the grid, this method may potentially be biased. This is unlikely in most natural wild rice lakes.
- Points are systematically set up, in other words, not randomly. If this is a concern, one way to make the points more random is to set up more points than are required and subsample a list of random points.

Helpful tips: If not all sample points in the grid are selected, try to cover the entire area of interest rather than clustering sample points. This will help avoid confounding factors that might exist in smaller areas (such as point-source pollutant discharges or nutrient inflows from streams) that might bias the overall study results.

Why completely random point placement is not recommended. For larger areas, there are several disadvantages: 1) random point placement can locate a large number of points in difficult to reach areas (such as the shoreline, which is often too shallow for canoe travel); 2) points may be clumped, leaving large areas under-sampled; 3) navigating to randomly located points greatly increases the field time needed to complete the sampling (Madsen and Wersal, 2012).

How to set up a grid map of sample points. Use ArcGIS or other mapping software to create a map and list of GPS coordinates for the sample sites. If sampling in deep lakes or areas where suitable wild rice habitat only covers a portion of the area, it will be helpful to create an outline of the sampling area first. A depth of four feet is recommended as the best known estimate for maximum rooting depth of wild rice. Due to the annual spatial variability in wild rice stands, use multiple years of historic data to gain a more accurate outline.

Make a waterproof copy of the map and list of coordinates for field use. Either laminate or print on water-resistant paper. If the GPS unit fails or satellite coverage is spotty, the map and list of coordinates can salvage the day. Including obvious shoreline landmarks on the paper map can be helpful if you need to navigate without a GPS unit. Without a working GPS unit, you won't know when you arrive at each point, but you can approximate the sampling grid using a paper map by trying to keep points a set distance apart and using landmarks. The paper map is also helpful for keeping track of which points have already been sampled, and to make notes on unusual things the crew sees while in the field.

Grid maps

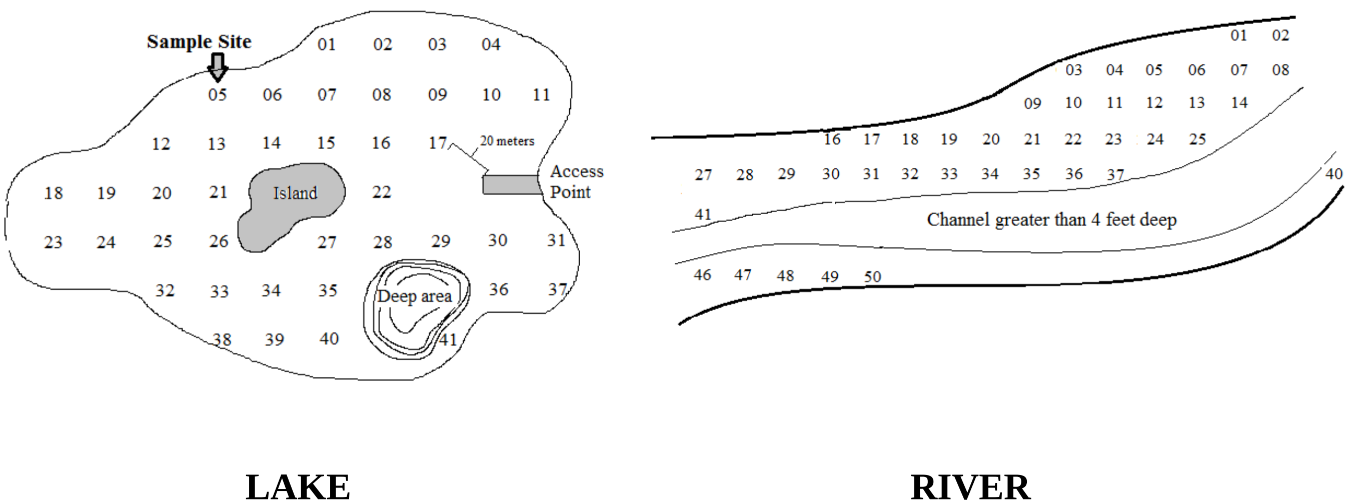


Figure 6. Grid map sample point design on a lake and a river

Other design considerations for setting up a grid map

1. Use a UTM coordinate system instead of a degree-based system. It will be easier to locate points based on the north and east coordinates (Madsen, 1999).
2. Use a round number for distance between grid points (i.e. 50 m) to make it easier to estimate the distance and find the next point in the field (Madsen, 1999).
3. Set the distance between grid points/quadrats to a minimum of 30 m, which will allow for the sampling points to be far enough apart to function as statistically independent samples. Distance between points/quadrats should also be based on the size of the area to be sampled and should ideally cover the entire area of suitable wild rice habitat. Practically speaking, sampling 40 grid points that are 50 to 250 m apart for core wild rice variables should be manageable in a day of field work.

4. Suitable wild rice habitat will include points up to four feet (~1.2 m) deep in August – October when wild rice sampling is done. These points may be deeper earlier in the season and may be different in rivers. More research is needed to test this depth as the maximum cut-off point. This depth cut-off point was established from an analysis of points sampled on 4 lakes in Minnesota and 2 lakes in Wisconsin (n=162)[6]. Points may be located either in the littoral zone or mid-lake (i.e. around islands).
5. Due to the accuracy level of most handheld GPS units, it's not expected that field crews will sample exactly the same spot each year, but rather that the sample site will consistently be within ~3-5 meters of the GPS coordinates (Minnesota DNR, 2012).

Table 3. Example of GPS coordinates list

Site ID	Longitude	Latitude	Sampled in 20XX
01	491355	5325676	x
02	490855	5325676	
03	490605	5325676	x
04	494105	5325926	

Alternative method: Line transects

The **line transect** method, another good option for selecting sample sites, involves selecting a random starting point for each transect and then laying out a transect line. Sampling is equally spaced along the line.

Advantages:

- Does not require mapping software to set up the sampling map
- Might reduce the time required to locate sample points in the field
- In a river, it may provide a better understanding of cross-section characteristics

Disadvantages:

- Works best when sampling in shallow shoreline areas
- If only sampling along shoreline of a lake, this method may inaccurately represent the wild rice growing in the middle of the lake
- Requires more training of field crew
- Likely to result in less spatial coverage of the water body being measured

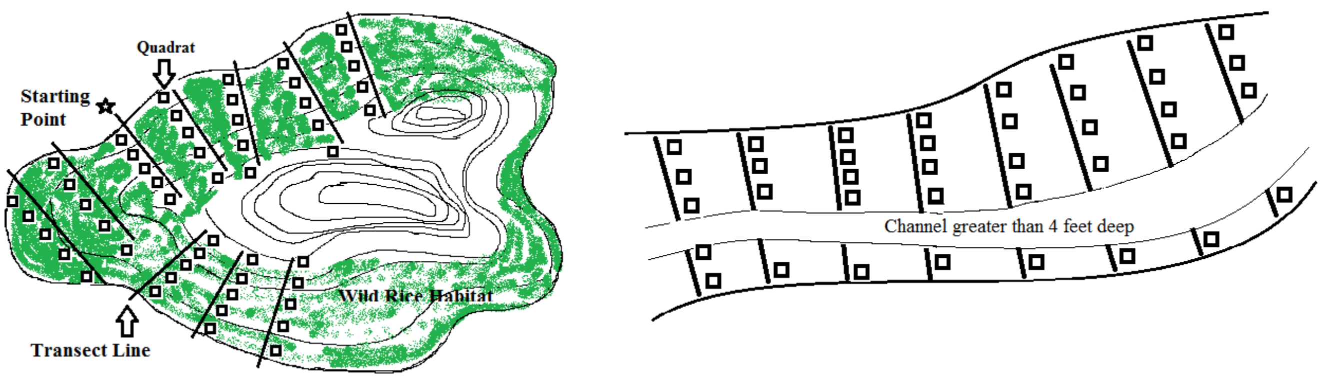
How to set up line transects. In a lake, transects should be set up perpendicular to the depth contours at regular intervals; preferably 30 m apart—but not less than 20 m apart. The transect end points will be where the water becomes too deep ($\geq$ 4 ft). Using a rope with floats can help to define transects. Sample quadrats at equally spaced 30 m intervals along the transect until you reach the end point (Uzarski, et al., 2014; Yost, et. al. 2013, Lee and Stewart, 1981). If the area is smaller, the quadrat

[6] These were the same lakes used for creating the wild rice biomass equations.

spacing may be reduced to 20 m. Record the GPS coordinates of the transect start and end points. In a river, transects should be located so as to be as representative as possible of the wild rice distribution, set at perpendicular angles to the flow.

Determine how starting points for transects will be identified randomly, either beforehand or once out in the field. Here are a few ideas for random placement:

- Prior to going out in the field, make a random mark on a map of the area. This point will identify the starting point for the first transect (not at the dock or access area). Separate each transect starting point 20 to 50 meters apart, depending on how large the area is to cover. Unless there is an obstruction, keep consistent spacing between transects; decide on a distance and repeat when setting up each transect. Record the distance used.
- In the field: Travel to the area where wild rice is growing and select a random starting point. Record the GPS coordinates of the start and end points of the transect.



LAKE **RIVER**

Figure 7. Line transect sample point design on a lake and a river

Dealing with areas that lack wild rice

Don't ignore open water areas if they are within suitable wild rice habitat. Because wild rice density varies spatially from year-to-year, open water areas that are suitable habitat for wild rice should be included in the sampling. The exception to this general rule will be when there has been no wild rice in those sites for a long time and it's not expected that wild rice will be able to grow there in the future (again, suitability of habitat is the deciding factor about whether or not to include the site). Documenting why sites are eliminated from sampling is a good practice for future reference. If sites are eliminated, new sites must be added in order to still have 40 sites. Sample points should ideally be selected prior to going out into the field to avoid the bias of picking the "best" points to sample.

Eliminating sites <u>prior</u> to field work. Sample sites may be eliminated prior to field work by comparing the grid map to a bathymetric map (one that shows the water depths). Since wild rice will not grow past a certain depth, sample points that are always deeper than the wild rice will grow can be eliminated prior to going out in the field. Estimates of maximum rooting depth range from 3 to 4 feet (0.9 to 1.2 meters). Use a depth of 4 feet as a cut-off level for sampling for most locations. If your wild rice plants are much taller on average, adjust the cut-off level accordingly.

In a Nutshell: Sample sites may be eliminated when they are not within <u>suitable wild rice habitat</u>.

Eliminating sites <u>during</u> field work. Sample sites may be eliminated when they are found to be too deep (greater than 4 feet), located on shore, sediment is unsuitable (cobbles, for instance), or there is some other type of obstruction to wild rice growth (e.g. floating mat of vegetation or a dock). If wild rice has been damaged or cut down for some reason, it is a good practice to make note of the damage, but don't include the site in the data analysis (unless you are particularly interested in this data).

IMPORTANT: If a sample point is **within suitable wild rice habitat**, and yet there is **no wild rice** present, **record a zero ("0")** for that plot. <u>Do not skip the point</u> because even a "zero" is a significant data point.

How to Determine Frequency of Sampling

Core wild rice variables should be collected annually, if feasible. Since wild rice populations vary considerably across time, annual monitoring will create a dataset that is most representative of actual wild rice yield. However, in some situations, for example when monitoring larger lakes it may be necessary to balance frequency of sampling and number of sample points to achieve your goals. In this case, one option is to select a few lakes to serve as index sites that will be monitored every year. Sample other lakes on a rotating basis (~ 2 to 3 years) to establish a baseline for those lakes.

<u>Below are some options to consider for different situations:</u>

- **Small lakes.** Ideally, all points on a smaller lake (or river reach) will be sampled every year if they are within suitable wild rice habitat (i.e. suitable depth, no obstructions, etc). Value has been found in sampling the same points each year (Vogt, 2014). However, a pilot study may be used to determine the number of points needed each year, and a random sample selected from available points used to determine that number.
- **Medium to large lakes.** An option to reduce field effort is to sample every other point every other year, while still sampling a minimum of 40 points. For example, sample odd-numbered sites in one year and even-numbered sites in the next year. A second option is to randomly subsample the grid points, but in this case you will want to make sure to cover the entire area of interest, and still sample 40 points. Another option is to divide the lake into zones and monitor several areas as baseline zones, but rotate monitoring of other zones per year as time and resources allow. Determine the number of sample points in each zone based on Table 2.

Record-Keeping

Be sure to keep track of the ArcGIS shape files, maps, and GPS coordinates associated with each sample point. Record metadata on how the maps were created (coordinate projections, etc.). If using line transects, keep a record of the GPS coordinates of the starting and ending point for each transect. These records will be useful for future spatial analysis. Other records that might prove to be useful include: 1) phenology of life stages of wild rice: When did seedlings begin to emerge? When did floating leaves appear? When did plants emerge out of the water? When did the seeds mature? and 2) phenology of water body condition/weather (i.e. ice-on date, ice-off date, lake levels, precipitation, etc).

SEQUENCE OF EVENTS DURING FIELD SEASON

Pre-field season preparations (June-July)

- ☐ Design monitoring plan and/or review prior year's plan
- ☐ Gather equipment and make sure it is working properly
- ☐ Train field crew
- ☐ Plan for cleaning boats when moving between water bodies to avoid spreading invasive species (very important!)

- ☐ Sample core wild rice variables when plants are mature
- ☐ Sample related environmental variables concurrently, if possible
- ☐ Decide on a labeling system ahead of time for sample points and collected plants
- ☐ In the field, store plants **on ice** in large zippered plastic bags

- ☐ Field season: mid-August to early-October
- ☐ If collecting plants for a biomass equation, collection should be completed by the end of September.

In the Lab:

- ☐ ASAP, move plants to paper bags and store in a dry location
- ☐ Identify other plants that were collected in 1-2 days to avoid decomposition and press right away if voucher specimens for later identification

As soon as possible:

- ☐ Oven-dry wild rice plants as soon as possible to avoid decomposition
- ☐ Oven-dried plants that have been left out overnight need to be re-dried. An oven-dried sample may increase in weight overnight by 5-10% through added moisture (Madsen, 1993)
- ☐ Process wild rice samples by either: 1) counting potential seeds (female pedicels) or 2) drying and weighing plants

After all data has been collected and recorded:

- ☐ Enter data into a spreadsheet (i.e. M.S. Excel)
- ☐ Clean the data (check for errors and/or outliers)
- ☐ Analyze the data (i.e. compute biomass and/or create site-specific equations)
- ☐ Upload data to a database if part of monitoring plan (i.e. AWQMS - WQX)
- ☐ Plan for next field season

Problems Faced When Doing Wild Rice Inventories and How to Solve Them

Cultural considerations and community concerns. Be aware that being out on the water conducting a wild rice study during harvest time may unsettle some people. Many Native Americans consider wild rice to be a sacred plant—and may not be comfortable with people paddling through the rice stands during harvest, especially if uprooting plants. Due to spiritual beliefs and negative experiences, some people will be disturbed by almost any type of scientific study being done on wild rice.
The methods in this Handbook have been designed to minimize effects on the wild rice plants. The recommended boat to use is a canoe. Using an airboat is too destructive; and, may offend people for cultural and spiritual reasons. Using a canoe with paddles will result in some bending of the wild rice plants when moving through dense patches, but soon after passing through the bed, the plants will usually stand up again and be as they were before.

<u>Here are possible solutions to consider</u>:

- Enlist help from tribal elders and leaders before any field surveys are conducted. Explain to them what you will be doing and why. Seek advice and listen to what they say.
- Take it slowly. This is a good way to build capacity—for know-how with the methods and for building trust and support within the community.
- Prior to the field season, consider notifying the local harvesting community through news media that you will be out in the lakes and rivers conducting a wild rice study and explain the benefits to the community and the safeguards you propose to protect the wild rice from damage.
- For collecting plants and seed counts, it is best to conduct the sampling when plants are mature (i.e. during harvest). If that is not possible, consider starting before the harvest. If you must wait until after harvest, don't wait too long, as senescing plants are hard to measure.
- Refer to the first pages of the Handbook for the quote from "Braiding Sweetgrass" by Robin Kimmerer. This passage illustrates a respectful, spiritual reasoning for conducting scientific studies.

In a nutshell: Proceed with awareness and respect when dealing with community and cultural concerns about doing wild rice studies.

Spatial variability. How to handle spatial variability is an important decision when designing a wild rice study. Wild rice often varies considerably in location annually—this is in a large part due to being an annual plant growing in a dynamic environment. Wild seeds tend to fall into the water near the parent plant, but there is still movement in wild rice beds each year due to many factors—wind and wave action, sediment transport and nutrient availability. As a result, wild rice plant distribution is not uniform across a given area, and dense patches are interspersed with open water. In addition, there are sometimes gaps along the edges of lakes.
While there are no strict rules for how to deal with wild rice spatial variability, it is important to think through how to handle this variability and to use consistent sampling methods from year-to-year and from one wild rice stand to the next.

One question that frequently arises is, "How do I handle open water areas?" The answer lies in thinking about the goals of the study, the historical distribution of wild rice, and the likelihood that open water areas may at some point contain wild rice. This last likelihood depends on the suitability of habitat, the seed source, and future plans for restoration. Suitable wild rice habitat is explained in depth in the section, "Biology of Wild Rice."

The section, "How to Determine Sample Point Location" explains more about making the decision about how to locate sample points, which is especially difficult for large areas of lakes that typically do not produce wild rice. This same section also provides guidance for the situation where there are separated areas of wild rice, such as isolated bays. When there are large areas of open water every year, it is often useful to do a baseline study in the first monitoring season to document the lack of wild rice presence and to assess the suitability of habitat. In subsequent years, sample plots might only be placed within areas that are known to produce wild rice consistently.

In a nutshell: Sample sites with zero ("0") rice should still be recorded and included in the data analysis when they are <u>within suitable wild rice habitat.</u>

Temporal variability. Wild rice varies annually in abundance, as measured by height, number of stalks, and biomass. Normal patterns of variability range from 3 to 7 years. The number of sample points required to achieve the same level of statistical precision will vary from year-to-year. In years when wild rice is sparse, there will be more areas with zero rice. Therefore, in order to accurately measure the wild rice present in sparse years, more sample points will be needed.

In a nutshell: In years of low biomass, more sample points will be needed to achieve the same level of statistical precision as in years of high biomass.

Sampling problems. Some sampling problems are predictable and can be mitigated or avoided, while others arise from unpredictable circumstances.

<u>The following are suggestions for avoiding problems:</u>

- **Site Access**. Access issues may occur in unfamiliar or less frequented areas, which could result in not enough time to complete the work as planned for the day.

  Avoid this problem: Do a dry run. Visit each of the sites ahead of time to assess the time it will take to drive there, load the equipment, and paddle to the wild rice areas.

- **Navigating using the GPS unit.** A common problem is difficulty navigating to the sample points on the water using a handheld GPS unit. This problem can be frustrating and greatly increases the amount of time needed to complete sampling.

  Avoid this problem:
  - Get to know your GPS unit ahead of time.

- Practice finding points on shore and on the water prior to starting the wild rice study.
- Keep in mind that arriving within 5 meters of the sample point is considered accurate enough.
- Features to look for when purchasing a new GPS unit include: waterproof, floats if dropped in the water, receiver capacity (to ensure it works well in remote areas), WAAS capability (to improve accuracy), waypoint capacity (number of points that can be stored), built-in electronic compass (to aid in navigation), a live tracking feature (for getting close to GPS points and for outlining wild rice stands). A helpful interface for uploading GPS points from ArcMap is called DNRGPS. This software is available free from the Minnesota DNR at: http://www.dnr.state.mn.us/mis/gis/DNRGPS/DNRGPS.html

- **Concerns about the time it will take.** At first there may be concerns about the amount of time and effort it will take to implement these methods. Experiencing the reality of doing the field work usually allays these concerns.

  Mitigate this problem:
  - Do a dry run or pilot study of 5 points to determine the feasibility, number of sample points needed, and number of lakes to sample.
  - Take it slowly. Start in year 1 by only collecting the core variables on one lake. Add more variables and water bodies over time.
  - Practice using the GPS unit prior to the start of field work on land and water.

- **Wind.** Windy days can be especially difficult for the sampling crew due to paddling against waves and maintaining a steady canoe while sampling.

  Avoid this problem:
  - Stabilize the canoe using an anchor in front and back or outriggers.
  - Don't work on windy days.

- **Plant senescence.** Wild rice plants sometimes mature and reach senescence earlier than expected, or earlier on some lakes relative to others. This is more likely to be a problem when sampling must be done after the harvest season. Measuring plant height and counting stalks is more difficult when plants are beginning to rot and fall back into the water.

  Avoid this problem:
  - Sample prior to or during harvest, if possible.
  - If sampling must be done after harvest is over, be sure to get out there as soon as possible.
  - A judgment call may be needed for when the plants are too decayed for accurate sampling, especially when collecting plants for a creating a new biomass equation. Ideally, plants should be collected when they are ready to harvest and at their prime.

In a nutshell: Doing a practice run ahead of time to test out the equipment and methods will go a long way towards mitigating many sampling problems.

Standard Operating Procedures

SOP #1: Measuring Core Wild Rice Variables

(Source: Kjerland, T. 2015. *Wild Rice Monitoring Field Guide*. The University of Minnesota Sea Grant Program, Publication #SH15. ISBN 978-0-9965959-0-2).

For every waterbody, field crews will need to outline the area occupied by wild rice according to the method selected by the resource manager.[7]

Field crews will collect the following core wild rice variables in approximately 40 sample points per waterbody.

Variables for Generic Biomass Model:

- Stalk density within the quadrat frame
- Water depth within the quadrat frame or as close as possible
- Sample plant height (ABOVE WATER or TOTAL)
- Seed heads from the sample plant so the pedicels can be counted back in the lab
- The names of other plant species within the quadrat frame.

Variables for Site-Specific Biomass Model:

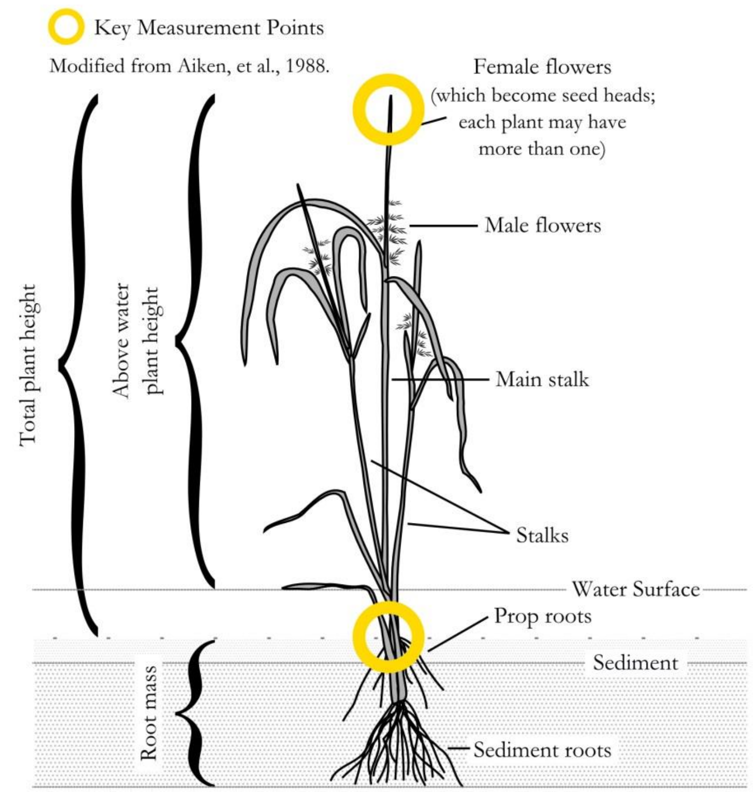
- Stalk density within the quadrat frame
- Water depth within the quadrat frame or as close as possible
- Collect entire sample plant collected so its dry weight can be determined back in the lab
- TOTAL sample plant height
- The number of stalks on the sample plant
- The names of other plant species within the quadrat frame

When conducting fieldwork, also note brown spot fungi information, shoreland and water use, weather information that might affect the data, and concerns for wild rice plant growth.

[7] See Appendix B, "Estimating Wild Rice Stand Area" or Step 12 in the field sampling protocols on Page 37.

Wild Rice Plants

Figure 8. Labeled illustration of wild rice plant



Prop roots are found on some plants, but not all. They are shorter and often colored differently compared to sediment roots—either more darkly or more lightly (even white). Prop roots are found above the sediment roots, and appear to be a second set of roots higher on the stalk. Prop roots do not have fine hairs.

Sediment roots are the lower roots on a wild rice plant that grow in the sediment, which every plant will have. Some plants will also have prop roots. Sediment roots have fine hairs for absorbing nutrients.

Equipment Needed

- ☐ Canoe
- ☐ Canoe cushions
- ☐ Paddles (3)
- ☐ Life jackets
- ☐ Drinking water and food
- ☐ First aid kit, hand sanitizer
- ☐ Hat and sunglasses, sunscreen, rain gear
- ☐ Cell phone, fully charged, in waterproof bag (for emergencies)
- ☐ Insect repellant
- ☐ Quadrat frame, 0.5 m^2, or 0.71 m x 0.71 m (one corner marked with colored tape, notch, or colored PVC elbow)
- ☐ Handheld GPS unit (fully charged, with spare batteries, ideally with tracking function)
- ☐ List of GPS points to sample printed on water-resistant paper
- ☐ Map of water body showing labeled GPS points, i.e. "grid map" OR if using transects, simply a map of the area (laminate or print on water-resistant paper)
- ☐ Metal box clipboard
- ☐ Device to measure water depth (e.g. secchi disk with chain or rope taped to meter stick or measuring rod—the measuring rod should rest on top of the secchi disk. This is needed to measure water depth in soft, flocculent sediments.)
- ☐ Permanent marker
- ☐ Water-resistant paper (for labels to put inside bags)
- ☐ Mechanical pencils
- ☐ Field data sheets printed on water resistant paper– see Appendix A
- ☐ Tape measure or meter stick (needed to measure wild rice plant height)
- ☐ Equipment for collecting water and/or sediment samples, if part of the sampling plan
- ☐ Wild Rice Monitoring Field Guide (includes Plant ID Key)
- ☐ Additional plant ID guides (for more comprehensive references)
- ☐ Permits, if needed
- ☐ Large (~2-gallon) zippered plastic bags (about 60) – for collecting seed heads and/or plants
- ☐ Large scissors (for collecting seed heads)
- ☐ Cooler with ice

Helpful Tip: Use a copy of the Field Data Sheet on page 102 to record data.

Field Sampling Protocol

1 **Locate Sample Points Using GPS Unit**
Referencing the map, navigate to the sample points using a GPS unit. If you are unfamiliar with this process or the GPS unit, practice ahead of time.

2 **Collect Water Quality and Sediment Samples…**
if required by your sampling plan. Do this BEFORE taking other measurements to avoid stirring up the sediment and contaminating samples.

3 **Place Quadrat Frame Over the Plants to Measure Stalk Density**
Lower the quadrat frame straight down over the wild rice plants to the side of the canoe next to the seat of the person in front (same side each time). When placing the frame, if there are any stalks leaning in or out (due to thick rice, wind, canoe movement, etc.) they should be moved in or out accordingly.

Avoid Sampling Bias

- Do not simply place the quadrat frame on an area that "looks good" or is easiest to measure. Instead, use a methodical, non-biased way of deciding where to place the frame.
- Navigate to within 5 meters (~16 feet) of sample point coordinates. Stop and quickly stabilize the canoe. Don't back up or paddle an extra stroke to reach a "better" area.
- Place the quadrat frame in the water next to the seat of the person in front. Use the same side of the boat each time.
- If taking two quadrat readings per sample point, decide ahead of time and be consistent about placing the frame. See "Two-points-per-stop" method described on page 21.

Skipping Sample Points

Sample points may be eliminated if they are not within suitable wild rice habitat. If sample points are skipped, add more sample points as needed to measure the required number of points. Reasons for skipping include:

- the water is too deep (greater than 4 feet for most locations)
- the point is located on shore
- there is an obstruction (e.g. a dock, floating mat of vegetation)
- the sediment is unsuitable

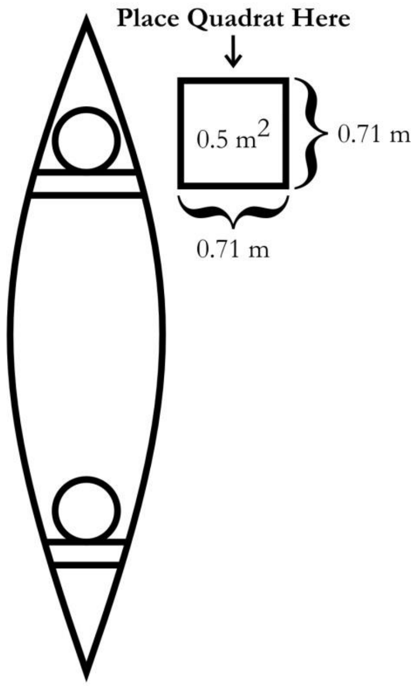


Figure 9. Quadrat placement

Record the reason for skipping on the Field Data Sheet

Having zero wild rice is not a valid reason to skip a sample point. If there is no wild rice in an otherwise suitable site, record is as "0" on the field data sheet along with the water depth and other plants. Don't leave blanks because this would mean "data missing." If wild rice has been damaged or cut down, make note and take photos, but don't include this point in the analysis unless you are particularly interested in this data.

4 **Measure Stalk Density**

Count the stalks that are inside the frame. **Count stalks, not plants**. Individual plants may have stalks within and outside the frame.

5

Identify Other Plants in the Quadrat

- Use the Plant Identification Key in the Field Guide or other reference guides. Record the common name(s), using abbreviations if needed.
- If a plant cannot be identified, collect the plant for later identification
- Label a large, zippered plastic bag: Unknown #1, etc.
    1. Sample ID# & waterbody name
    2. Date & time of day
    3. Water depth
    4. Note observations about leaves, flowers, or fruits:
        - Emergent (above water, like wild rice)
        - Floating (floating on the surface)
        - Submersed (below the surface entirely)
    5. Color of flower
    6. Technician initials
  - Collect entire plant—flowers, fruits, roots, stems, leaves…everything.
  - Wash the roots carefully but thoroughly in the water
  - Remove sticks, bugs, etc., that are clinging to the plant.
  - Include a duplicate label on water –resistant paper inside the bag.
  - Store plants on ice in the cooler.

6

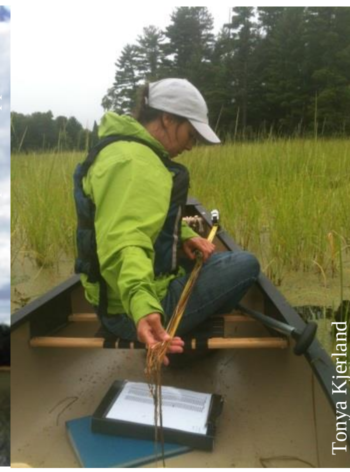
Select the Sample Plant

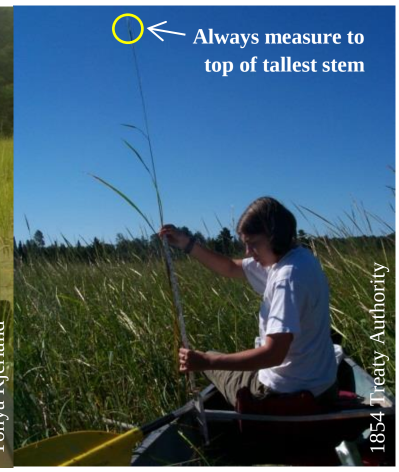
- Find the corner of the quadrat marked with colored tape, notch, or PVC elbow
- Select the wild rice stalk that is nearest to this designated corner. Whichever plant this stalk is growing from is the sample plant.
- This will be the plant you measure and either:
    A) collect seed heads from, OR
    B) collect in its entirety.

7 Measure Sample Plant Height

- Circle on the Field Data Sheet whether measuring in inches or centimeters
- Check box for which method used, and record plant height. Use one of the following methods:
  - A) Above water. Measure the sample plant's height from the water line to the top of the tallest stem.
  - B) Total. Uproot the plant and measure the distance from the top of the roots to the top of the tallest stem. If two sets of roots, measure from the top of the prop roots.

A) Above Water





B) Total

8 Measure Water Depth as close as Possible to the Sample Plant

Circle on the Field Data Sheet whether measuring in inches or centimeters. Use one of the following methods:

- A) Use a device for measuring depth and record the device type used. Measuring water depth can be difficult due to thick plant growth and soft lake bottoms that are hard to define. The recommended device is a secchi disk attached to a marked rope or chain, which can be allowed to settle to the bottom. Temporarily tape the secchi and its chain or rope to a meter stick or measuring rod, then allow the secchi to settle to the bottom so that the stick rests directly on top of the secchi disk.
- B) Measure water depth by uprooting the sample plant and measuring from the top of the roots to the water line on the plant. If there are two sets of roots, measure from the top of the prop roots (See page 38, Wild Rice Plants).

9 Collect Seed Heads OR Sample Plants to Take Back to the Lab for Analysis

A) Seed Heads from Sample Plant

To assess the potential number of seeds requires removing the seed head portion of the plants and then counting the tiny stalks that hold female flowers (called pedicels).

- Label a plastic zippered bag with the sample point ID #, water body name, and date.
- Include a duplicate water-resistant label inside the bag.
- Using a scissors, cut the stem below the seed head on every stem of the sample plant and place it in a plastic zippered bag, store on ice. Gather all of the seed heads on the sample plant.

Back in the lab, to avoid decay, ***remove seed heads from the plastic bags as soon as possible*** *and store in labeled* ***paper*** *bags to dry until ready to count pedicels. Counting pedicels is necessary to calculate the number of potential seeds and whole plant biomass.*

B) Entire Sample Plant and Count Number of Stalks

- Label a large (~2 gallon-size) zippered plastic bag with sample point ID #, water body name, plant height (indicate units), and date.
- Include a duplicate water-resistant label inside the bag.
- Holding the bag to catch falling seeds, carefully run your hand over the seed head to collect loose seeds.
- Pull the plant slowly up out of the sediment, trying to retain as many seeds and roots as possible.
- Gently wash the roots in the water, and pick off sticks, bugs, or other materials sticking to the wild rice plant.
- Fold the plant accordion style, trying to save as many seeds as possible, and place the whole plant in the bag. Store on ice.

Back in the lab, within 24 hours, ***remove the wet plants from their bags.*** *Repackage in labeled* ***paper*** *bags and store in a dry area. Note**

About Collecting Seed Heads

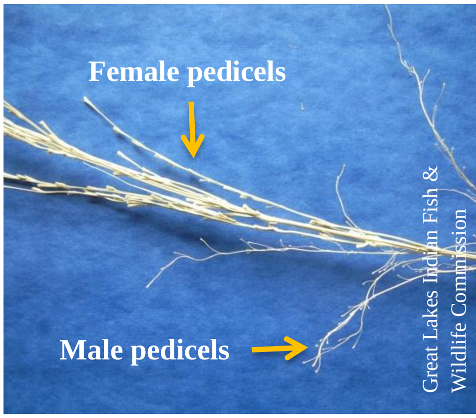
For information on processing the samples (i.e. counting potential seeds/female pedicels) see page 44, SOP #2 Drying and Weighing Wild Rice Plants. It is important to collect the entire seed head from every stalk on the sample plant and process them as soon as possible after returning to the lab.

About Collecting Wild Rice Plants

To create a site- or area-specific biomass equation, it's necessary to collect wild rice plants, dry and weigh them. These results are compared to stem height and seed number to develop the equation. Specific biomass equations are optional, as generic equations exist; see page 57, SOP #4 Using Generic Wild Rice Biomass Equations.

*Alternatively, allow plants to drip-dry on canvas in the lab. Tag them for later identification with folded-over "lab tape" or aluminum write-on tags.

Helpful tip: the female pedicels are larger and sturdier and located above the male structures on the stem (see photo, below left). Because seeds fall off regularly, counting pedicels is the best way to estimate total seed production. When counting pedicels, it is important to count only the female ones.



A) Female Pedicels on Seed Head

B) Collection of Wild Rice Plants

10 Record Field Notes

These observations will help reveal the environmental conditions that affect wild rice growth

- Complete weather and comments on the Field Data Sheet
- Note presence of animals, birds, pests, and signs of plant disease.
  Examples: Rice Worms (*Apamea apamiformis*), Muskrats, Ducks, Other Birds, Rusty Crawfish, Ergots, etc.
- Write legibly using pencil or waterproof ink!
- Important: Do not leave blanks on the datasheet. If the data cannot be collected, record the reason. A blank dataset means "data missing", whereas "zero" means "we looked and didn't detect this variable."

Wild Rice Worm

Wild Rice Worm and Seed

Ergots on Wild Rice

Muskrat Lodge

11 **Record Brown Spot Fungal Disease Severity Within the Quadrat Frame**

- Record the severity of brown spot fungal disease at five random sample points across the water body.
  SEVERITY INDEX: “0” = wild rice leaf is free of the disease; “low” = less than 1/3 of the leaf if covered; “high” = more than 1/3 leaf is covered. See images below.
- Make your best estimate, being as consistent as possible across the sites.

“Low” severity infection
LESS than 1/3 of leaf covered

“High” severity infection
MORE than 1/3 of leaf covered

12 **Estimate Wild Rice Stand Area**

Method A: Canoe or walk around the wild rice stand using a GPS with a tracking function to record points and get an outline (bare minimum points needed = 4; 5-sec. or shorter setting for tracking function recommended). The edge of the stand may be identified by moving to the open water where there is no wild rice and then defining the edge according to the most outlying stem. Even one stem is considered part of the wild rice stand. This is a relatively time-consuming method. If there are areas without wild rice, or areas in which wild rice is of differing densities, these areas may need to be treated separately. (Reference: Valerie Brady, Natural Resources Research Institute)

Method B: While completing sampling, the field crew uses a map of the water body printed on waterproof paper with a grid of GPS points. Throughout the day, the crew draws areas of 1) wild rice, 2) sparse rice, 3) open water, or 4) other vegetation. Later, using a transparent grid overlaid on the lake map, estimate area of wild rice in relation to total lake area. These polygons may also be digitized for use with mapping software. For purposes of making within lake comparisons, “Sparse wild rice” may be defined as areas with greater than one canoe length between rice stalks. (Reference: Darren Vogt, 1854 Treaty Authority)

About Estimating the Area of a Wild Rice Stand
It is useful to create an approximation of the outline of areas where wild rice is found growing each year. Knowing this area is essential to computing overall biomass and for mapping challenges, such as interpolating values between sample points. Because using GPS to outline wild rice beds is subjective; the accuracy of area measurements may vary between surveyors. Areas may move considerably year to year due to the variability of wild rice growth. In order to standardize these approximations, it is recommended that whoever does the work be given clear instructions, make notes on what criteria they used to determine where to map and that the same crew assess each area each year. Because of GPS inaccuracy and field technician subjectivity associated with collecting this type of data, it should only be used as an estimate for comparing year-to-year variability *within* a specific waterbody. It is not intended to provide a mechanism for assessing relative condition or productivity *between* (or *across*) wild rice waterbodies.

Multiple methods for estimating the area of wild rice stands are described in Appendix B. The two methods recommended in these field sampling protocols and in the Field Guide were chosen due to their ease of implementation.

Back in the Lab: Dry and Weigh Wild Rice Plants
Instructions are provided in Standard Operating Procedure #2, "Drying and Weighing Wild Rice Plants."

SOP #2: DRYING AND WEIGHING WILD RICE PLANTS

Helpful Tip: Use the lab data sheet provided in Appendix A for recording data.

Obtain permission first. Wild rice is considered to be a sacred plant by many Native Americans and like-minded people (Vennum, 1988). Pay attention to local cultural protocols and consult with tribal authorities to determine what is appropriate. At the end of the study, treat the plant materials with respect. Again, ask ahead of time about local cultural protocols and follow the advice of tribal leaders and elders for disposing of plant materials.

Rules and protections for wild rice exist in many areas. If you are considering physically collecting wild rice plants, think carefully about whether or not this is necessary and then check into tribal, state, and other laws to determine if you need a permit in order to collect plants. Permits may also be required for collecting seeds heads.

Equipment Needed:

Field (also included in equipment list for SOP #1)

- ☐ Large (~2-Gallon) plastic zippered bags (At least 60, enough for 40 plots plus 20 for collecting other plants if need for identification.)
- ☐ Permanent markers
- ☐ Mechanical pencils
- ☐ Extra water resistant paper for placing labels inside bags
- ☐ Cooler with ice
- ☐ Measuring tape or stick
- ☐ Lab tape or aluminum write-on wire tags for identifying plants (optional)

Lab

- ☐ Small paper bags (i.e. lunch bags), one per plant
- ☐ Permanent markers
- ☐ Pencils
- ☐ Data recording sheets for plant weight (see *Plant Weight Lab Data Sheet*)
- ☐ Large sink for washing plants, preferably with a sprayer that can be set to a gentle spray setting
- ☐ Drying oven or incubator
- ☐ Refrigerator
- ☐ Scientific balance, ideally accurate to 0.001 grams, but with minimum accuracy of 0.01 grams (properly calibrated)
- ☐ 2 large trays (~9"x13")
- ☐ Small plastic weigh boats
- ☐ Tweezers
- ☐ Magnifying glass

Collecting Wild Rice Plants

In order to compute a site- or area-specific biomass equation, collect entire wild rice plants as described in SOP #1 and the Field Guide. Wild rice roots account for approximately 10% to 15% of the total plant weight (T. Kjerland analysis of data collected by Vogt, 2014). Stalks usually account for between 65 and 75% of the total plant weight, and seeds may account for 10% to 25% of total plant weight.

Washing, Drying and Weighing Plants

Plants can be dried and weighed using a variety of methods. The methods presented in this section will produce accurate results and are the same as used to compute the generic biomass equation.

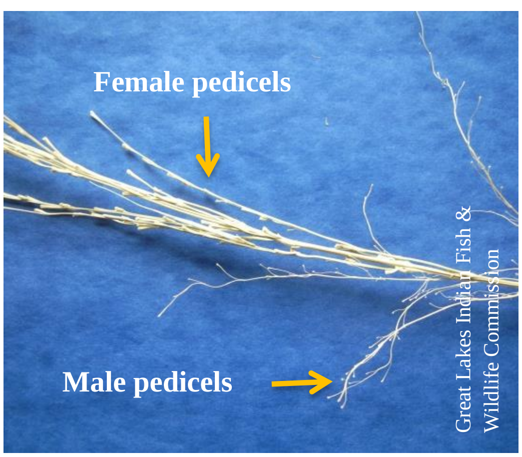
Timing. Ideally, plants will be dried as soon as possible after collecting, but they can be stored for up to several weeks if kept in a very dry location. Rather than keeping plants in a refrigerator where they are likely to decay quickly, wash the plants at once and put them into paper bags to air dry. When plants begin to decay they lose weight, and counting pedicels will become difficult.

Washing and Drying Plants

1. Have on hand a stack of small brown paper bags and a permanent marker.
2. One plant will go into each bag, which will be labeled with same information as on the plastic bag used to collect plants in the field.
3. Label the paper bag

   Waterbody name
   Site ID#
   Date
   Technician initials

4. Carefully remove a plant from its plastic bag into a large sink with a screen stopper.
5. Cut off the seed head including the male and female pedicels. Place the seed head into the small brown paper bag, being careful to include any seeds that get knocked off. Another option is to collect all seeds into a separately labeled paper envelope and place this in the bag.



Helpful Tip: The female pedicels are larger and sturdier and are located above the male structures on the stem. Because seeds fall off continuously, counting pedicels is the best way to estimate total seed production. When counting, it is important to count only the female pedicels.

Figure 10. Photo showing the difference between female and male pedicels

6. Wash the roots thoroughly but gently. If any roots break off, retain them with the original plant for weighing. Retain all plant materials for each plant; the plant doesn't have to be intact to be weighed.
7. Cut off the roots of the plant at the node directly above the prop roots, if any exist. If no prop roots, then cut above the sediment roots. Place roots in the same labeled paper bag.

8. Refold the remaining stem of the plant accordion style and place into the paper bag.
9. Keep the bag upright and the top open for air circulation.
10. Repeat until all plants have been processed.
11. Store bags open side up in a dry room until drying can be completed in the incubator or drying oven. Try to complete the drying as soon as possible, within at least 1-2 weeks.
12. Dry plants in an incubator or drying oven at 60^{o} C for 24 hours prior to weighing. The idea is for the plant material to have reached a constant, stable weight.
13. Weigh plants as soon as they are removed from the drying oven, if possible. If plants sit out more than overnight they will need to be re-dried in the oven because the plants will absorb moisture from the air.

About Seed Viability: Viability usually refers to the ability of a seed to germinate, and so the "half-empty hull" test is only a rough estimate. It is important to take care when collecting the plants to collect as many seeds as possible, and also to collect plants at the harvest-ready state, if possible. At that point, seeds left on the plant will be the most representative of the ratio of viable to non-viable seeds produced. Viable seeds should weigh considerably more. If you find they don't, check again. For computing total plant weight, viable and non-viable seeds will be weighted for the % collected per plant.

Weighing Plants

1. Weigh plants immediately after removing from drying oven.
2. Remove each plant from the small paper bag onto a large tray.
3. Record the collection location site and plant height on the Plant Weight Lab Data Sheet, see Appendix A.
4. Separate the 3 parts of the plant: 1) roots, 2) stems/leaves, and 3) seeds.
5. Remove the seeds from the plant and store in a pile.
6. Tare the weigh boat on the scale.
7. Weigh the roots of the plant and record weight in grams to the nearest highest level of accuracy the scale allows, ideally to 0.001 mg.
8. Weigh the stems/leaves of the plant together, including the seed head (minus seeds).
9. Separate the seeds into viable, non-viable, and ergot-infested piles.
    a. To test for viable seeds, press on the seed with your index finger and if over half of the hull is filled, this is considered a proxy for "viable." Viability usually refers to the ability of a seed to germinate, and so this test is only an estimate. When determining an approximate weight for seeds during data analysis, viable and non-viable seeds will be

weighted for their percent left on the plant. This is why it is important to take care when collecting the plants to collect as many seeds as possible, and also to collect plants at the harvest-ready state, if possible.

   b. Seeds with ergots should be noted and counted but <u>not included as part of the wild rice plant weight</u> because the fungal growth is not part of the plant and adds weight.
   c. Record number of seeds with worm holes.

10. Count the viable and non-viable seeds and record these separately on the data sheet.
11. Weigh the viable and non-viable seeds, and record these separately on the data sheet.
12. Count and record the number of female pedicels on the seed heads. Use a tweezers and magnifying glass to help see these small plant parts. Be sure you are only counting the larger pedicels from the top (female) part of the seed head because these are the ones that produce seeds. Male pedicels are smaller, less sturdy, and located on the lower portion of the seed head.
13. Return all plant parts to original paper bag and save them until you are certain that you have all of the data and it is accurately recorded.

SOP #3: IDENTIFYING AQUATIC VEGETATION

Preparations Prior to Field Work

- Look through the list of species often found growing with wild rice (Table 4).
- Determine if there are additional species of concern for your area and add them to the list.
- Obtain a selection of plant identification guides.
- If you don't know how to identify plants or plant taxonomy, reading the field guides will help. Look up words you don't know in the glossary or online. Knowing botanical terms is needed for using plant identification keys.
- Do preliminary training for plant identification by collecting a sampling of plants found in your area and identify them using plant keys. Check with an expert to verify the identifications, if possible.
- For aquatic plant identification training, check with biological stations or colleges in your state; many offer one-day classes for natural resources personnel that range from basic to advanced. In Minnesota, the Water Resources Center at the University of Minnesota offers plant identification courses every summer as part of their wetland delineation certification program.

Equipment Needed

Field (also included in equipment list for SOP #1)

- ☐ Large (~2-gallon) plastic zippered bags
- ☐ Permanent marker
- ☐ Mechanical Pencils
- ☐ Field guides for plant identification, e.g. Wild Rice Monitoring Field Guide
- ☐ Cooler with ice

Lab

- ☐ 2-3 plant identification guides and keys (appropriate for region)
- ☐ Computer for using web-based resources
- ☐ Magnifying glass

How to collect plants

See Step 5 in SOP #1 and the Field Guide for instructions on how collect plants if it is not possible to identify them in the field.

Identifying Plants

The *Wild Rice Monitoring Field Guide* includes photographs of plants commonly found growing with wild rice. The list of plants included in the Field Guide is shown in Table 4.

Plant identification tip: The plants shown in this Handbook are the most common ones found growing with wild rice, but it is likely you will find other species that look similar because they are closely related. When in doubt, collect the whole plant for later identification.

Rare or endangered plants

If possible, identify plants in the field without removing them from the sediment in order to keep the community as intact as possible and because many aquatic plants are relatively rare. In some cases, removing a small part of the plant for closer inspection, such as a leaf or flower, will allow for identification. If it is not possible to identify the plant in the field and you are concerned that it may be rare or endangered, you may wish to photograph it rather than collecting it.

Plants of special concern

Reasons to collect data about other plants growing with wild rice include identifying and locating plants of special concern. These plants may out-compete wild rice or cause other issues, such as recreational water use problems. The resource manager should identify any species of special concern. Plants that are categorized by the Minnesota Department of Natural Resources as "invasive" or "introduced" are noted below.

Field crews should note plants of special concern within the water body where they are sampling. Record the plant's name in column 3 of the field data sheet when found within the quadrat. If found growing outside the quadrat, also make note of its presence in a separate area, such as in the field notes on second page of the field data sheet. Photograph the plant and collect a sample plant for identification in the lab. In order to be able in order to be able to relocate the site where plants are growing, identify the site by recording a GPS point or indicate the location on a map.[8]

[8] For more about threats from plant competition, see "Natural Wild Rice in Minnesota." A wild rice study document submitted to the Minnesota Legislature by the Minnesota Department of Natural Resources, February 15, 2008.

Table 4. Plant species often found growing with wild rice

Common name	Scientific Name	Invasive	Introduced
Arrowhead	*Sagittaria latifolia*	N	N
Bulrush, Hard-stem	*Schoenoplectus acutus*	N	N
Bulrush, Soft-stem	*Schoenoplectus validus*	N	N
Bur-reed, Giant	*Sparganium eurycarpum*	N	N
Cattail, Narrow-leaved	*Typha angustifolia*	N	Y
Cattail, Broad-leaved	*Typha latifolia*	N	N
Cattail, Hybrid	*Typha x glauca*	N	Y
Coontail	*Ceratophyllum demersum*	N	N
Duckweed, Lesser	*Lemna minor*	N	N
Grass, Manna	*Glyceria* species[9]	na	na
Grass, Reed Canary	*Phalaris arundinacea*	Y	N
Horsetail, Water	*Equisetum fluviatile*	N	N
Loosestrife, Purple	*Lythrum salicaria*	Y	N
Lotus	*Nelumbo lutea*	N	N
Pickerelweed	*Pontederia cordata*	N	N
Pondweed, Large-leaved[10]	*Potamogeton amplifolius*	N	N
Pondweed, Curly	*Potamogeton crispus*	Y	N
Pondweed, Floating-Leaved	*Potamogeton natans*	N	N
Pondweed, Leafy	*Potamogeton foliosus*	N	N
Reed, Common	*Phragmites australis*	Y	N
Rush, Flowering	*Butomus umbellatus*	Y	N
Smartweed, Water	*Persicaria amphibia*	N	N
Water-milfoil, Common	*Myriophyllum sibiricum*	N	N
Water-milfoil, Eurasian	*Myriophyllum spicatum* L.	Y	N
Watershield	*Brassenia schreberi*	N	N
Water lily, Common White	*Nymphaea odorata*	N	N
Water lily, Common Yellow	*Nuphar variegate*	N	N

[9] There are many species within the genus *Glyceria* that are commonly referred to as “manna grass”. Some are native and some are not. Record “manna grass” for all similar-looking species due to the difficulty in telling them apart without botanical training.

[10] There are many species within the genus *Potamogeton* that are commonly referred to as “pondweeds.” Due to the difficulty in telling the species apart without botanical training, record “pondweeds” for these similar-looking species while monitoring wild rice.

References for Identifying Aquatic Plants

Bell Museum Herbarium
http://www.bellmuseum.umn.edu/ResearchandTeaching/Collections/ScientificCollection/PlantCollection/InfoonMinnesotasFlora/index.htm

Board of Water and Soil Resources (BWSR), Minnesota Wetland Delineation
http://www.bwsr.state.mn.us/wetlands/delineation/index.html

Board of Water and Soil Resources (BWSR), Minnesota Wetland Restoration Plant ID Guide
http://www.bwsr.state.mn.us/wetlands/plantid/

Borman, S., R. Korth, J. Tempte, and C. Watkins. (1997) Through the Looking Glass: A Field Guide to Aquatic Plants. Wisconsin Lakes Partnership, Stevens Point, WI.

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Crow, G.E. and C.B. Hellquist. (2000) Aquatic and Wetland Plants of Northeastern North America. 2 volumes. The University of Wisconsin Press, Madison, Wisconsin.

Eggers, S.D. and Reed, D.M. (2013) Wetland Plants and Plant Communities of Minnesota and Wisconsin. Version 3.1. The U.S. Army Corps of Engineers, St. Paul, Minnesota. (online only) http://www.mvp.usace.army.mil/Missions/Regulatory.aspx

Gleason, H.A. and A.E. Cronquist. (1991) Manual of Vascular Plants of Northeastern United States and Adjacent Canada. The New York Botanical Gardens, Bronx, New York.

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Hellquist, C.B. (1993) Taxonomic considerations in aquatic vegetation assessments. Lake and Reservoir Management 7(2): 175-183.Minnesota Department of Natural Resources (2014) Aquatic Plants. http://www.dnr.state.mn.us/nr/plants/aquatic/index.html

Minnesota DNR, Native Plant Communities
http://www.dnr.state.mn.us/npc/index.html

Minnesota DNR, Invasive Plants
http://www.dnr.state.mn.us/invasives/terrestrialplants/index.html

MN Wildflowers (App available)
http://www.minnesotawildflowers.info/

Newmaster, S.G., A.G. Harris, and L.J. Kershaw. (1997) Wetland Plants of Ontario. Lone Pine Publishing, Edmonton, Alberta, Canada. 240 pp.

Robert Freckman Herbarium – University of Wisconsin, Stevens Point
http://wisplants.uwsp.edu/search.html

Skawinski, P.M. (2011) Aquatic Plants of the Upper Midwest: A Photographic Field Guide to Our Underwater Forests.

USDA Plants Database, Natural Resources Conservation Service (scope – United States)
http://plants.usda.gov/

Voss, E.G. (1972) Michigan Flora. Part I. Gymnosperms and monocots. Cranbrook Inst. Sci. Bull. 55, Bloomfield Hills, Michigan.

Voss, E.G. (1985) Michigan Flora. Part II. Dicots (Saururaceae-Cornaceae), Cranbrook Inst. Sci. Bull. 59, Bloomfield Hills, Michigan.

Wisflora: Wisconsin vascular plant families
http://www.botany.wisc.edu/wisflora/

Techniques for creating a collection of species

Haynes, R. R. (1984) Techniques for collecting aquatic and marsh plants. Annals of Missouri Botanical Garden 71:229-231.

Wood, R.D. (1970) Hydrobotanical methods. University Park Press, Baltimore, Maryland.

SOP #4: USING GENERIC BIOMASS EQUATIONS

The following two equations define relationships between wild rice biomass (weight) and variables that are easy to measure, such as plant height and potential number of seeds (# female pedicels). These equations provide a short-cut way to estimate biomass without collecting plants. Which one you use will depend upon the input variable you choose; either plant height or number of potential seeds. The decision is based on which variable you prefer to measure or are able to measure most accurately. The following two equations were developed from wild rice plants collected in Minnesota and Wisconsin. See Appendix C for the raw data and summary statistics for all lakes that went into computing these equations.

Generic Wild Rice Biomass Equations
1) Plant weight/stalk = $(9.03 \times 10^{-6}) \times (\text{total plant height in cm})^{2.55}$
2) Plant weight/stalk = $(0.137) \times (\text{number of female pedicels per stalk})^{0.917}$

- **FAQ: Wild rice plant height and seed number change from year-to-year, so how can only one equation capture this change?**
  By using the same biomass equation each year on a water body, quantifiable trends can be recognized (i.e. biomass is increasing, decreasing, or staying the same). The goal of using this method is to obtain an estimate of biomass; not to measure biomass exactly. In order to measure biomass exactly, it would be necessary to collect all plants in a quadrat, dry, and weigh them.

Calculate biomass per unit area by multiplying the weight of the sample stalk by the stalk density:

$$\text{Biomass } (g/m^2) = \text{Weight per stalk} \times \text{Density } (\#\ \text{stalks}/m^2)$$

In order to scale this statistic up for an entire water body (Total Biomass), multiply by the area in square meters. If wild rice grows only in certain areas of the water body and you want a more accurate measurement, divide the water body into zones and calculate the biomass separately for each zone, then sum the results.

GLOSSARY
Biomass is another name for “weight.” This Handbook uses “plant weight per stalk” and “grams per square meter” as the units for biomass.

Biomass Equation 1: Plant height - Weight per stalk

This equation may be used to compute plant weight **per stalk** (grams) using total plant height in centimeters as the input variable.

Equation 1 in words: Plant weight per stalk (in grams) = (9.03 x 10^{-6}) times [total plant height in centimeters] raised to the 2.55 power

Equation 1 $\mathbf{y = (9.03 \times 10^{-6})x^{2.55}}$

Where x = total plant height in centimeters
y = plant weight per stalk (units in grams)

Statistics: n=132; $p<<0.001$

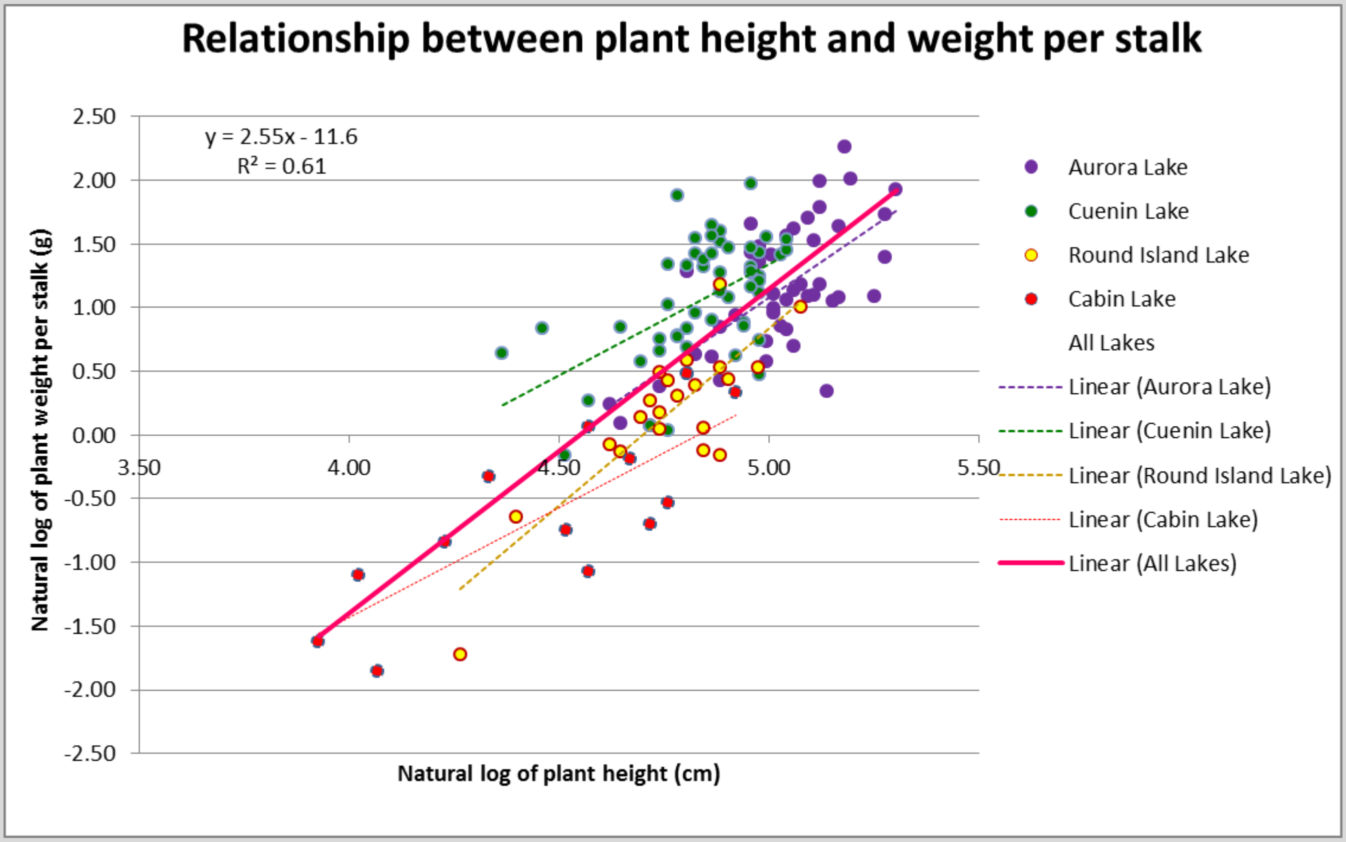


Figure 11. Relationship between plant height and weight for Equation 1

Total plant height is measured in centimeters from the sediment-water interface, or top of highest roots, to height of tallest stalk. Plant weight per stalk (y) is given in grams (T. Kjerland analysis of data collected by Vogt, 2011 and Lewis, 2014).
Note: Data from Campers and Stone Lakes were not included in this equation because the linear regressions showed a lack of significance for these two lakes.

Biomass Equation 2: Number of potential seeds per stalk - Weight per stalk

The following equation may be used to compute **plant weight per stalk** using number of **potential seeds** (#pedicels) **per stalk** as the input (x) variable. Weight is given in grams.

Equation 2 in words: Plant weight per stalk (in grams) = 0.137 times [potential seed number per stalk (pedicels)] raised to the 0.917 power.

Equation 2 $y = 0.137x^{0.917}$

Where x = Number of pedicels per stalk
y = Plant weight per stalk (units in grams)

For Equation 2: n=162; $p << 0.001$

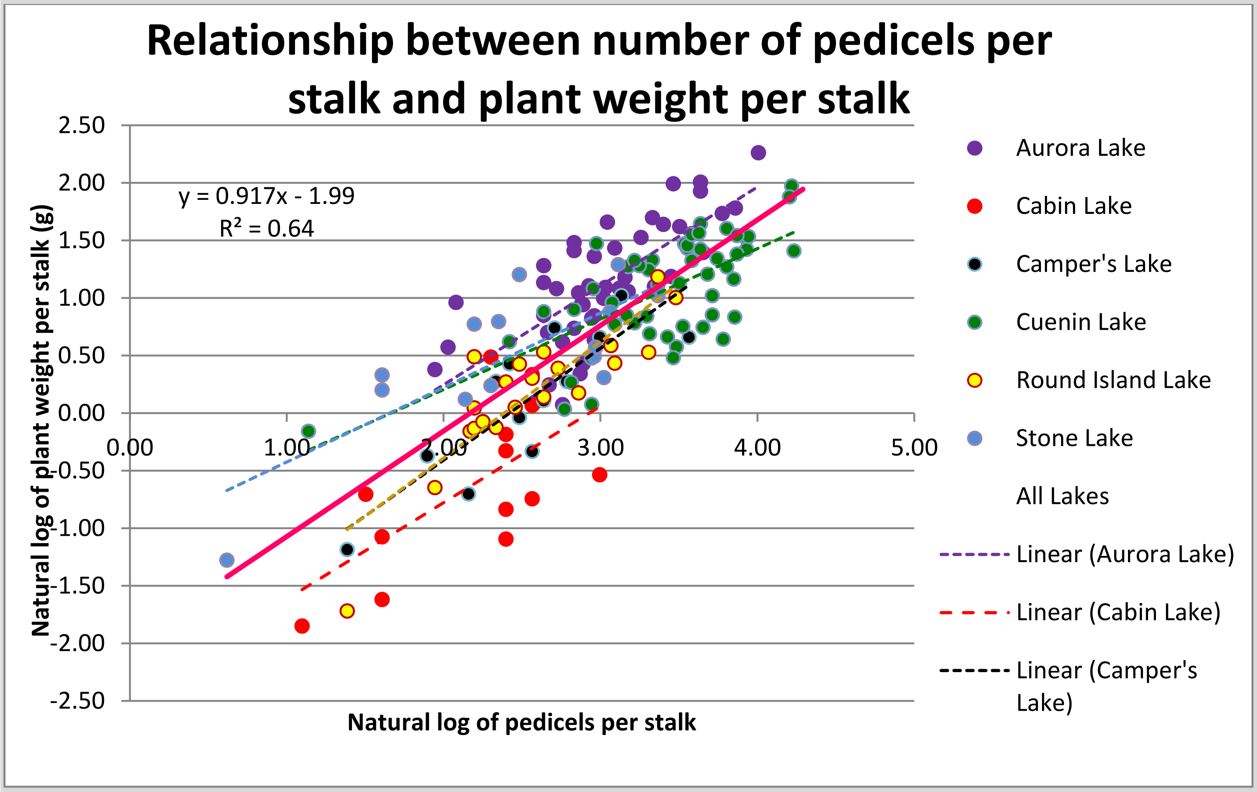


Figure 12. Relationship between pedicel number per stalk and weight per stalk for Equation 2

Step-by-Step Instructions for using Equation 1 in Microsoft Excel

STEP 1. Set up an Excel spreadsheet and enter the data or use the file provided for download from the Minnesota Sea Grant Program web page: **www.seagrant.umn.edu/coastal_cities/wildrice**.
See SOP #5 for instructions on how to enter field and lab data into the spreadsheet. Use the example below to learn how to add columns for the computing biomass.

Enter total plant heights (units are in cm) in the appropriate column. In this example, we use column A.

STEP 2. In column B, add a heading, "plant weight per stalk in grams." Type the following function into Cell B2. Note that the caret ^ symbol in Excel means, "raise to the power of." Remember the equal sign before the function.

	A	B
1	Total plant height in cm	Plant weight per stalk in grams
2	122	1.89
3	117	1.70
4	91	0.89
5	97	1.05
6	137	2.54

= 0.00000903*A2^$^{2.55}$

Verify you did it correctly:
If the plant height is 122 cm, the plant weight in grams per stalk would be 1.89 (grams). The actual number of digits shown will depend on your cell formatting.

Common problems:

- Did you forget the "=" sign before the function?
- Did you paste everything exactly as it reads from the right side of Equation 1 into the cell in column B? **= 0.00000903*A2^$^{2.55}$**
- Did you use the correct number of zero's (5) to the left of the "9"?

STEP 3. Copy and paste the function in cell B2 down the column.

STEP 4. Convert the number of stalks measured in the field with a 0.5 m^2 quadrat to units of stalks per square meter (1.0 m^2) by multiplying by 2. Enter the density of stalks per square meter in Column C.

STEP 5. Compute **biomass per square meter**

Enter "=B2*C2" in Column D to compute grams of wild rice per square meter.

	A	B	C	D
1	Total plant height in cm	Plant weight per stalk in grams	Density_stalks per meter	Biomass_grams per meter
2	122	1.89	2	3.78
3	117	1.70	20	33.93
4	91	0.89	86	76.87
5	97	1.05	2	2.10
6	137	2.54	24	60.89

= B2*C2

STEP 6. Find the **average biomass per square meter** (g/m^2). This statistic can be used to compare annual trends on a given water body. Enter the following formula to compute the average:

	A	B	C	D
1	Total plant height in cm	Plant weight per stalk in grams	Density_stalks per meter	Biomass_grams per meter
2	122	1.89	2	3.78
3	117	1.70	20	33.93
4	91	0.89	86	76.87
5	97	1.05	2	2.10
6	137	2.54	24	60.89
7				35.5

=AVERAGE(D2:D6)

STEP 7. Compute **biomass for an entire water body**. Multiply average biomass per square meter computed in Step 6 by the wild rice area measured by the field crew. The result will be the biomass of wild rice in a given wild rice lake or stream, expressed as grams per square meter. If using zones to delineate areas, weight the average biomass by the proportion of the area represented by each zone.

Step-by-Step Instructions for Using Equation 2 in Microsoft Excel

STEP 1. Set up an Excel spreadsheet or use the file provided for download from the Minnesota Sea Grant Program web page: **www.seagrant.umn.edu/coastal_cities/wildrice**
See SOP #5 for instructions on how to enter field and lab data into the spreadsheet. Use the example below to learn how to add columns for the computing biomass.

Enter number of pedicels in the appropriate column. In this example, we use column A.

STEP 2. In column B, add a heading, "plant weight per stalk in grams." Type the following function into Cell B2. Note that the caret ^ symbol in Excel means, "raise to the power of."

Remember the equal sign before the function.

	A	B
1	Number of pedicels per STALK	Plant weight per stalk in grams
2	13	1.46
3	13	1.46
4	21	2.19
5	7	0.82
6	8	0.92

= 0.137*A2^$^{0.917}$

Verify you did it correctly:

If the number of pedicels is 13, the plant weight in grams per stalk would be 1.46 (grams). The actual number of digits shown will depend on your cell formatting.

Common problems:

- Did you forget the "=" sign before the function?
- Did you paste everything exactly as it reads from the right side of Equation 2 into the cell in column B? **= $0.137x^{0.917}$**
- Did you use the correct number of zero's (5) to the left of the "9"?

STEP 3. Copy and paste the function in cell B2 down the column.

STEP 4. Convert the number of stalks measured in the field with a 0.5 m^2 quadrat to units of stalks per square meter (1.0 m^2) by multiplying by 2. Enter the density of stalks per square meter in Column C.

STEP 5. Compute **biomass per square meter**

Enter "=B2*C2" in Column D to compute grams of wild rice per square meter.

	A	B	C	D
1	Number of pedicels per STALK	Plant weight per stalk in grams	Density_stalks per meter	Biomass_grams per meter
2	13	1.46	248	363
3	13	1.46	46	67
4	21	2.19	98	214
5	7	0.82	22	18
6	8	0.92	172	159

= B2*C2

STEP 6. Find the **average biomass per square meter** (g/m^2). This statistic can be used to compare annual trends on a given water body. Enter the following formula to compute the average:

	A	B	C	D
1	Number of pedicels per STALK	Plant weight per stalk in grams	Density_stalks per meter	Biomass_grams per meter
2	13	1.46	248	363
3	13	1.46	46	67
4	21	2.19	98	214
5	7	0.82	22	18
6	8	0.92	172	159
7				164.3

=AVERAGE(D2:D6)

STEP 7. Compute **biomass for an entire water body**. Multiply average biomass per square meter computed in Step 6 by the wild rice area measured by the field crew. The result will be the biomass of wild rice in a given wild rice lake or stream, expressed as grams per square meter. If using zones to delineate areas, weight the average biomass by the proportion of the area represented by each zone.

SOP #5: DEVELOPING AREA-SPECIFIC BIOMASS EQUATIONS

Any software program that can do linear regression may be used to compute a biomass equation. The steps below are for Microsoft Excel because this is the most widely available.

If you do not have the Data Analysis Toolpak installed for your version of Excel, you will need to install it. Instructions for installing the Data Analysis Toolpak are available online from Microsoft.
It only takes about one minute to install and it is included with Microsoft Office Essentials.

Instructions for How to Load the Microsoft Excel Data Analysis ToolPak
http://office.microsoft.com/en-us/excel-help/load-the-analysis-toolpak-HP001127724.aspx

Spreadsheet design. Be sure to clearly label the columns on your spreadsheets so that someone looking at this spreadsheet (maybe you!) in future years can tell exactly what data each column refers to. It is important to indicate units of measurement the formulas require. Also note if PLANT HEIGHT was measured as "above water" or "total".

Be sure to save your data often!

Data entry and analysis instructions

1. Set up spreadsheet to house data from the Field Data Sheet and Lab Data Sheet. The easiest way to do this is to use the pre-designed spreadsheet available for download at www.mnseagrant.umn.edu/coastal_cities/wildrice.[11] The filename is "Spreadsheet for Field and Lab Data" (See Figure 13 and Figure 14; also see Appendix A). Alternatively, set up the spreadsheet using instructions shown in Table 5.

2. Set up a "METADATA" tab (unless you are using the downloadable spreadsheet mentioned in 1, which already includes metadata). Metadata are descriptions of the data that define the meaning and units of measure of each column heading, or variable (See Figure 15). This information can be extremely helpful to someone else looking at the data, thus making the data more broadly useful and increasing its longevity. By storing the metadata within the spreadsheet, there won't be an additional file to keep track of.

3. Enter data from Field Data Sheet

4. Enter data from the Lab Data Sheet

[11] The spreadsheet available for download from the Minnesota Sea Grant website, "Spreadsheet for Field and Lab Data" was designed to double as an import configuration for the Ambient Water Quality Monitoring System (AWQMS). The import configuration, "Wild Rice Field and Lab Data" (available in AWQMS) is compatible with this spreadsheet for submitting data to the U.S. Environmental Protection Agency's STORET/WQX data management and storage system.

5. QA/QC the data by checking for outliers, missing data and data entry errors (See page 68).

6. Convert units of variables if needed. Convert plant height and water depth to centimeters. Plant weight should be recorded in grams. Multiply by 2 to convert stalk density measured in a 0.5 m^2 area quadrat (0.71 m x 0.71 m frame) to stalks/1.0 m^2.

7. Protect the data (this is to prevent problems with accidentally changing the field or lab data)
    a. Copy the worksheet with data onto a new tab and use this separate tab for computing biomass; or
    b. Lock the cells that have original data in them (using Excel's "lock cell" feature; do not use a password—leave the password blank so that it's easier to unlock the cells).

8. For each sample point, compute the biomass per square meter area using Generic Biomass Equation #1 (page 60) or Equation #2 (page 61).[12]
    a. If using a generic biomass equation, you're done!
    b. If calculating a site- or area-specific biomass equation, continue to 8.

9. Verify that all of the formulas are entered correctly in your spreadsheet. The variables to be used in the linear regression should be log-transformed (ie. natural log of plant height, natural log of plant weight per stalk, and natural log of pedicels per stalk).

10. Calculate biomass equation by performing a linear regression as described on page 69.

[12] For AWQMS/WQX users, keep all columns and maintain their order when using the spreadsheet with the import configuration, "Wild Rice Field and Lab Data". Do not include extra columns that you may have added, such as to convert units or compute biomass. The AWQMS system will not recognize extra columns and may generate an error message.

Set up spreadsheet

Enter the column headings shown in Table 5 horizontally in a new spreadsheet.[13]

Table 5. Column headings and formulas for combined field and lab data

Legend: grey = from both data sheets; green = from Field Data Sheet; orange = from Lab Data Sheet; white = formula; g = grams

Column Headings	Data or Formula?	Formula and Notes
Date	Data	MM/DD/YYY
Water Body	Data	"Monitoring Location ID" is the AWQMS/WQX term associated with a waterbody name or sample site.
Sample ID#	Data	"Sampling Component Name" is the AWQMS/WQX term associated with a sample point or plot.
Activity ID	Formula[14]	=CONCATENATE(B2,":",C2,":",TEXT(A2,"yyyymmdd"))
Number of rice stalks **per 0.5 m^2**	Data	Quadrat area is one-half square meter (0.71 m x 0.71 m)
Taxon Present 1 (Y/N)?	Formula	=IF(ISTEXT(G2),"Y","N")
Other vegetation 1	Data	Other plants in quadrat, one name per column
Taxon Present 2 (Y/N)?	Formula	=IF(ISTEXT(I2),"Y","N")
Other vegetation 2	Data	Other plants in quadrat, one name per column
Taxon Present 3 (Y/N)?	Formula	=IF(ISTEXT(K2),"Y","N")
Other vegetation 3	Data	Other plants in quadrat, one name per column
Taxon Present 4 (Y/N)?	Formula	=IF(ISTEXT(L2),"Y","N")
Other vegetation 4	Data	Other plants in quadrat, one name per column
Plant Height-TOTAL (cm)	Data	Enter data in the column corresponding to how plant height was measured—either as total or above water. *If using this spreadsheet as an import configuration for WQX/AWQMS, include both column headings for plant height (TOTAL and ABOVE).*

[13] Notes pertaining to AWQMS/WQX users refer to the Ambient Water Quality Monitoring System (AWQMS) and WQX systems for managing and transferring data into the U.S. EPA STORET database.
[14] Unique identifier for a sample or measurement as consistent with AWQMS/WQX terminology

Column Headings	Data or Formula?	Formula and Notes
Plant height-ABOVE (cm)	Data	Enter data in column corresponding to how plant height was measured—either as total or above water. *If using this spreadsheet as an import configuration for WQX/AWQMS, include both column headings for plant height (TOTAL and ABOVE).*
Water depth (cm)	Data	Units are in cm
Number of stalks on sample plant	Data	Only needed if computing site- or area-specific biomass equation
Brown spot fungal disease	Data	(0, low, high)
Shoot_weight (Units in grams)	Data	
Root_weight_g	Data	
Viable seed weight_g	Data	
Viable seed number	Data	
Non-viable seed weight_g	Data	
Non-viable seed number	Data	
Number pedicels per PLANT	Data	
Number seeds with ergots	Data	
Number seeds with worm holes	Data	
Number of Total seeds found	Formula	Viable seed number + Non-viable seed number
Number of pedicels per STALK	Formula	Number pedicels per plant/# stalks per sample plant
Ratio Viable seeds	Formula	(Viable seed number)/ (#Total seeds found)
Ratio Non-viable seeds	Formula	(Non-Viable seed number)/ (#Total seeds found)
Viable seed weight average_g	Formula	(Viable seed wt_g)/ (Viable seed number)
Nonviable seed weight average_g	Formula	(Non-Viable seed wt_g)/ (NonViable seed number)
Average seed weight_g	Formula	[(Viable seed wt ave_g)*(Ratio viable seeds)] + [(NonViable seed wt ave_g)*(Ratio NonViable_seeds)]
Total seed weight_g	Formula	Number pedicels per PLANT * Average seed wt_g
Number of rice stalks **per 1.0 m^2**	Formula	**2 x** (Number of rice stalks per 0.5 m^2) *Note: This formula assumes using a quadrat with area equal to one-half square meter, as per*

Column Headings	Data or Formula?	Formula and Notes
		instructions in this Handbook. Dimensions would be 0.71 m x 0.71 m for a 0.5 m^2 quadrat.
actual plant weight PER STALK_g	Formula	(actual_plant_weight TOTAL_g)/ Number of stalks per sample plant
Actual plant weight TOTAL_g	Formula	(Shoot wt_g) + (Root wt_g) + (Total seed wt_g)
natural log plant weight per stalk_g	Formula	LN(actual plant weight PER STALK_g)
natural log total plant height_cm	Formula	LN(TOTAL plant height_cm)
natural log pedicels per stalk	Formula	LN(Number of pedicels per STALK)

	S	T	U	V	W	X	Y
1	Shoot weight (Units in grams)	Root weight_g	Viable seed weight_g	Viable seed number	Non-viable seed weight_g	Non-viable seed number	Number pedicels per PLANT
2	4.301	1.944	0.456	10	0.122	14	106

Figure 13. Example of data entered in the Lab Data portion of spreadsheet

	A	B	C	D	E	F
1	Date (MM/DD/YYYY)	Water body	Sample ID#	**Activity ID**	Number of rice stalks **per 0.5 m^2**	**Taxon Present 1 (Y/N)?**
2	10/15/2014	Name of Lake	RL08	Name of Lake:RL08:20141015	124	**Y**

Figure 14. Example of data entered in the Field Data portion of spreadsheet

	A	B	C	
1	**Variable**	**Description**	**General Notes**	**AWQMS - WQX User No**
29	Number of Total seeds found	Sum of all seeds found when plant when plant was collected	Viable seed number plus non-viable seed number	The remaining columns a biomass. For AWQMS - will be ignored when usi the existing import confi Region 5 Wild Rice Data
30	Number of pedicels per STALK	Number of pedicels per plant divided by the number of stalks on the plant being measured		
31	Ratio Viable seeds	Ratio of seeds considered viable according to proxy measure of amount of hull filled	Viable seeds were those with **half or greater** of the seed casing filled with a solid seed	
32	Ratio Non-Viable seeds	Ratio of seeds considered non-viable according to proxy measure of amount of hull filled	Nonviable seeds were those with **less than half** of the seed casing filled with a solid seed	
33	Viable seed weight average_g	Average weight of viable seeds		
34	Non-Viable seed weight average_g	Average weight of non-viable seeds		
35	Average seed weight_g	Average weight of seeds found adjusted for ratio that were viable vs. non-viable		
36	Total seed weight_g	Number pedicels per PLANT * Average seed weight_g		
37	Number of rice stalks **per 1.0 m^2**	**2 x** (Number of rice stalks per 0.5 m^2)	This formula assumes using a quadrat with area equal to one-half square meter, as per instructions in the Wild Rice Monitoring Handbook. Dimensions would be 0.71 m x 0.71 m for a 0.5 square meter quadrat.	
38	Actual plant weight per STALK_g	"Actual plant weight TOTAL_g" divided by "Number of stalks per sample plant"		
39	Actual plant weight TOTAL_g	Sum of shoots, roots, and seeds on sample plant		
40	Natural log plant weight per stalk_g	Natural log of plant weight per stalk	Log-transformed variable for creating site- or area-specific biomass equation	
	Natural log tot... ...eight_cm	Natural log of total plant height in centimeters	Log-transformed variable for creating site- or area-	

Main | **Metadata** | Sheet1

Ready 100%

Figure 15. Example of metadata

QA/QC (data quality control)

Always quality-check the data prior to beginning any analysis. Reasons why this is important:

- Because in every data set there are almost always errors. The sources may be human errors (such as in data entry) or sampling errors (such as instrument calibration or misuse).
- It saves time later. Data analysis takes time; you do not want to have to redo it. You want to be sure the dataset you are working from is not going to change. Even one decimal point out of place or too many zeros in a number can throw off statistics significantly and distort conclusions.
- Data checking helps identify outliers in your data set. Even 1-2 outliers can strongly influence statistics computed from your data.

STEP 1. Verify that the data were entered accurately. If you cannot read a handwritten number properly and don't have any way to check, then you should throw out that data point. If possible, have a different person from the one who entered the data, check every entry to make sure all values are entered correctly. One way to do this is to have the first person read off the numbers from the field and lab data sheets while the second person looks at the computer screen to verify the numbers. Alternatively, use a double-entry method, which will generally catch the most mistakes. However, it is more time-consuming that merely checking re-entered data. For the double-entry method, have the second person enter the data in a different spreadsheet. Use a "comparison" function to compare the two spreadsheets, which will automatically highlight discrepancies. Research the discrepancies and input correct numbers.

STEP 2. Calculate summary statistics: mean, median, standard deviation, and ranges.

STEP 3. Graph your data.

a. Research any suspicious data points, such as outliers. Outliers are usually defined as points that are more than 3 standard deviations from the mean. Some statistical packages will calculate and identify outliers. Even one high or low number can affect the computations (See Figure 16). If you do have outliers, go to 3b. If not, go to 3c.
b. Decide how to handle outliers. Whether or not to remove outliers depends on the statistical analysis. If they are valid data points, they should be kept. You should know why you're eliminating a data point and have a good reason, such as you suspect it to be an error or you think there was some interference with collecting the data point properly. One reason for eliminating a data points would be if you suspect operator error or an equipment malfunction. Always document removing any outliers and why you removed them. Adding a column to the metadata tab would be one way to record removal of data points. Go to 3c.
c. Look for unexpected relationships in the graphs which may indicate a problem with the data.

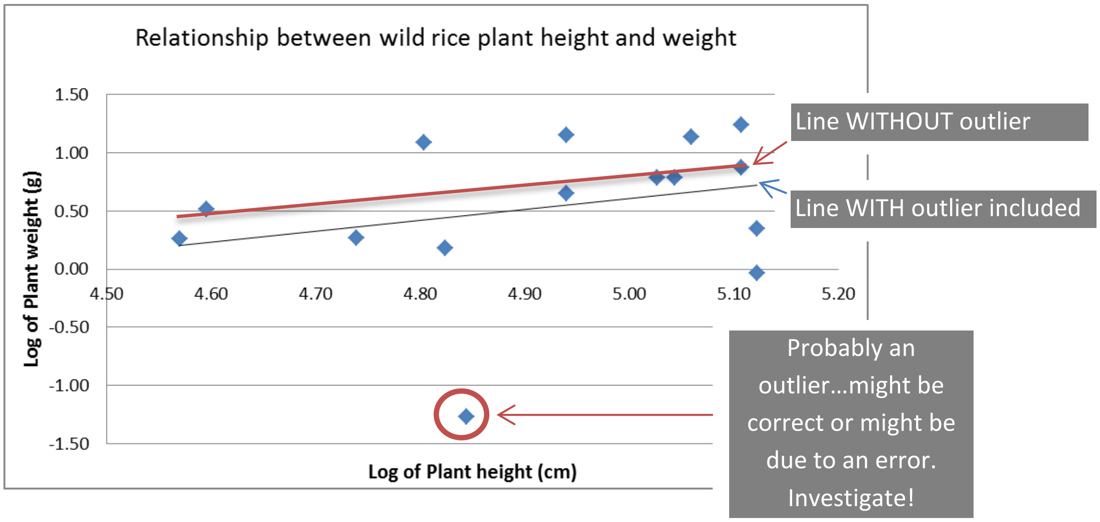


Figure 16. Illustration of outlier effects

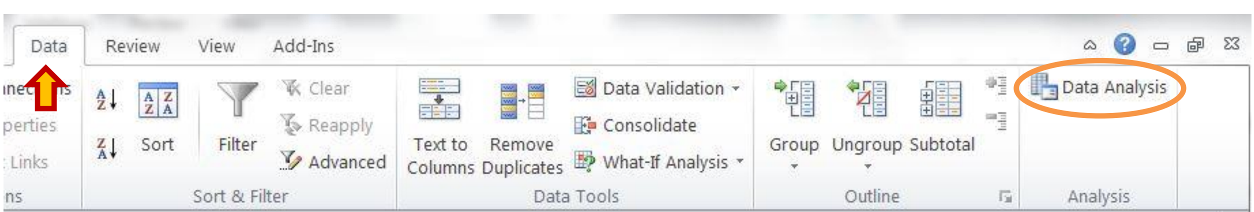
STEP 4. Another way to check for suspicious data points is to sort your data in each column from largest to smallest and check the high and low ends (being very careful to sort every column simultaneously so you don't disassociate the data across rows).

Calculate Biomass Equations

Verify that you have set up the spreadsheet properly. The list in Table 5 (page 65) shows the proper column headings and cell contents. The easiest way to do this is to use the spreadsheet available for download from the Minnesota Sea Grant website (www.mnseagrant.umn.edu/coastal_cities/wildrice).

Next, perform a linear regression with **natural log of plant height** as the x-axis (input variable) and **natural log of plant weight** on the y-axis (outcome variable). The steps below walk you through this process.

STEP 1. Click the "Data" tab in Excel and select "Data Analysis." This requires the free and downloadable Microsoft Data Analysis Toolpak if you are using Excel.

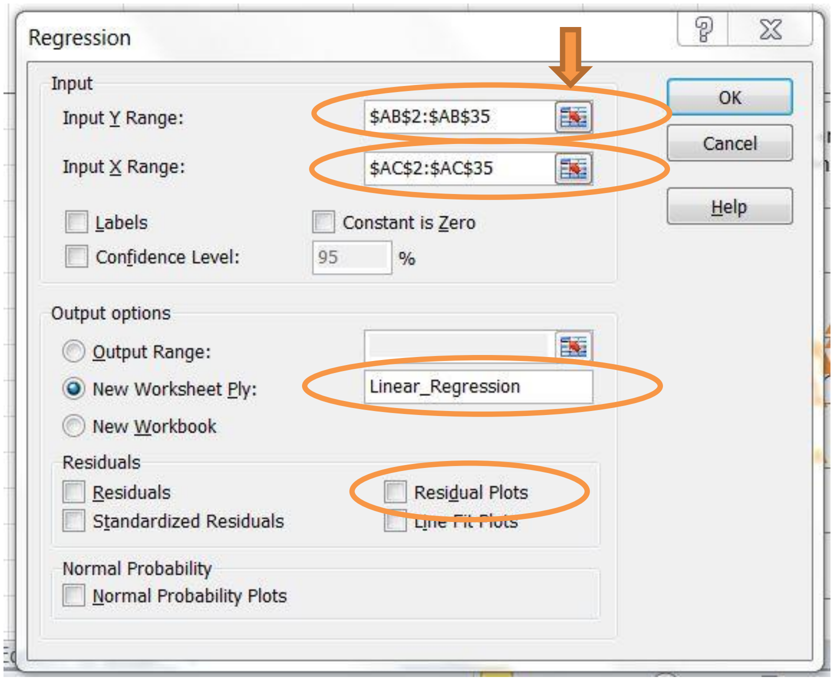


STEP 2. Select "Regression" from within the Data Analysis window. A new window pops up with options for setting up a linear regression (see below). Select the icon with the tiny red arrow and

highlight the “Input Y Range” which will be “natural log of plant weight”. Hit “Enter” to reselect the same icon to close the input window.

Repeat for entering “Input X Range.” The X data will be the “natural log of plant height.”

(Note: Alternatively, you can type range values directly in to the box. In the example below, the text to enter would be, $AB$2:$AB$35 for the Y Range).



Select “New Worksheet Ply:” and type in a meaningful title, such as “Linear Regression.” This will create a new tab in your spreadsheet to store the results of the regression.

STEP 3. Examine the results of the regression (see Figure 17 for an example).

Find the R-Square value. The R-Square (R^2) value represents the percentage of the change in the y direction (plant weight) that can be explained by changes in the x direction (plant height). If plant height were a perfect predictor of plant weight, the R^2 value would be 1. If the plant height predicted none of the variability in plant weight, the R^2 value would be 0. The higher the R^2 value, the stronger the relationship is between your “x” and “y” variables.

How high should the R^2 be? There are no hard and fast rules for how high an R^2 value needs to be, because it depends on how much predictability you need and on the type of data being compared. By looking at the R^2 values in the equations in this Handbook, you can get an idea of the range of values to expect using different types of plant data. Appendix C shows all of the linear regression equations for each of the lakes used to create the biomass equations, along with their R^2 values.

Next find the y-intercept and slope values. These will be used to create your final equation.

Find the P-value for the slope of the regression line (listed in the row labeled “X Variable 1”). The P-value and R-squared indicate whether the slope of the regression line differs from zero at the given level of significance. P-value should be 0.05 or less. If it's larger than 0.5, you may wish to collect more plants because you don't have enough statistical significance.

Remember, the "y" and "x" input values were natural logs of the plant height and weight, therefore to use this equation for directly computing plant weight from height in cm, you need do some algebra, as explained in Step 4.

Example of linear regression output

The figure below shows the result of a linear regression performed on data collected from the 5 lakes used to create Equation 1 (T. Kjerland analysis of data collected by Vogt, 2011 and Lewis, 2014.) The "R-Squared" value is circled, as are the intercept, slope, and p-value of the slope.

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.7795387
R Square	0.6076805
Adjusted R Square	0.6046627
Standard Error	0.4911812
Observations	132

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	48.58053	48.58053	201.3626	3.44182E-28
Residual	130	31.36366	0.241259		
Total	131	79.94419			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-11.615254	0.874831	-13.2771	5.89E-26	- 13.34600293	-9.88451	-13.346	-9.88451
X Variable 1	2.5536677	0.17996	14.19023	3.44E-28	2.197639163	2.909696	2.197639	2.909696

p-values << 0.001

Slope of the line

y-intercept

Figure 17. Linear regression results for relationship shown in Equation 1: natural log of plant height vs. natural log of plant weight

STEP 4. Create an equation based on the output of the linear regression. Your equation in the format $y = mx + b$, where m = slope and b = y-intercept. Example equation from linear regression above:

$$y = 2.55x - 11.6$$

STEP 5. Transform the equation you found in Step 4 so that the "y" input is simply plant weight in grams and the "x" is plant height in cm. This is necessary because the equation at this point is still using log-transformed variables.

You want to convert your equation from Step 4 to the following form:

Plant weight (g) = a(plant height cm)^m

The exponent "m" of this equation is exactly the same as the slope "m" of the linear regression. The coefficient "a" is e (2.7182), the base of natural logarithms, raised to the power "b" from the linear regression: $a = e^b$

To Transform Your Equation
START HERE → Example equation from linear regression: y = 2.55x – 11.6

Note: At this point, keep all digits for these calculations. Later, round the numbers to account for significant figures.

$$m = 2.55x$$

$$a = e^{-11.615} = 0.00000903 = 9.03x10^{-6}$$

Final Equation
Plant weight (g) = 0.00000903*(plant height, cm)$^{2.55}$

CONGRATULATIONS! YOU'RE DONE! From now on, you will be able measure only your "x" variable, such as "plant height in cm", and use your new equation to compute plant weight (biomass). Go to SOP#4 if you wish to learn more about using biomass equations.

To create biomass equation for pedicel number-weight: These same steps may be used for creating a biomass equation to relate pedicel number to plant weight. Use "natural log of number pedicels per stalk" (i.e. number of potential seeds) as the "x" variable when performing the linear regression. Use "natural log of plant weight per stalk_g" as the "y" variable.

Work an example problem for practice

Working through this problem will allow you to test out the linear regression methods and make sure you're doing the process correctly. To do the problem, open an Excel spreadsheet and follow the steps below:

STEP 1. Enter the following data as shown below.

Data for sample problem from Round Island Lake
(T. Kjerland analysis of data collected by Vogt, 2011.)

	A	B	C	AI	AJ
1	Date	Water_body	Sample_ID#	nat_log_plant _weight	nat_log_plant height
100	8/25/2011	Round Island Lake	RI01	0.27	4.72
101	8/25/2011	Round Island Lake	RI02	-0.16	4.88
102	8/25/2011	Round Island Lake	RI03	1.00	5.08
103	8/25/2011	Round Island Lake	RI04	-0.65	4.40
104	8/25/2011	Round Island Lake	RI05	-0.13	4.65
105	8/25/2011	Round Island Lake	RI06	0.53	4.98
106	8/25/2011	Round Island Lake	RI07	0.53	4.88
107	8/25/2011	Round Island Lake	RI08	-1.72	4.26
108	8/25/2011	Round Island Lake	RI09	0.42	4.76
109	8/25/2011	Round Island Lake	RI10	0.04	4.74
110	8/25/2011	Round Island Lake	RI11	-0.07	4.62
111	8/25/2011	Round Island Lake	RI12	0.30	4.78
112	8/25/2011	Round Island Lake	RI13	0.18	4.74
113	8/25/2011	Round Island Lake	RI14	0.43	4.90
114	8/25/2011	Round Island Lake	RI16	1.18	4.88
115	8/25/2011	Round Island Lake	RI17	0.05	4.84
116	8/25/2011	Round Island Lake	RI18	0.39	4.82
117	8/25/2011	Round Island Lake	RI19	0.49	4.74
118	8/25/2011	Round Island Lake	RI20	0.59	4.80
119	8/25/2011	Round Island Lake	RI21	0.14	4.69
120	8/25/2011	Round Island Lake	RI22	-0.12	4.84

STEP 2. Starting with STEP 1 above under the heading, "Calculate Biomass Equation," run through the steps using the data you entered.

STEP 3. The linear regression results are shown below. Check to make sure they match yours. Troubleshooting: If the results don't match, first check that you entered the data properly. Next, make sure you selected the correct columns on your spreadsheet when running the regression.

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.84019892
R Square	0.70593422
Adjusted R Square	0.69045708
Standard Error	0.33102324
Observations	21

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	4.997932	4.997932	45.6114	1.88119E-06
Residual	19	2.081951	0.109576		
Total	20	7.079883			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	-13.041295	1.958297	-6.65951	2.28E-06	-17.14005639	-8.94253	-17.1401	-8.94253
X Variable 1	2.77500479	0.410891	6.753621	1.88E-06	1.914999191	3.63501	1.914999	3.63501

STEP 4. Transform the equation because the variables are in a log-transformed format at this point.

START HERE → Equation from linear regression: $y = 2.775x – 13.041$

$m = 2.77$ (Slope =“X Variable 1”)

Intercept = -13.041

$a = e^{-13.041} = 0.00000217 = 2.17 \times 10^{-6}$

Final Equation for Sample Problem – FOR ILLUSTRATION PURPOSES ONLY

Plant weight (g) = (2.17×10^{-6})*(plant height, cm)$^{2.77}$

Biology of Wild Rice

This section provides a brief introduction to the biology of wild rice. Particularly useful references include: Aiken, et al. (1988) "Wild Rice in Canada"; Vennum, (1988) "Wild Rice and the Ojibway People," and Dore, (1969) "Wild Rice."

LIFE CYCLE

Wild rice is an annual plant. Wild rice (*Zizania palustris*[15]) seeds sprout and grow an entirely new plant each year. Some wild rice plants have been known to grow up to 10 feet tall! And this astonishing feat happens without roots from the prior year to "jump start" growth in the spring.

Once mature, wild rice seeds fall from the parent plant into the water and sink quickly down into the sediment. Their aquadynamic shape and weight aids them in moving easily through the water. Wild rice seeds have sharp barbs on one end called "awns" that act like rudders and help drill the seeds down into the muck by keeping them vertical as they fall through the water.


Tonya Kjerland

Because they are heavy, seeds usually don't fall too far from the parent plant, which helps insure that they land in a spot where they can grow. The exception is when currents are swift, such as in rivers, or in high winds, or when seeds are carried by birds or animals.

The average height and weight of rice plants on Big Rice Lake in St. Louis County, Minnesota was 1.5 m (~5 feet, from sediment to height of tallest stalk) and ~6 grams (0.01 lbs). over the past 16 years[16]. For more examples and information about variability, see "Case Study: 1854 Treaty Authority – Results of Long Term Monitoring of Wild Rice."

Overwintering. Wild rice seeds only germinate under conditions that mimic being buried in aquatic sediments over a winter or with scarification. Normally, seeds must be kept cold and wet for a period of about 3 months in order to germinate. Desiccation of seeds reduces germination rates considerably. Another way to break seed dormancy is to scrape away the pericarp by hand or mechanically, which is called "scarification."

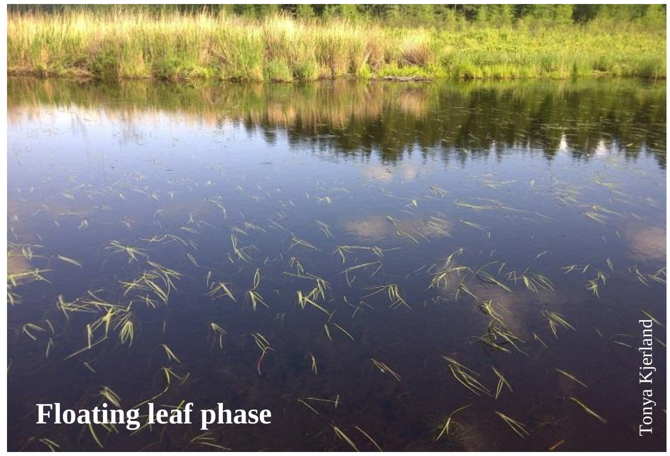
The emerging seedling phase (~late April, early May in northern Minnesota). In the early spring, wild rice seeds germinate, probably triggered by temperature, chemical, and light cues in their surroundings. The seed sends a shoot upward at the same time that it sends other shoots downward into

[15] A note on taxonomy. The taxonomy has not always been clear within the literature. For one thing, northern wild rice (*Zizania palustris*) and southern wild rice (*Zizania aquatica*) are frequently confused. Refer to Aiken, et.al. (1988, pp. 21-38) for more on this subject.

[16] The average height and weight is based on data collected between 1998 and 2014 by the 1854 Treaty Authority (Vogt, 2014.) Weight was computed from height using the "Number of Sample Points Equation". The sizes of these plants may not reflect their natural historic sizes due to possible human impacts, including numerous mining operations in the area.

the sediment. The upward growth of the stem growing towards the surface of the water is prioritized energetically over root elongation. This is because the plant must reach the surface of the water and produce aerial shoots in order to be able to reproduce.
The shoot growing upward towards the light relies on nutrients transferred from the sediment by the early small root system and the seed's own stored energy to grow new cells. If the water is too deep, the plant might take too long to reach the surface, and become dormant, die or not be able to generate enough energy to reproduce before the season ends.

Floating leaf phase (~May to early June).
As soon as the first and only stem (at this point) reaches the surface of the water, the plant sends out two or more leaves along the surface. These leaves develop a waxy cuticle (covering) on one side and stomata (openings to allow for gas exchange of O_2 and CO_2) on both sides, primarily on the top surface (John Pastor, personal observation). Once the floating leaves begin to develop, the plant can use them to photosynthesize more efficiently than is possible under water. Photosynthesis is the means by which plants convert energy in the form of light into biologically-usable energy. At this point, the plant puts more energy into root development to create a foundation for producing aerial (above water) shoots.



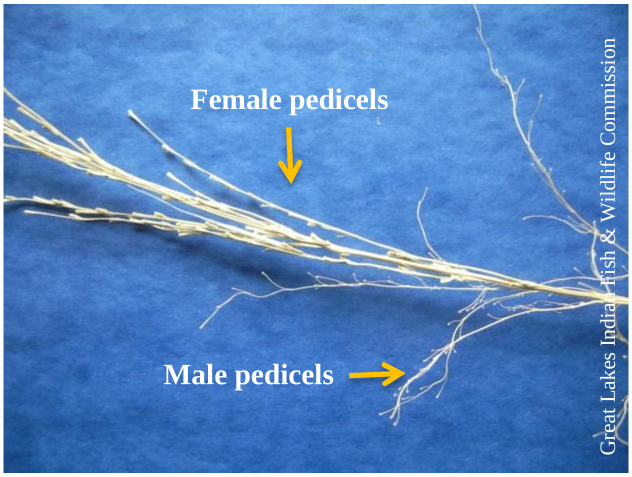
This is a critical phase for wild rice survival. The floating leaves are like buoys attached to the roots. If the water level rises suddenly, or there is choppy water as from a storm or wakes from passing motorboats, the young plant may be easily uprooted because the root system is still not fully developed, and waves create a force against the floating leaf which can uproot the whole plant. Rapidly-rising water levels that remain high may also damage the plant due to the increased difficulty of photosynthesizing under water. If the water level rises gradually, plants may be able to recover by growing taller.

Aerial leaf phase (~ mid June to July). Once root development is sufficient, the plants begin sending shoots up out of the water. Nutrients and sugars are retracted from the floating leaves and used to build shoots whereupon the floating leaves die.

At this point, the plant is able to produce sufficient resources from the energy generated by photosynthesis and nutrients in the sediment. The plant sends up one or more stems that have reproductive structures at the top. The main stem will likely have the most seeds, but there may be many additional stems with seed heads. Factors affecting the number of stems include water depth, nutrient availability, and space to grow.

Reproductive phase (~early to mid August). The female flowers mature earlier than the male flowers, ensuring that the female flowers will be ready for pollination when pollen is available. Male flowers are located below the female flowers on the stem. This helps decrease self-pollination and encourages cross-pollination with other plants because the pollen is shed below the female flowers. Pollen is generally dispersed by wind, although flies, bees, and other insects gather wild rice pollen and may secondarily fertilize female flowers, according to unpublished observations. However, little is known about insects gathering wild rice pollen.

Once female flowers are pollinated, they immediately start forming seeds. The seeds will be tightly held against the seed head at first, and will begin as empty seed hulls. As the seed grows, it fills in the hull and becomes firm. A viable seed is one which will germinate. For the purposes of this Handbook, viable seeds are considered to be those with half or more of the seed hull filled/solid. Each seed grows on a stalk called a pedicel. The male flowers also grow on pedicels, but these are smaller and more delicate compared to the female flowers.



Helpful Tip: The female pedicels are larger and sturdier and are located above the male structures on the stem (see photo, left). Because seeds fall off continuously, counting pedicels is the best way to estimate total seed production. When counting, it is important to count only the female pedicels.

Milk phase (~mid to late August). During the milk phase, the seeds become solid inside and appear plump, but when broken open will be filled with a milky white substance.

Mature phase (~early to mid September). Like berries, the seeds ripen gradually in sections. Due to the gradual ripening of seeds, it is possible to harvest multiple times from the same plants over 2-3 weeks. Seeds are considered mature and viable when the hull is at least halfway filled with solid seed. At this point, the seeds will be easily removed from the stem. High winds at this phase can destroy a harvest in a matter of hours by knocking the seeds from their pedicels. The color of the plants turns from bright green to a lighter, more subdued green, and then to golden amber.

Senescent phase (starts late September to early October). Once plants have lost nearly all of their seeds, stems begin to dry out, rot, and bend over, sinking back into the water. In some places where there are slow currents and dense production for many years, the sediment becomes covered with a thick mat of decaying wild rice. This does not seem to hinder the development of seeds in the coming spring, and instead tends to correlate with highly productive areas, according to anecdotal observations. Wild rice plants take a year or longer to decay and release nutrients for the next generation, which research has shown contributes to annual population variability.

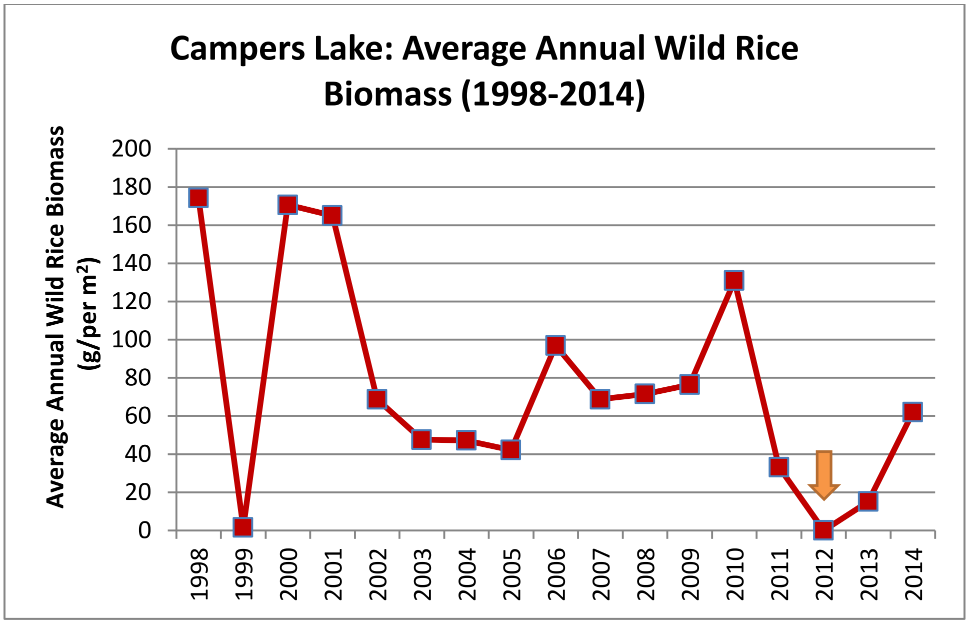
VARIABILITY

Wild rice growth varies greatly from year-to-year in amount and spatial distribution. Many sources have reported a 3 to 5 year cycle in amount of wild rice produced. Analysis of 15 years of data collected by the 1854 Treaty Authority in northeastern Minnesota showed that these lakes often had years of high production followed by a crash and several years of recovery, as well as other, less defined patterns (T. Kjerland analysis of data collected by Vogt, 2014.) These results suggest that abundance and distribution commonly vary in natural wild rice stands.

The documented variability in productivity across years is a clear indication that measurement of a wild rice population needs to be based on several years of data. Due to the lack of knowledge about wild rice populations, more research on these patterns is needed to gain a better understanding of the mechanisms that control variability in wild rice productivity.

Wild rice seeds can remain dormant over a growing season, and probably for 5 years or more. No one knows how long wild rice seeds remain viable in the sediment in natural settings. Evidence for survival of seeds in sediments is demonstrated by cases in which an entire water body becomes barren of wild rice for one season, and then the following year makes a recovery to former, or near former, production levels.

A case in point is Campers Lake in Lake County (MN DNR ID# 38-0679 00), which had no wild rice growing on in it 2012. The following year, the wild rice returned to a greater-than-average cover of 96% and an average biomass of 15 grams per square meter. A similar event happened in 1999 on this same lake, with a full recovery the following year. (See Figure 18)



T. Kjerland analysis of data collected by Vogt, 2014

Figure 18. Wild rice biomass on Campers Lake over 16-years illustrates the variability that can be seen in wild rice populations and the recovery possible from buried seed.

Note: On average, 20 quadrats were measured for all years except 1999, when only 6 were measured due to a low percentage of lake coverage (~6%) by wild rice (Vogt, 2014).

Many water bodies that historically supported vast stands of wild rice have become less productive or even totally lost their wild rice due to human impacts and natural disturbances such as beaver dams. More research is needed to understand conditions and mechanisms that lead to successful wild rice restoration. The successes that have been achieved demonstrate that, when suitable wild rice habitat is restored, these areas can become productive wild rice stands again.

WILD RICE HABITAT

Aspects to consider:

- Water Quality
- Water Depth
- Water Flow
- Sediment
- Plant Community Interactions

Water Quality

Wild rice is considered to be a bio-sentinel for water quality due to its tendency to thrive under specific conditions. If you are interested in measuring effects of water quality on wild rice, you should consider the whole system. Differing conditions of water chemistry have been recorded within wild rice stands compared to open water areas, but these fluctuate considerably with the seasons. In general, water

quality is highly variable across time and location, so it is important to measure it over the entire growing season and in conjunction with quantifiable measurements of wild rice growth. Methods described in this Handbook may be adapted for use throughout the growing season.
Surface water chemistry influences wild rice growth through mechanisms taking place largely in bottom sediments, so sediment characteristics and chemistry should be studied concurrently with water quality. Water flows should also be measured due to the effects of hydrology on sediment transport and transport of associated water-borne particles or elements.

In theory, because it rapidly takes up large amounts of nutrients, wild rice might also *affect* water quality in ways that are beneficial for the ecosystem as a whole. While it is beyond the scope of this Handbook to review the research on water quality and wild rice, this section considers two cases that illustrate complex interactions.

The case of sulfate/sulfide serves to illustrate an important set of interactions between water chemistry, sediments, and wild rice growth. The case of nutrients—phosphorus and nitrogen— explains the most likely mechanism for population oscillations and demonstrates interactions between nutrient availability, decomposition of wild rice detritus, and wild rice productivity. Both cases show the importance of considering the big picture of how the various parts of the system interact through space and time to better understand how water quality affects the condition and extent of wild rice beds.

Sulfate/Sulfide. Recent research regarding the effects of sulfate on wild rice shows that when plants are grown in water with elevated levels of sulfate, each successive generation produces fewer seeds, and a smaller proportion of viable seeds[17]. The same study found other negative effects of increased sulfate, including a reduced germination rate and decreased survival of seedlings. In other words, each successive year of exposure to high sulfate in surface or ground water levels leads to further decreases in the plants' ability to thrive and reproduce. In natural stands, the effect of elevated levels of sulfate is expected to be a continual reduction in the amount of wild rice plants and their reproductive ability.

Although the mechanisms for how elevated sulfate in surface water affects wild rice are still being studied, recent research supports the hypothesis that the conversion of sulfate to sulfide in anoxic bottom sediments is the cause of these detrimental effects (Summary report of the meeting to peer review MPCA's *Draft analysis of the wild rice sulfate standard study* by Eastern Research Group, 2014).

GLOSSARY
Anoxic means a lack of available oxygen for biological processes such as respiration. Anoxic sediments are common in wetlands and many other aquatic environments. An anoxic environment develops due to the normal functioning of bacteria in the process of decomposing biological materials.

Sulfate, which is the common form of sulfur in surface and ground waters, is converted to sulfide in anoxic environments by sulfate-reducing bacteria. This occurs in a region of the sediment where reduction of sulfate to sulfide is the favorable form of respiration for bacteria, which has been referred to as the sulfidic zone (Canfield and Thamdrup, 2009). In an environment without oxygen, these bacteria in sediments convert sulfate to sulfide as part of their natural life cycle of decomposition and respiration.

[17] This section on water quality draws from Pastor (2013) and Moyle (1944).

Sulfate occurs naturally in rocks. It is also discharged and regulated in various industrial processes, such as domestic waste water treatment plants. When rocks high in sulfur are brought to the surface, as in taconite or copper-nickel mining, this brings with it the likelihood that water from the mining operation or leaching from overland runoff will carry high amounts of sulfate into streams and lakes.

Minnesota has a sulfate standard for wild rice waters of 10 mg/L. This standard was established in 1973 based on a scientific survey conducted in 1944 by John Moyle, a respected Minnesota DNR biologist. Moyle sampled waters across the state of Minnesota and showed that while wild rice thrived in waters with low sulfate, no large productive stands existed in waters with sulfate levels higher than 10 mg/L, or 10 ppm. Recent research commissioned by the State of Minnesota and conducted by several research teams from the University of Minnesota strongly supported the science behind this standard ((Summary report of the meeting to peer review MPCA's *Draft analysis of the wild rice sulfate standard study* by Eastern Research Group, 2014).

At the writing of this Handbook (Spring 2015), the Minnesota Pollution Control Agency has put forth a draft proposal recommending a new sulfate standard for wild rice waters. Analysis of the proposal is outside the scope of this Handbook.

Nitrogen and Phosphorus. Nitrogen is the most likely limiting nutrient for the production of wild rice, and phosphorus is likely the second-most limiting nutrient.

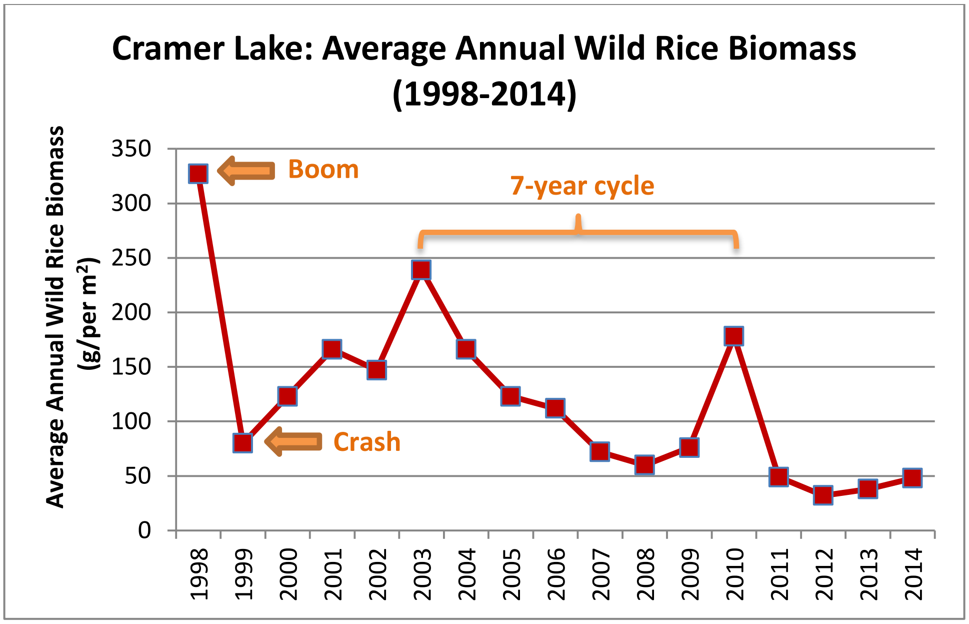
What this means is that even if all other conditions are right for growth, without sufficient nitrogen, the plant's growth will be limited.

Besides recycling existing materials in the system, the primary naturally-occurring sources for nutrients in wild rice waters are surface runoff from the land and ground water inflows. Many land use factors affect the amount of nutrients that will be carried into the water from the land such as amount of erosion, amount of agriculture, use of suburban fertilizers, wastewater treatment plants, etc. Other examples of factors affecting nutrient transport are topography (height and slope of land), morphology (shape of the lake or stream), number of inlets, flow rates, and amount/rate of precipitation.

Wild rice tends to grow best when there is an adequate but not over-supply of nutrients. Too much phosphorus or nitrogen in the water column may lead to increased competition from plants that are able to draw nutrients directly out of the surface water, such as floating-leaved plants. Wild rice gleans its nutrients from the root-sediment zone.

Population patterns.[18] Wild rice harvesters and biologists have long observed that wild rice populations show patterns that resemble cycles. These cycles are not always observed in natural wild rice stands, and vary across sites, but, in general, the cycle consists of a "boom" year of great production followed by a population "crash" to very low levels, then two to three years of recovery, and another boom year (Figure 19). These patterns are sometimes called population oscillations, and are common in natural populations of many plants and animals.

[18] This section on population oscillations draws upon research by Grava and Raisanen (1978), Sain (1984), Walker et al. (2006) and Walker et al. (2010.)



T. Kjerland analysis of data collected by Vogt, 2014

Figure 19. Population variability pattern on Cramer Lake in Northern Minnesota illustrates cycles that have long been observed by wild rice harvesters and biologists.

Why does this happen? In the absence of other mitigating factors, population oscillations may be regulated by nitrogen availability and plant decomposition in the root zone of bottom sediment (Walker, et al. 2010).

To understand what this means, it is important to know how decomposition works. Decomposing vegetation is often referred to as “straw” or “litter.” Bacteria are the primary decomposers of wild rice straw, although small invertebrates and fungi also likely play a role in the process. The rate at which they decompose the straw is affected by its chemical composition, such as the ratio of carbon to nitrogen. As bacteria decompose wild rice, they essentially “feed” on the straw and incorporate nitrogen from the straw as well as from the water and sediment into their cells. Thus, less nitrogen remains available for the plants to take up via their roots because it is tied up in bacteria.

Eventually, the straw is mostly decomposed. Gradually, the nitrogen gets released back into the sediment in a usable form (mostly as ammonium) which is again available for plants to use.

The timing of all this is important. If the litter nitrogen isn’t recycled back into the root zone environment in a form usable by plants when they need it, then plant production may be reduced.

Decomposition rates vary for different types of plants and, consequently, so does the timing of the release of “available” nitrogen. Wild rice has been shown to decay slowly over the course of about one year, with dead roots taking even longer due to their higher concentrations of lignin, which is harder to decompose.

To understand this process, it is important to understand the timing of when nitrogen is needed in the wild rice growth cycle. Wild rice has the highest nitrogen needs about 1.5 to 2.0 months after seedling emergence, and again during seed production. The amount of nitrogen available at that time will have a strong effect on the amount of wild rice produced. Since wild rice takes a year or more to decompose, the nitrogen from the previous year's straw is still "immobilized" in the bacterial biomass during the following year of growth.

When large amounts of wild rice straw are produced, most of the available nitrogen in the system remains in the plant litter until after the growth spurt for the following year is over. Without enough nitrogen to grow, the following year's crop is strongly nitrogen limited and a "crash" in production occurs. However, by the following year, the nitrogen bound in bacteria is released as the bacteria die as they exhaust their food resources. The wild rice populations begin to recover gradually until the next highly productive year, whereupon the cycle starts again.

Note that this description of wild rice growth and nitrogen recycling in the bottom sediments is somewhat idealized since nitrogen dynamics are one of many factors that affect wild rice productivity. Examples of other factors include water levels, water quality, storms, temperature, wind, wave action, and more. More research is needed to better understand the main causes of variability in the distribution and abundance of wild rice.

Water Depth

Wild rice grows across a limited range of water depths. It is important for the wild rice to be able to get high enough out of the water soon enough after ice-out to produce seeds before the season ends. According to analysis of points sampled for six lakes in Minnesota and Wisconsin, up to four feet (~1.2 m) in August-October is the maximum depth for most stands of wild rice[19]. Michigan may have a larger range of desirable depths due to the ranges and hybridization of two species of wild rice of varying sizes: *Zizania palustris* and *Zizania aquatica*, which predominate in northern and southern Michigan, respectively. No studies designed to analyze maximum rooting depth of wild rice were found at the time of writing of this Handbook.

Water depths that are either too high or too low during the critical growing periods, especially during the floating leaf stage, will hamper wild rice growth. However, plants are quite adaptive to water depths, and respond to water depth changes by allocating more or fewer resources to adding height. Observers report that wild rice seeds will also remain dormant when the water depths are too high, indicating some mechanism (such as pressure) may dampen germination in poor growth conditions. Wild rice seeds require water deep enough to allow them to grow to the emergent state, but once the stalks are strong enough the plants are likely to be able to sustain themselves in fairly low depths.

[19] This sample set included 4 lakes in northeastern Minnesota and two in Wisconsin as described in the section on wild rice biomass equations.

Water depth averaged only ~0.37 cm (14.4 inches) in the most productive part of the Vermilion River (Table 6). An interplay between water depth, current, nutrient supply, and variability throughout the year is likely important. Also, water depth affects the makeup of the community of plants and thus the level of competition.

Table 6. Water depth comparison chart of wild rice stands and water depths

During the top 10 most productive years, water depth ranged between 37 and 95 cm in a set of water bodies from northern Minnesota*

Lake Name	Year	Average Annual Wild Rice Biomass (g/m^2)	Average water depth at time of wild rice sampling (cm)	Number of quadrats sampled
Vermilion River	2006	749	37	19
Vermilion River	2002	586	69	22
Vermilion River	2008	468	66	20
Stone Lake	2001	467	66	20
Stone Lake	1998	440	59	20
Breda Lake	2001	385	77	20
Vermilion River	2004	384	50	22
Vermilion River	2013	379	43	20
Breda Lake	1998	343	70	20
Stone Lake	2002	331	95	22

*Data collected by the 1854 Treaty Authority on 9 lakes and 1 river in Minnesota (1998-2014). Water depth was collected at the same time as wild rice data in August/September.

Helpful Tip: Water depth should be measured over the entire growing season and at points coinciding with wild rice stands.

Water Flow

Research and common wisdom suggests that wild rice requires some water flow to do well, possibly due to input of nutrients and oxygen provided by currents[20]. Wild rice tends to grow best near inlets and outlets. Stagnant waters do not support wild rice populations.

Water flow rates and spatial patterns generally have a large impact on the amount of sediment transported and where it gets deposited. Sedimentation rates may be an important determining factor in the availability of nutrients and minerals that wild rice needs to grow. The transport of sediment is affected by many factors such as shape of the lake or stream. While some current is helpful, too much can lead to “sediment scouring”, in which softer, more organic materials are flushed away so that the area no longer supports wild rice.

[20] This section on water flow draws from research by Meeker (1996).

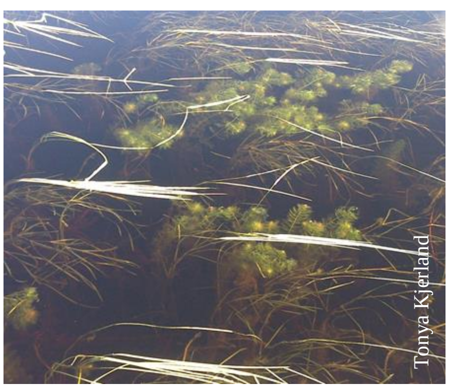
Sediment

Research has shown that wild rice grows over a wide range of sediment types, but there is disagreement over the conditions in which wild rice does best.[21] The characteristics of the sediment that seem to matter most include:

- **Texture**—the sediment must be soft enough for roots to penetrate, but not too soft. Hard substrates may be unsuitable mainly due to a lack of nutrients rather than to the inability of roots to take hold. Soft sediment is generally better, and wild rice seems to thrive in some sites that are too soft for other species.
- **Amount of organic matter**—wild rice generally does better in organic sediments
- **Amount of available nutrients**— wild rice is both influenced by nutrient availability while in turn affecting nutrients due to plant uptake and litter decomposition. The supply rate is what matters most, but this is difficult to measure—and not the same as measuring standing pools of nutrients. For these reasons, while nutrients in sediment are important, it is difficult to list optimal levels.
- **Oxygen levels/Redox potential**—lower growth in anoxic sediments (see Sulfate/Sulfide).

In determining where unsuitable sediment conditions may be affecting wild rice habitat, consider historical records as well as current uses of the waterway. For example, certain types of boating activity such as duck hunting in the fall, churn up the sediment. Some level of this activity may be helpful to wild rice growth if it distributes wild rice seeds more broadly. During other times of the year, boating activity is likely to be harmful, such as from high wakes uprooting young plants, removal of wild rice around docks, or chopping up the plants with motors. Research in many U.S. lake areas has pointed to the significance of boat wakes in degrading nearshore habitats.

Effects of sedimentation, i.e. the deposition of sediment over time, on wild rice have not been studied extensively. Evidence suggests that wild rice prefers flowing water and may alter local sedimentation patterns as it grows. Sediment would be expected to have a positive effect due to the transport of nutrients from land and upstream. However, sediment deposition may have a negative effect if it causes the burial of seeds too deeply for germination. The ability of wild rice to survive in the sediment for mulitple years may be a natural protection against seed burial, and also may explain why it has been reported that churning up sediment (i.e. a moose running through a wetland) may result in fresh growth where previously there was none. More research is needed to understand the effects of sedimentation on wild rice growth.



PLANT COMMUNITY INTERACTIONS

This Handbook recommends identifying other plants as an important parameter for wild rice monitoring plans because, while other plants are suspected to have effects on wild rice, not much is known about how this happens or which species are most influential. Observations suggest that certain types of vegetation

[21] This section on sediment draws from research by Lee and Stewart (1984), Lee (1986), Aiken et al. (1988), Day and Lee (1989), Painchard and Archibald (1990), Lee and McNaughton (2004).

have negative effects on wild rice, creating areas of lower density or no wild rice. On the other hand, wild rice is frequently found growing productively with other plants. More research is needed to understand the species that have positive, neutral, or negative impacts on natural stands of wild rice.

Wild rice plants must compete for space, light, and nutrients with other plants. In some situations, wild rice may be disadvantaged by being an annual which must grow from a new seed each year. When wild rice populations crash or have a bad year, this opens up the space for perennials to take over the space. Perennial plants have roots left over from the previous season, which gives them an advantage in being able to grow more quickly in the early season, sometimes shading or crowding out wild rice seedlings and reducing survival.


Great Lakes Indian Fish & Wildlife Commission

Besides space and light, plants compete for limited nutrients from the sediment. Plants that are most efficient at "harvesting" nutrients from the sediment due to their root structures or other efficiencies will have a better chance to thrive.

From a management perspective, it is important to keep ecological systems intact and avoid drastic actions (i.e. winter drawdowns) when it is unclear what impact these actions will have on the ecosystem. Little is known about wild rice interactions with other plants, and even less is known about interactions with animals such as aquatic insects, bacteria, frogs, turtles, or muskrats. Wild rice naturally thrives within highly a diverse population of other plants and animals.


Fond du Lac Band of Lake Superior Chippewa

Case Study: 1854 Treaty Authority in Minnesota – Results of Long Term Monitoring of Wild Rice

This section demonstrates ways to analyze data collected using methods described in this Handbook. Results are presented from a set of four wild rice waters: Breda Lake, Kettle Lake, Round Island Lake, and Vermilion River. Since 1998, the 1854 Treaty Authority has monitored wild rice waters using methods that are nearly identical to those described in this Handbook (Vogt, 2014).

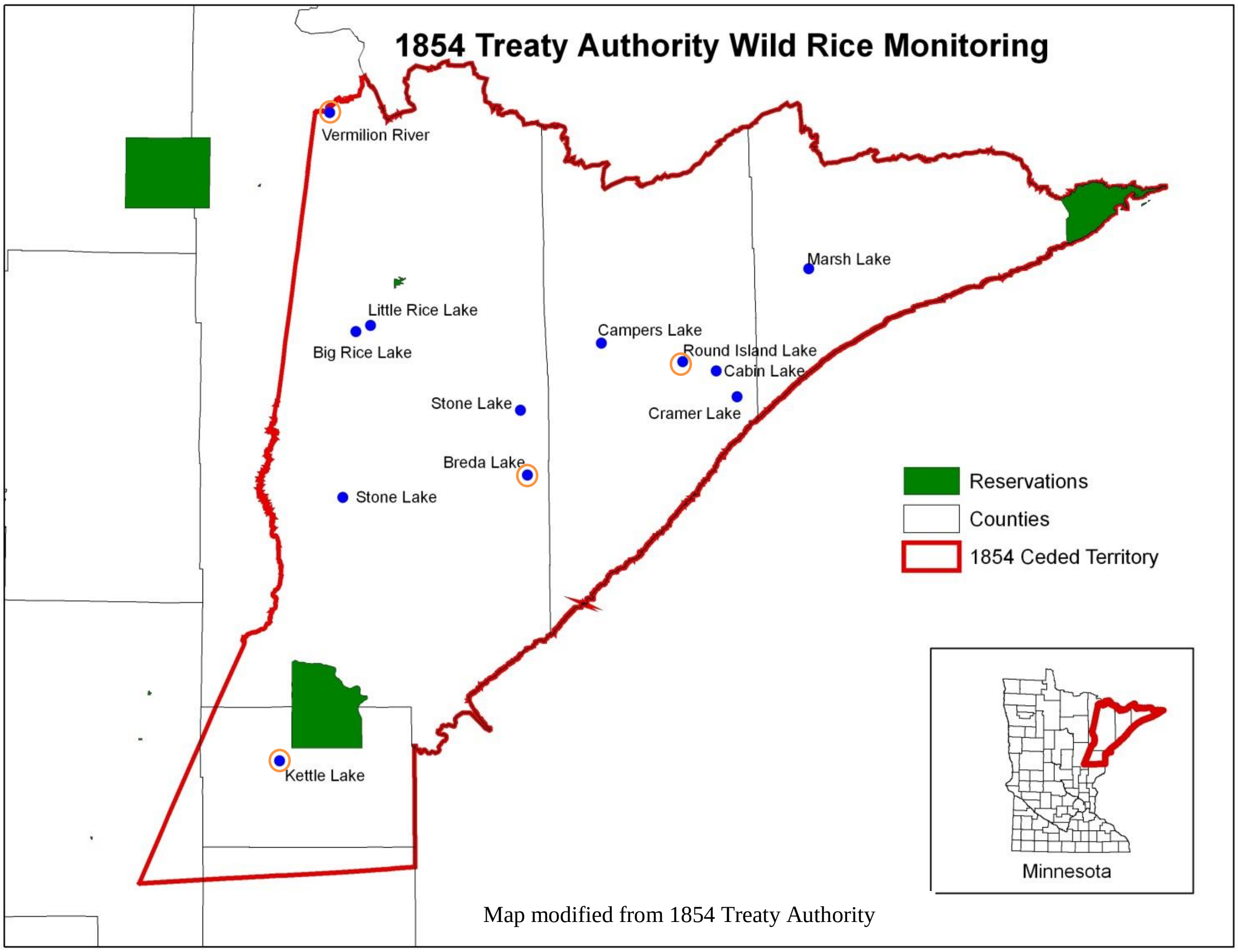


Figure 20. Map of wild rice water bodies where detailed monitoring is conducted annually by the 1854 Treaty Authority

Breda Lake

DNR # 69-0037 00

Context. Located in St. Louis County, Breda Lake is a 137 acre (55 hectare) lake. Petrel Creek flows into and out of Breda Lake, and is fairly large. For this reason, the lake is subjected to highly variable water level fluctuations. Breda Lake is shallow; typically less than 3 feet deep across the whole lake. Most or all of the lake can produce rice, but there is often sparse rice or other vegetation (such as water lily) dominating the south end. Although the access is by a 30 minute paddle down Petrel Creek to the lake, it can have heavy use by wild rice harvesters, and some use by duck hunters. There is no public access or development around the lake. Management efforts have included wild rice seeding in the past by the U.S. Forest Service. There has also been some cutting and prescribed burning on a small island area on the north end in an effort to improve waterfowl habitat.

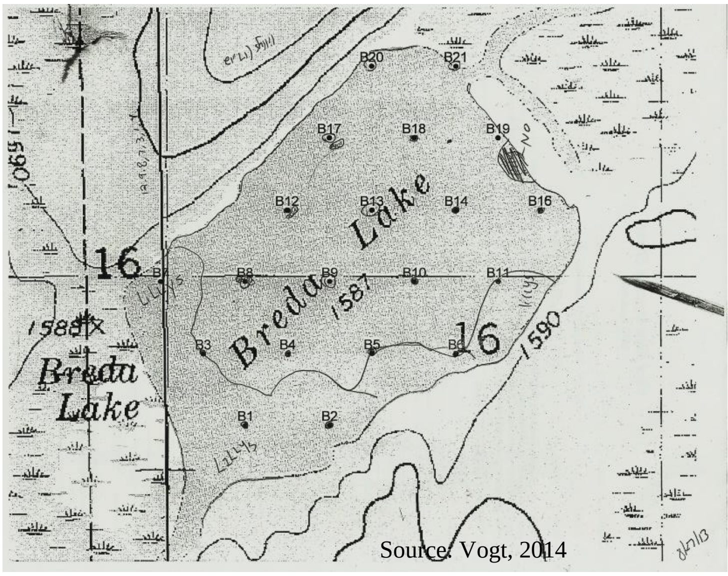


Figure 21. Topographic map showing wild rice sampling points on Breda Lake

Computing biomass. For each water body in this case study, the average annual wild rice biomass amounts were calculated using the "Biomass Equation 1" from this Handbook. Biomass equations are explained in the Sampling Design section. Biomass values represent grams per square meter as measured using 0.5 m^2 quadrats (photo, right). The same sample plots were measured every year, as shown on the map above in

Figure **21**. Quadrats with areas of 0.5 m^2 were used in this study, but to make the data easier to talk about these values were multiplied by 2 to be shown as biomass per 1.0 m^2.

Biomass. Population cycles of 3-6 years are evident in the Breda Lake system. A crash in production in 2015 or 2016 to below 50 g/m^2 would be expected based on this pattern. However, other factors such as weather or flooding might change the actual outcome.

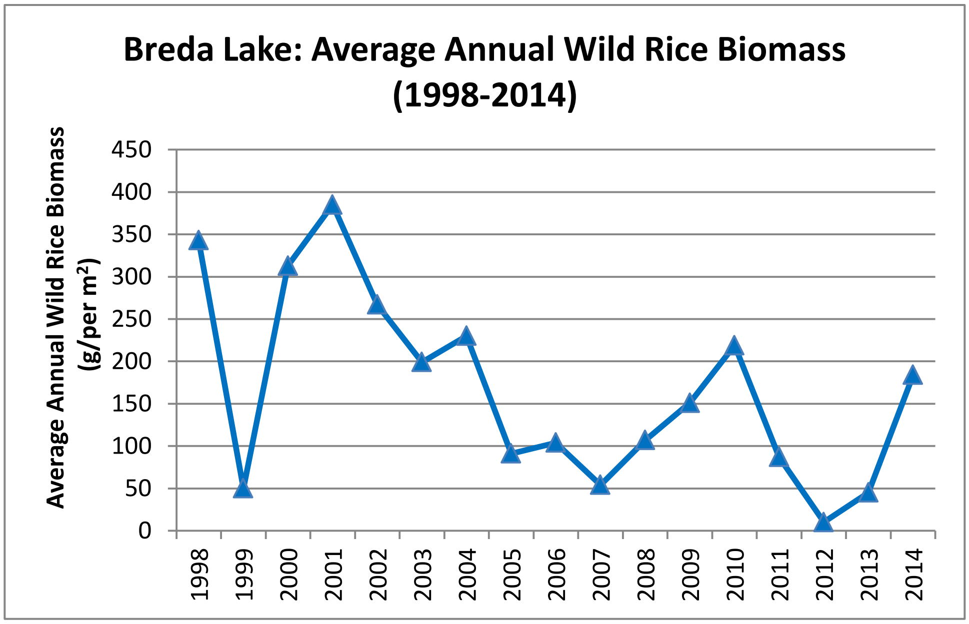


Figure 22. Trends in average wild rice biomass on Breda Lake show population cycles of 3-6 years.

Spatial analysis is useful for relating biomass to other spatial factors such as plant competition, land use or stream inflows. Maps below show the highest biomass areas in red and the lowest areas in green. These maps were created with ArcMap using the inverse distance-weighted (IDW) interpolation method. This means that biomass between quadrats was estimated using a mathematical calculation.

To incorporate spatial analysis into your work, it is recommended that each year wild rice beds be delineated using a GPS. While mapping wild rice beds with a GPS is highly subjective (and takes time), it is needed for doing interpolations in spatial analysis. The accuracy level does not need to be any greater than the distance between sample points.

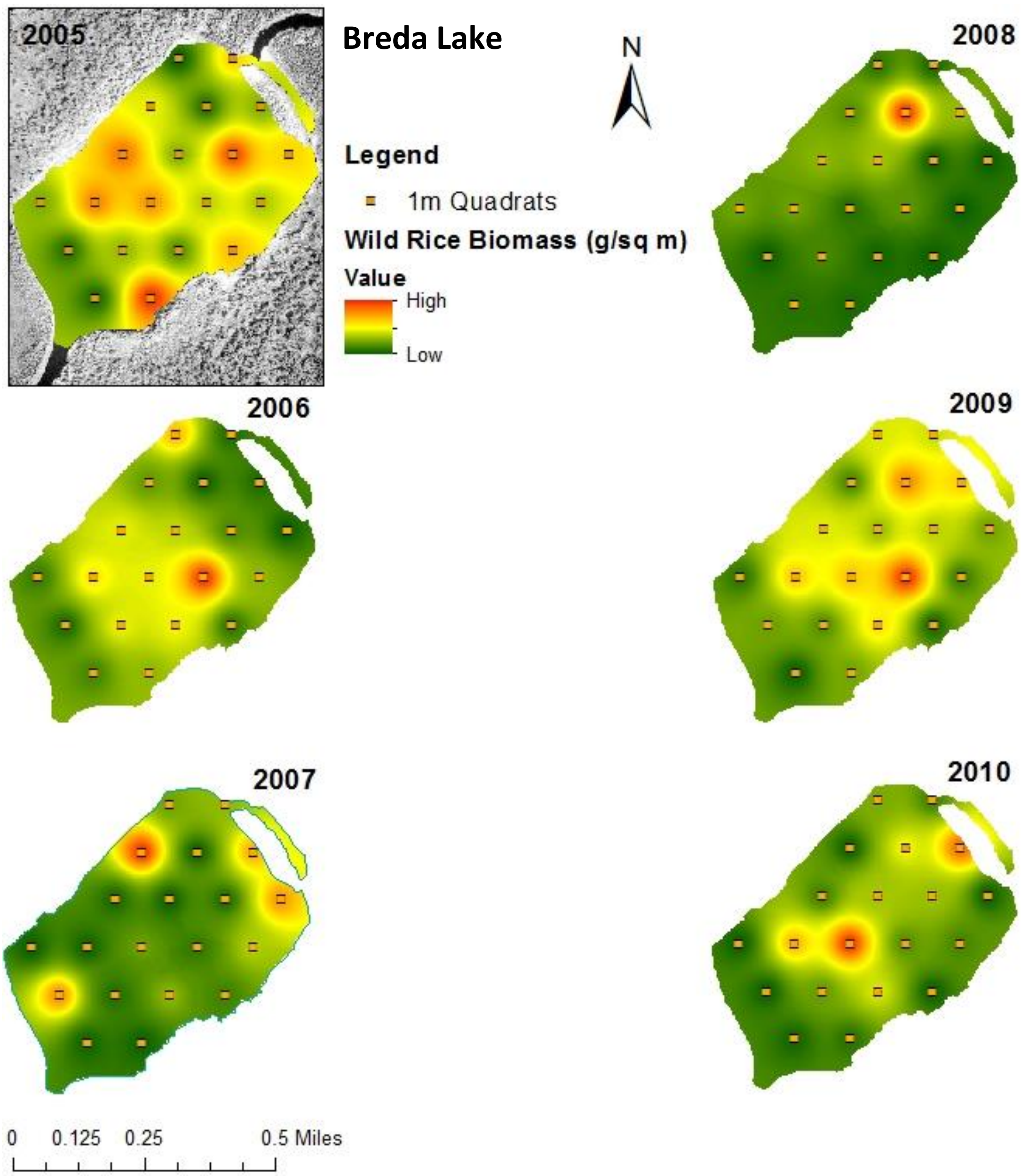
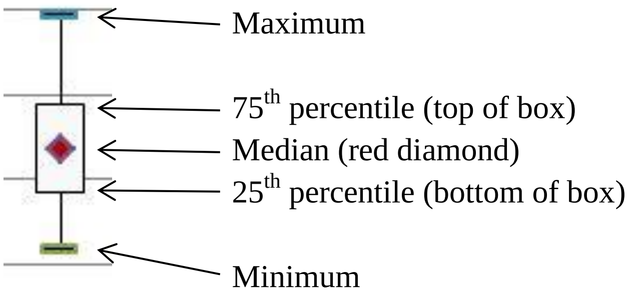


Figure 23. Heat maps of wild rice biomass on Breda Lake between 2005-2010 show that the spatial distribution of areas of highest and lowest biomass vary across time.

Density. The natural variability in density structure of the population is clear from the box and whisker plots below. These plots show changes in average wild rice density (# stalks/m^2) since 1998.

How to read the box and whisker plots



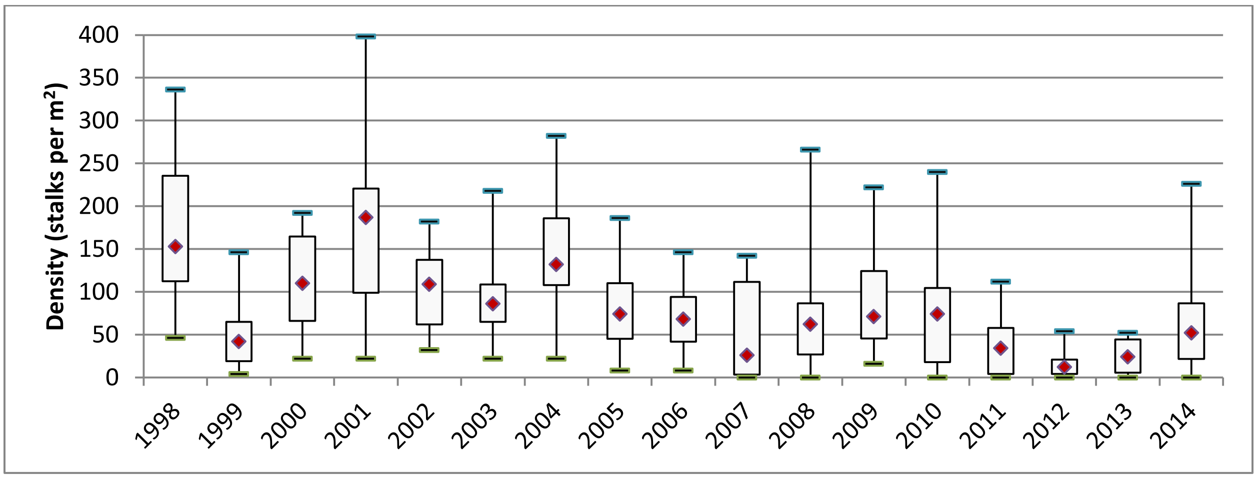


Figure 24. Breda Lake: Wild rice density (1998-2014)

Range of plant characteristics. In the most productive year, median wild rice stalk density was 187 stalks per square meter. Plant height ranged from 33 to 77 inches (0.84 to 2.0 m). Biomass of the most productive plot was 780 g/m^2, and this sample point had a water depth of 30 inches (0.76 m) on August 15, 2001, the date of sampling.

Table 7. Breda Lake: Range of values in most productive year (2001) since 1998

Variable	Min	Median	Max
Total Plant Height (inches)[meters]	33 [0.84]	52 [1.3]	77 [2.0]
Density (Stalks per m^2)	22	187	398
Wild Rice Biomass (g/m^2)	91	354	780
Water Depth at Sampling Date (inches)[meters]	18 [0.46]	30 [0.76]	37 [0.94]
Water Depth at most productive plot = 30 in. [0.76]			

Source: T. Kjerland analysis of data collected by Vogt, 2011

Other plants. 28% of plots contained at least one other species of plant besides wild rice over the entire monitoring period, for a total of 9 different species. The most prevalent species identified was water lily, *Nymphaea or Nuphar spp.* (16% of all plots). Next most prevalent were bladderwort, *Utricularia spp.* (3%), pondweed, *Potamogeton spp.* (3%), and bur-reed, *Sparganium spp.* (2%).

Summary. As expected, after the "down" years of 2012 and 2013, Breda Lake showed a rise in productivity in 2014. Nonetheless, density box plots show that there is a trend over the past ten years (2005-2014) of reduced median density (below 100 g/m^2) compared to the previous seven years. This may indicate a persistent dampening of productivity relative to past conditions. Collection of "related environmental variables", as described in this Handbook, would help identify possible causes.

KETTLE LAKE

DNR #09-0049 00

Context. Located in Carlton County, Kettle Lake is a 611-acre (247-ha) lake with no well-defined inlet, but a large outlet to Kettle River. Inflows are from wetland seepage and drainage from a peat operation. Water levels can fluctuate and be fairly high at times. Flooding in 2012 led to total wild rice failure. Public access is by carrying watercraft down to the lake from a parking area. Harvesters make use of the lake in years when the crop is good. The eastern end—about 25% of the lake—is covered by bog, but rice can be produced across the rest of the lake. Wild rice is often sparse near the center. There is no development on the lake.

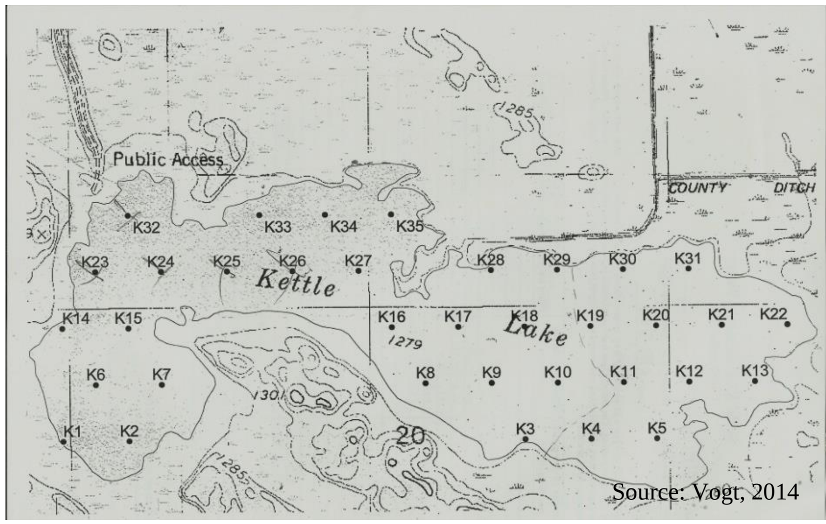


Figure 25. Topographic map showing wild rice sampling points on Kettle Lake

Biomass. Kettle Lake wild rice productivity crashed for the entire lake in 2000, 2005 and 2012. Each time the lake recovered within one to two years. Kettle Lake is a good example of the natural variability and resilience of wild rice beds, and how a lack of plants in one year does not indicate the ability of a sufficient seed bank to produce wild rice in following years. Seed banks are seeds that lie dormant in the sediment.

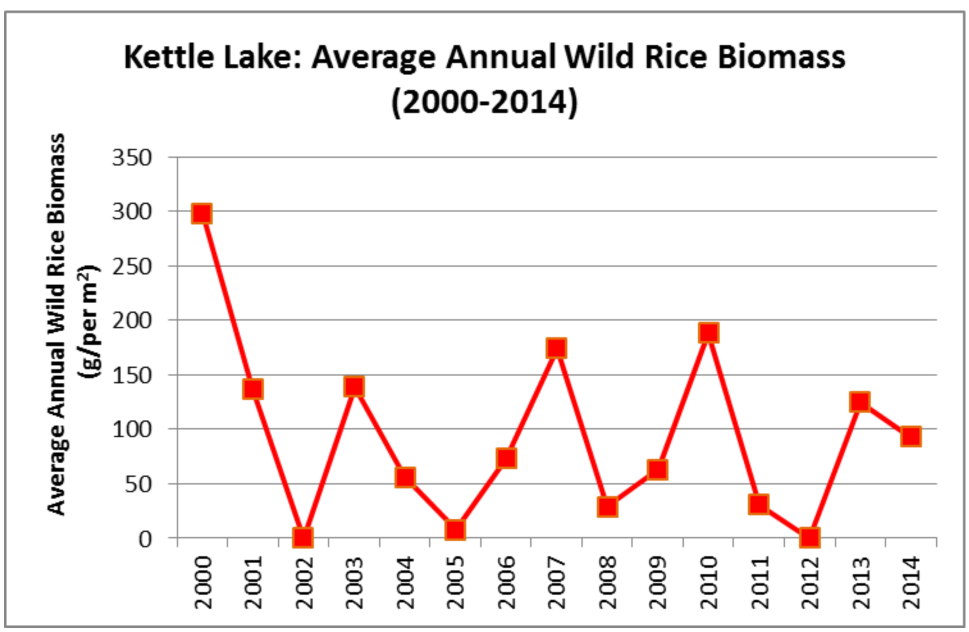


Figure 26. Trends in wild rice biomass on Kettle Lake

Table 8. Kettle Lake: Range of values in most productive year (2000) since 2000

Variable	Min	Median	Max
Total Plant Height (inches)[meters]	56 [1.4]	69 [1.8]	78 [2.0]
Density (Stalks per m^2)	34	55	166
Wild Rice Biomass (g/m^2)	113	265	576
Water Depth at Sampling Date (inches)[meters]	30 [0.76]	41 [1.0]	57 [1.5]
Water Depth at most productive plot = 30 in[0.76 cm]			

Source: T. Kjerland analysis of data collected by Vogt, 2014

Range of plant characteristics. In the most productive year, median wild rice stalk density was 55 stalks per square meter. Plant height ranged from 56 to 78 inches (1.4 to 2.0 m). Biomass of the most productive plot was 576 g/m^2, and had a water depth of 30 inches (0.76 m) on the date when monitoring occurred, August 18, 2000.

Density. The box and whisker plots show that the spread of wild rice density varies greatly from year-to-year on Kettle Lake. It also shows that spatial distribution of density across the lake varies within a given year. Therefore, the amount of biomass also varies across the lake. These plots show changes in wild rice density (# stalks/m^2) since 2000.

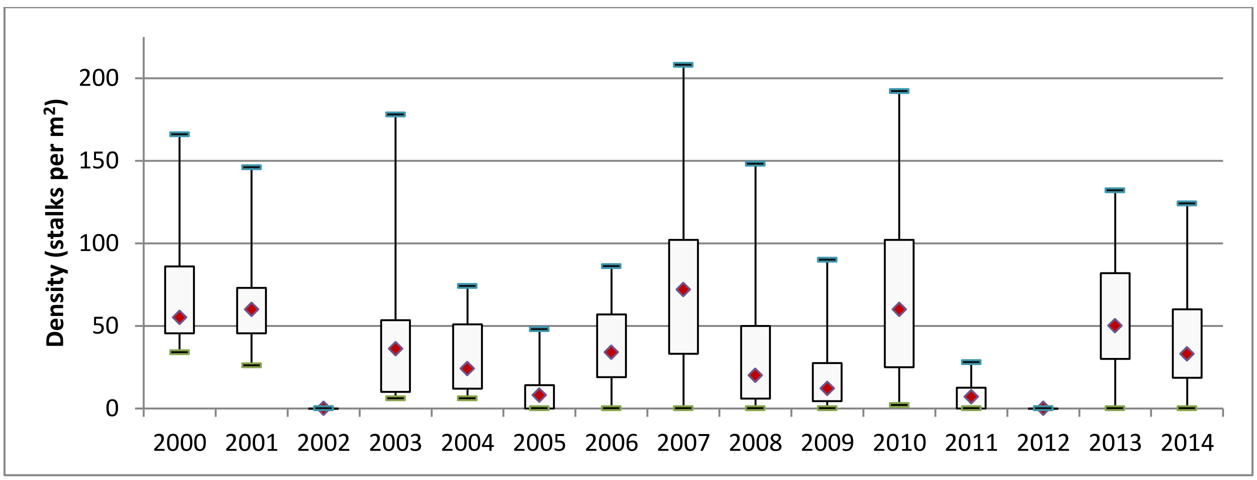


Figure 27. Kettle Lake: Wild rice density (2000-2014)

Other plants. 40% of plots contained at least one other species besides wild rice over the 13 years monitored, for a total of 12 different species. The most prevalent species identified was watershield, *Brassenia schreberi* (19% of all plots). Next most prevalent were pondweed, *Potomageton spp.* (14%), bur-reed, *Sparganium spp.* (5%), and coontail, *Ceratophyllum demersum* (3%).

Summary. Kettle Lake is a resilient, healthy wild rice lake. The population showed recovery after a total crash in production in 2012, which was a year of extreme flooding. The density box and whisker plots demonstrate why more sample points are needed to measure biomass in years of low productivity. Lack of wild rice in a point means there is no measure of density at that point except "zero." Therefore, more sample sites should be added in order to measure density in years when wild rice is sparse.

ROUND ISLAND LAKE

DNR #38-0417 00

Context. Located in Lake County, 54-acre [22-ha] Round Island Lake is shallow and produces wild rice across most or all of its area. There is no defined inlet, and a small creek on the south is the only outlet. The lake has a history of beaver activity, which has been managed by the Minnesota Department of Natural Resources, Ducks Unlimited, and the 1854 Treaty Authority. Public access is by a narrow, rough road that provides only carry-down access to the lake. The access road is on private land, but there is a permanent conservation easement in place to allow for public access for ricing, hunting, and fishing on the public lands surrounding most of the lake. There is no development on the lake. The lake contains a fairly unique flora of small white water lily and small yellow water lily, as identified by the Minnesota Department of Natural Resources.

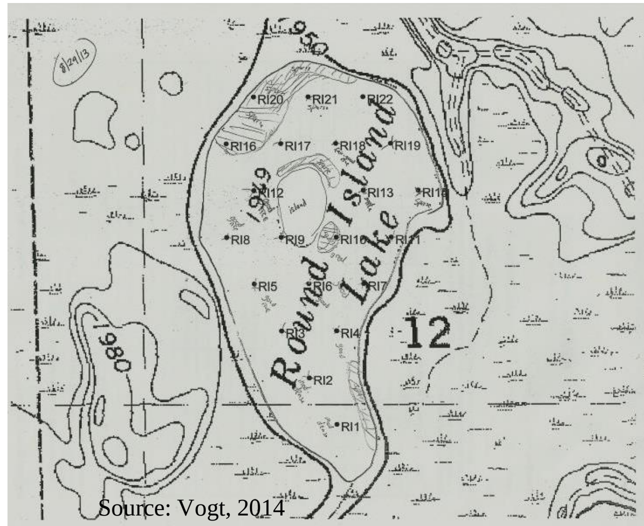


Figure 28. Topographic map of Round Island Lake shows location of wild rice sampling points

Biomass. Population cycles of 3-6 years are evident in the graph below showing average annual biomass. Maximum biomass produced in “boom” years appears to be holding steady at about 250-300 grams per square meter (g/m^2). Note the “crash” in 2008 when biomass fell to record lows, followed 3 years later by a total recovery to maximum levels of production. Graphical estimates would predict productivity for 2015 to increase.

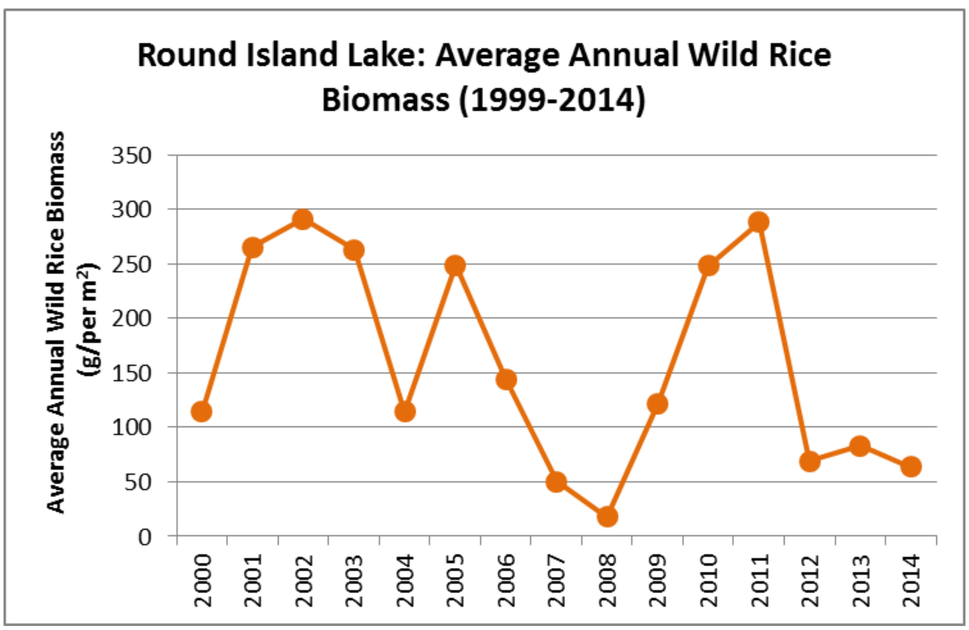


Figure 29. Wild rice biomass on Round Island lakes demonstrates a crash in 2008 followed by gradual recovery in subsequent years

Density of wild rice was highest in the northern half of the lake, but there were two hot spots south of the island with high amounts of biomass, probably due to larger (but fewer) plants. The similarities between the maps of number of pedicels per plant (potential seeds) and individual plant weight are not surprising, given that the number of potential seeds is positively related to plant weight, or biomass.

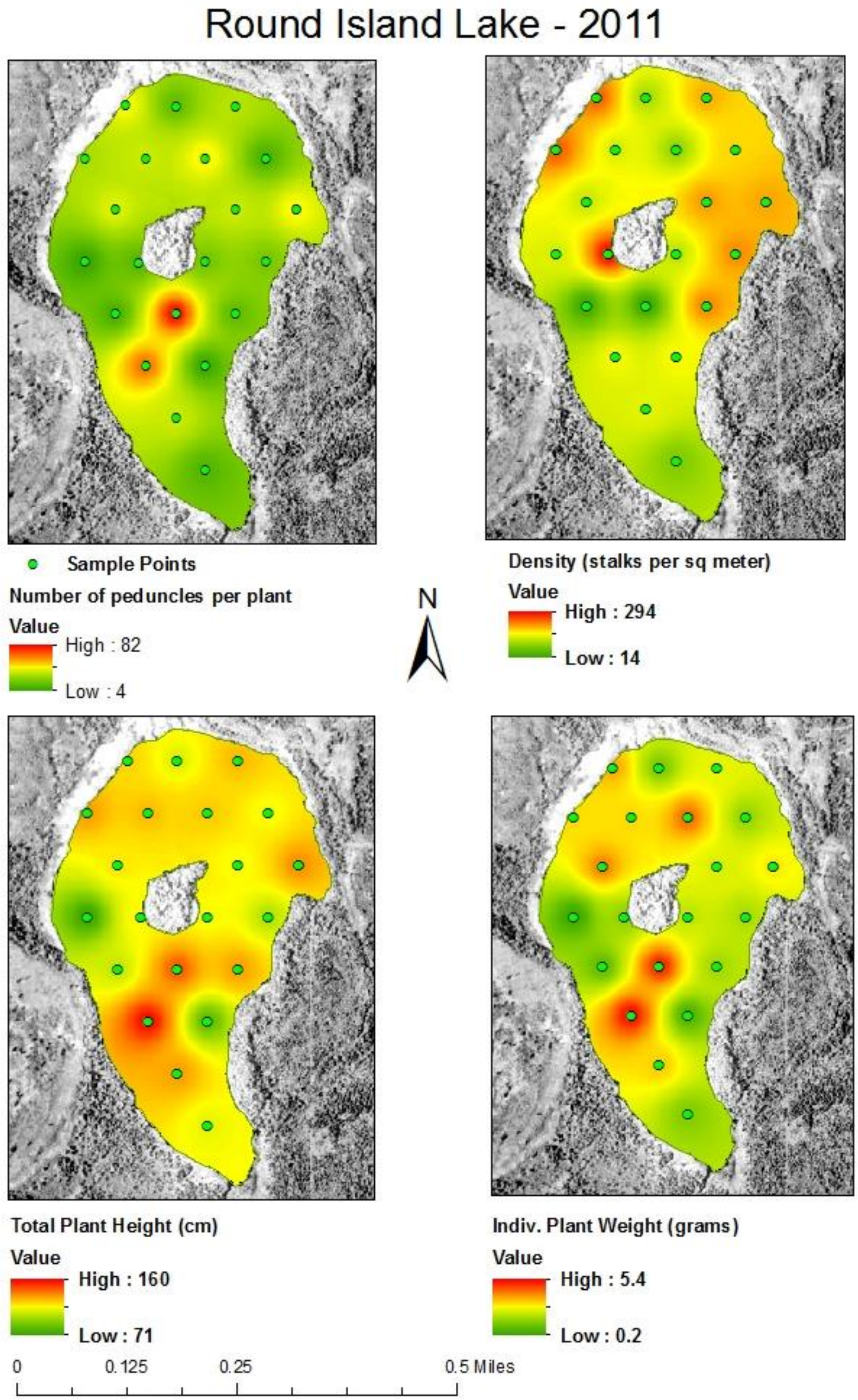


Figure 30. Heat maps of Round Island Lake depict four different parameters of the wild rice population in 2011: number of pedicels, density, plant height, and individual plant weight

Range of plant characteristics. In the most productive year, median wild rice stalk density was 146 stalks per square meter. Plant height ranged from 14 to 68 inches (0.36 to 1.72 m). Biomass of the most productive plot was 661 g/m^2, and it had a water depth of 10 inches [0.25m] on the date when monitoring occurred, August 20, 2002.

Table 9. Round Island Lake: Range of values in most productive year (2002) since 1999

Variable	Min	Median	Max
Total Plant Height (inches)[meters]	14 [0.36]	42 [1.07]	68 [1.72]
Density (Stalks per m^2)	62	146	626
Wild Rice Biomass (g/m^2)	12	308	661
Water Depth at Sampling Date (inches)[meters]	2 [0.051]	11 [0.228]	24 [0.61]
Water Depth at most productive plot = 10 in. [0.25m]			

Source: T. Kjerland analysis of data collected by Vogt, 2014

Other plants. 61% of plots contained at least one other species of plant besides wild rice between 2001 and 2013, for a total of at least 7 different species, not including unknowns. The most prevalent species identified was water lily, *Nymphaea or Nuphar spp.* (46% of all plots). Next most prevalent were bladderwort, *Utricularia spp* (11%), spatterdock, *Nuphar polysepala* (6%), pondweed, *Potamogeton spp.* (6%), and watershield, *Brassenia schreberi* (5%).

Table 10. Weight of wild rice seeds, roots, and shoots based on plants collected in 2011 on Round Island Lake

Variable	Min	Median	Max
Individual Total Plant Weight (grams)	0.179	2.38	5.45
# Potential Seeds	4	29	82
Root Weight (grams)	0.013	0.232	0.986
Shoot Weight (grams)	0.150	1.87	4.21
Viable Seed Weight (grams)	0.016	0.291	0.813

Source: T. Kjerland analysis of data collected by Vogt, 2011

Plant weight data. Round Island Lake was one of the lakes used to create the biomass equations shown in this Handbook. Table 10 shows summaries of the plant weight data from this lake.

Helpful Tip: The values shown above are reasonable ranges for lakes of *Zizania palustris* with similar growing conditions. However, due to genetic and environmental differences, other wild rice populations may show different values. For example, another lake in northern Minnesota showed values on the order of 5-10 times greater than the values shown here (Kjerland, unpublished data).

Summary. It is somewhat surprising that Round Island Lake sustains such a large population of water lily (46% of all plots measured) while still maintaining a strong production of wild rice. Round Island Lake is another example of how a wild rice water body can experience a year of nearly zero production (2008) followed by a full recovery.

VERMILION RIVER

Context. Vermilion River is located in northern St. Louis County. The monitored river reach spans 303 acres [123 ha]. There is also wild rice in other parts of the river. There is no development around this section of the river with the exception of the Goldmine Resort, which has a few cabins and docks on the west end of the reach. Fishing boats use the river channel. The land ownership around the area is primarily state and federal. Public access is afforded by carry-down entry, and is a short paddle down a creek into the river. The area can have significant use by harvesters, and it has been an area of consistently good production along the open/deep river channel. Water levels tend to fluctuate, as is common in a river system, but this doesn't seem to damage the wild rice. In some years, wild rice worms have had a large impact on the crop.

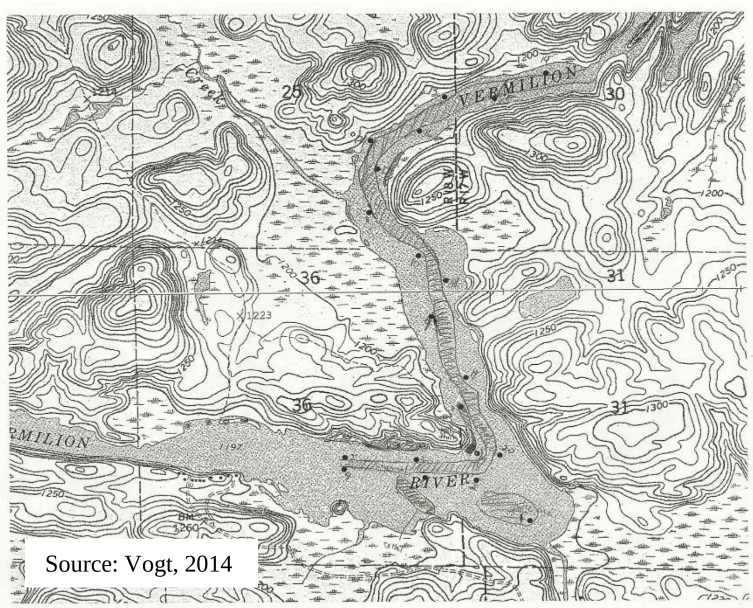


Figure 31. Topographic map of Vermilion River reach showing wild rice sampling points

Biomass. The river produces wild rice consistently well year-to-year. Population oscillations are less evident in the wild rice data from Vermilion River compared to the lakes studied. One explanation could be that flowing water provides consistent nutrient supplies and removes the previous year's wild rice stalks. These conditions would dampen the productivity-nutrient dynamics described in the "Biology of Wild Rice" section.

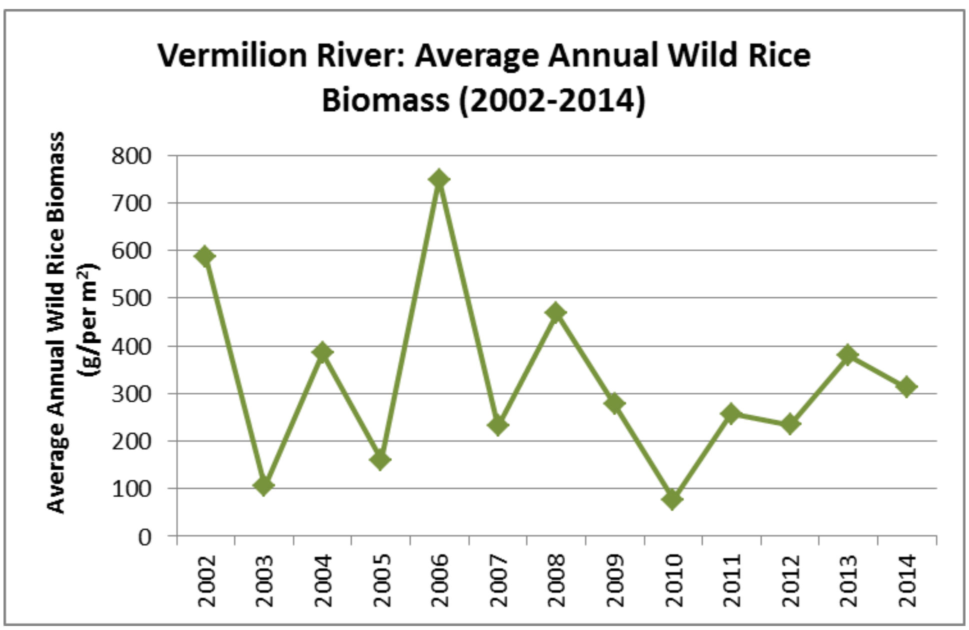


Figure 32. The amount of wild rice biomass growing on the Vermilion River has frequently been the highest among the wild rice waters monitored by the 1854 Treaty Authority

Table 11. Vermilion River: Range of values in most productive year (2006) since 2002

Variable	Min	Median	Max
Total Plant Height (inches)[meters]	47 [1.2]	61 [1.5]	79 [2.0]
Density (Stalks per m^2)	52	186	410
Wild Rice Biomass (g/m^2)	99	727	1435
Water Depth at Sampling Date (inches)[meters]	0.25 [0.0064]	13 [0.33]	33 [0.84]
Water Depth at most productive plot = 13 in.[0.33 m]			

Source: T. Kjerland analysis of data collected by Vogt, 2014

Range of plant characteristics. In the most productive year, median wild rice stalk density was 186 stalks per square meter. Plant height ranged from 47 to 79 inches (1.2 to 2.0 m). Biomass of the most productive plot was 1445 g/m^2 (the highest among the 10 water bodies monitored). The water depth was 13 inches (0.33 m) on the date when monitoring occurred—August 23, 2006.

Other plants. 65% of plots contained at least one other species of plant besides wild rice over the entire monitoring period, for a total of 16 different species. The most prevalent species identified was duckweed, *Lemna spp.* (42% of all plots). Next most prevalent were arrowhead, *Sagittaria latifolia* (15%), coontail, *Ceratophyllum demersum* (9%), and pickerel weed, *Pontederia cordata* (8%).

Summary. The Vermilion River has consistently produced good harvests of wild rice and was frequently the best performing water body among those monitored over the past 16 years. As mentioned above under the “Biomass” section, one explanation for this pattern may be the river flow. The Vermilion River had the highest percentage of plots with other plants besides wild rice at 65%, and 42% of these were duckweed, which was also unusual. However, the presence of these other plant species does not appear to hamper wild rice growth in this highly productive river.

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Resources

Standard operating procedures for Related Environmental Variables:

American Public Health Association. (2011) Standard methods for the examination of water and wastewater. 25th Ed., Washington, DC.

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See also, Appendix D

For creating a reference collection of plants:

Haynes, R. R. (1984) Techniques for collecting aquatic and marsh plants. Annals of Missouri Botanical Garden 71:229-231.

Wood, R.D. (1970) Hydrobotanical methods. University Park Press, Baltimore, MD.

For identifying aquatic plants

See list in SOP#3: Identifying Aquatic Vegetation

See *Wild Rice Monitoring Field Guide* for Plant Identification Key

Appendix A: Field and Lab Data Sheets

Go to next page →

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Wild Rice Field Data Sheet

Water body name:___________________________

County:_______________ Township: _____________ Range: _______________ Sections(s): ______________
Date: ______________ Crew: _______________________ Sheet is #____ of ____ (# of sheets for water body)

Be sure to record the units of measurement you are using!

			SAMPLE PLANT		
Sample ID#	**# of rice stalks within 0.5 m^2 quadrat**	**Other vegetation present**	**Height** ☐ **Above water** ☐ **Total** **cm / in**	**Water depth cm / in**	**# of stalks on plant (if collecting whole plants)**

(Source: Kjerland, T. 2015. *Wild Rice Monitoring Field Guide*. The University of Minnesota Sea Grant Program, Publication #SH15. ISBN 978-0-9965959-0-2. Field data sheet modified from 1854 Treaty Authority "Wild Rice Density Sheet," 2010.)

Wild Rice Field Notes Water body name________________________________

Do not forget to map area occupied by wild rice.

Indicate Sample Point ID #'s where appropriate.

Weather conditions (current and past 2-3 days):____

Plots skipped (record Sample Point ID#'s and reason for skipping)

____

____

Observed **Shoreline use** (docks, roads, parking lots, houses, buildings, access points)

____

____

Observed **Water use** (boat traffic, other recreational use)

____

____

Potential concerns for wild rice growth (i.e. pollutants, leaking septic systems, runoff or erosion areas, dredging, physical damage, etc.)

____

____

Brown spot fungal disease - Record severity level *3-5 times per water body* as "0" if wild rice leaf is free of disease, "low" (less than $^1/_3$ of leaf covered) or "high" (more than $^1/_3$). See photos in Field Guide or SOP #1.

ID#:	Leaf coverage: ☐ 0 (none) ☐ Low (less than $^1/_3$) ☐ High (more than $^1/_3$)
ID#:	Leaf coverage: ☐ 0 (none) ☐ Low (less than $^1/_3$) ☐ High (more than $^1/_3$)
ID#:	Leaf coverage: ☐ 0 (none) ☐ Low (less than $^1/_3$) ☐ High (more than $^1/_3$)
ID#:	Leaf coverage: ☐ 0 (none) ☐ Low (less than $^1/_3$) ☐ High (more than $^1/_3$)
ID#:	Leaf coverage: ☐ 0 (none) ☐ Low (less than $^1/_3$) ☐ High (more than $^1/_3$)

Presence of animals, birds, pathogens, or pests

Type	**Presence (check if present)**	**Comments**
Beaver	☐	
Muskrat	☐	
Rusty Crawfish	☐	
Swans	☐	
Ducks	☐	
Geese	☐	
Rice worms	☐	
Ergots	☐	
Leaf sheath & stem rot	☐	
Unusual seed head shape	☐	
Other	☐	
Unknown	☐	

Instructions for Collecting Wild Rice Field Data

1. **Locate sample points using GPS unit.**
2. **Collect water quality and sediment samples, if part of sampling plan.**
3. **Lower the 0.5 m^2 quadrat straight down over the wild rice plants.**
   When placing the quadrat, if there are any stalks leaning in or out, they should be pulled in or out accordingly. If the sample point doesn't contain wild rice, then measure water depth, document presence of other vegetation, write "0" in the other columns, and move on.
4. **Record number of rice stalks within quadrat.**
   Count stalks, not plants.
5. **Identify other plants in the quadrat.**
   Consider creating abbreviations for names of other vegetation to save space.
6. **Select a sample plant that is nearest a designated corner of the quadrat.**
7. **Measure plant height.**
   Decide whether you will measure above water plant height or total plant height, and check the box to indicate your choice. (Note: At this point, you should also take into account whether you will eventually only collect seed heads or the entire plant, Step 9.) If measuring above water plant height, measure from the water line to the top of the tallest stem. If measuring total plant height, pull the plant and record measurement from the top of the roots (if 2+ sets, top of the prop root) to the top of the tallest stem (stems have seeds). Circle the unit of measurement.
8. **Measure water depth.**
   For this measurement, you can either use a Secchi disk or other tool OR, if you pulled the plant, you can measure from the top of the sediment roots or prop roots (if they exist) to the water line. Circle the unit of measurement.
9. **Collect a sample to take back to the lab for analysis.**
   See Step 9 on page 16 of the *Wild Rice Monitoring Field Guide* for instructions on collecting wild rice plants. Decide whether you will collect seed heads only or the entire sample plant. If only collecting seed heads, collect seed heads from every stem on the sample plant. If collecting the entire plant, count and note the number of stalks on the sample plant. Store seed heads or plants on ice until returning to the lab. Be sure to label the bag properly.
10. **Record Field Notes.**
11. **Record brown spot fungal disease severity (randomly at 3-5 points across the waterbody).**
12. **Estimate wild rice stand area.**

Note: Upon returning to the lab, process samples as soon as possible.

(Source: Kjerland, T. 2015. *Wild Rice Monitoring Field Guide*. The University of Minnesota Sea Grant Program, Publication #SH15. ISBN 978-0-9965959-0-2.)

Wild Rice Lab Data Sheet

Water body name:________________________

Date: ___________ Staff initials: ___________________Sheet #___ of ___ (# of sheets for water body)

Plant materials dried for _____ hours at _____ degrees Celsius

Date plant materials were dried: ___________________ Date plant materials were weighed: ___________________

Record weight to the nearest 0.001 grams

Sample ID#	**Shoot weight (g)**	**Root weight (g)**	**Viable seed weight (g)**	**Viable seed number**	**Non-viable seed weight (g)**	**Non-viable seed number**	**Number of pedicels per PLANT**	**Number of seeds with ergots**	**Number of seeds with worm holes**

(Source: Kjerland, T. 2015. *Wild Rice Monitoring Field Guide*. The University of Minnesota Sea Grant Program, Publication #SH15. ISBN 978-0-9965959-0-2.)

(Sample field and lab data sheets filled out)

Wild Rice Field Data Sheet

Water body name: Round Island Lake

County: Lake Township: 59N Range: 8W Sections(s): 12

Date: 8/25/11 Crew: AL, MB Sheet is # 1 of 1 (# of sheets for water body)

Be sure to record the units of measurement you are using!

			SAMPLE PLANT		
Sample ID#	# of rice stalks within 0.5 m^2 quadrat	Other vegetation present	Height ☒ Above water ☐ Total cm / in (circled: in)	Water depth cm / in (circled: in)	# of stalks on plant (if collecting whole plants)
RI14	101	AH = arrowhead	31	22	2
RI13	104	AH	24	21	2
RI19	88	WS = watershield	28	17	1
22	98	pondweed, AH	24	26	3
18	44	∅	23	26	3
21	51	∅	19	24	1
17	60	pondweed	24	26	3

Wild Rice Field Notes Water body name Round Island Lake

Do not forget to map area occupied by wild rice.

Indicate Sample Point ID #'s where appropriate.

Weather conditions (current and past 2-3 days): Sunny & calm, rained hard past 2 days

Plots skipped (record Sample Point ID#'s and reason for skipping)

RI23 - on shore, RI40 = dock

Observed **Shoreline use** (docks, roads, parking lots, houses, buildings, access points)

New house being built on southern shore, near R20

Observed **Water use** (boat traffic, other recreational use)

Vegetation (including rice) cleared for dock & beach area for new home (near R20)

Potential concerns for wild rice growth (i.e. pollutants, leaking septic systems, runoff or erosion areas, dredging, physical damage, etc.)

Rainbow-colored, oily film on water near bridge over Turtle Creek - possibly from road; timber being harvested upstream

Brown spot fungal disease - Record severity level *3-5 times per water body* as "0" if wild rice leaf is free of disease, "low" (less than 1/3 of leaf covered) or "high" (more than 1/3). See photos in Field Guide or SOP #1.

ID#: 19	Leaf coverage:	☐ 0 (none)	☒ Low (less than 1/3)	☐ High (more than 1/3)
ID#: 13	Leaf coverage:	☐ 0 (none)	☒ Low (less than 1/3)	☐ High (more than 1/3)
ID#: 11	Leaf coverage:	☐ 0 (none)	☒ Low (less than 1/3)	☐ High (more than 1/3)
ID#: 7	Leaf coverage:	☒ 0 (none)	☐ Low (less than 1/3)	☐ High (more than 1/3)
ID#: 1	Leaf coverage:	☒ 0 (none)	☐ Low (less than 1/3)	☐ High (more than 1/3)

Presence of animals, birds, pathogens, or pests

Type	**Presence (check if present)**	**Comments**
Beaver	☐	
Muskrat	☒	1 lodge = RI14
Rusty Crawfish	☐	
Swans	☒	flock of 4
Ducks	☐	
Geese	☐	
Rice worms	☐	
Ergots	☒	RI 31, 42
Leaf sheath & stem rot	☐	
Unusual seed head shape	☒	crow's foot = RI03
Other	☐	
Unknown	☐	

Wild Rice Lab Data Sheet Water body name: Round Island Lake

Date: 8/30/15 Staff initials: MB Sheet # 1 of 1 (# of sheets for water body)

Plant materials dried for 24 hours at 60 degrees Celsius

Date plant materials were dried: 8/30/15 Date plant materials were weighed: 8/30/15

Record weight to the nearest 0.001 grams

Sample ID#	Shoot weight (g)	Root weight (g)	Viable seed weight (g)	Viable seed number	Non-viable seed weight (g)	Non-viable seed number	Number of pedicels per PLANT	Number of seeds with ergots	Number of seeds with worm holes
RI01	1.063	0.187	0.016	2	0.044	9	11	0	0
RI02	2.574	0.214	0.445	19	0.090	11	35	0	2
RI03	4.205	0.436	0.331	16	0.219	28	65	0	0
04	0.436	0.048	0.008	1	0.031	6	5	0	0
05	0.623	0.076	0.171	8	0.005	1	8	0	0
06	3.981	0.515	0.106	8	0.359	57	82	0	0

Appendix B: Estimating Wild Rice Stand Area

Background
Each method below includes a description, contact person, organization and experience using the method. In any given year, knowing the area where wild rice grew is essential for computing overall biomass and for mapping, such as interpolating values between sample points. Therefore, it is useful to create a rough approximation of the outline of areas where wild rice is found growing each year. Because outlining wild rice beds with a GPS unit is subjective, the accuracy of area measurements may vary between surveyors. Furthermore, wild rice stands often move considerably from year to year due to the variability of annual growth. In order to standardize these rough approximations, it is recommended that whoever does the work be given clear instructions, make notes on what criteria they use to determine where to map, and if possible, the same crew assesses each area each year. Because of GPS inaccuracy and field technician subjectivity associated with collecting this type of data, it should only be used as an estimate for comparing year-to-year variability *within* a specific wild rice waterbody. It is not intended to provide a mechanism for assessing relative condition or productivity *between* (or *across*) wild rice waterbodies.

The most accurate method for creating wild rice maps is to use a hand-held GPS unit and a boat as described in Method A. Radomski et al. (2011) found that using a hand-held GPS unit to delineate bulrush stands in lakes where a surveyor can boat or wade around an area was a reliable method for estimating stand area. Surveyor instructions should be consistent for how to perform the delineation, such as how to handle areas with mixed wild rice and other vegetation. Other factors influencing mapping in the Radomski et al. (2011) study were plant density, patch size and fragmentation, water depth, weather conditions, and lakeshore development. Another consideration is the type of GPS unit, GPS settings, and GIS data processing. For example, surveyors processed the data by extending their nearshore bulrush track lines to the land-lake boundary layer and connected track lines of offshore stands. Radomski et al. (2011) recommend using a 5-sec. interval for the tracking function, depending on desired level of precision.

Method A: Canoe or walk around the wild rice stand using a GPS with a tracking function to record points and produce an outline (bare minimum points needed = 4; 5-sec. or shorter setting for tracking function recommended). The edge of the stand may be identified by moving to the open water where there is no wild rice and then defining the edge according to the most outlying stem. Even one stem is considered part of the wild rice stand. This is a relatively time-consuming method. If there are areas without wild rice, or areas in which wild rice is of differing densities, these areas may need to be treated separately.
Source: Valerie Brady, Natural Resources Research Institute, 5013 Miller Trunk Highway, Duluth, Minnesota 55881; Contact info: http://www.nrri.umn.edu/staff/vbrady.asp; How used: estimating areas of various stands of aquatic vegetation.

Method B: While completing sampling, the field crew uses a map of the water body printed on waterproof paper with a grid of GPS points. Throughout the day, the crew draws areas of 1) wild rice, 2) sparse rice, 3) open water, or 4) other vegetation. Later, using a transparent grid overlaid

on the lake map, estimate area of wild rice in relation to total lake area. These polygons may also be digitized for use with mapping software. For purposes of making within lake comparisons, "Sparse wild rice" may be defined as areas with greater than one canoe length between rice stalks.
Source: Darren Vogt, 1854 Treaty Authority, 4428 Haines Road, Duluth, Minnesota 55811-1524; Contact info: www.1854treatyauthority.org/contactus.htm ; How used: for annual wild rice inventories.

Variation on Method B: Print a color photo of each site from Google Earth for the field crew rather than using the map of GPS points. In the field, the crew uses a marking pen to draw the outlines of the wild rice beds on the photo. Later, back in the office, an analyst brings up the Google Earth image again. Looking at what the field crew drew and the measuring tool in Google Earth, an area estimate for the wild rice stand is determined. This variation would be expected to have a lower accuracy compared to the method used by the 1854 Treaty Authority.
Source: Valerie Brady, Natural Resources Research Institute, 5013 Miller Trunk Highway, Duluth, Minnesota 55881; Contact info: http://www.nrri.umn.edu/staff/vbrady.asp; How used: estimating areas of various stands of aquatic vegetation.

Method C: Use laser range-finders to estimate stand size. This method has been successfully used for other types of aquatic vegetation such as cattails. Accuracy depends upon the field crew being able to see clearly the edge of the bed from where they are AND have a good vertical target at that edge to "shoot" the laser against. This is a time-saving method, but accuracy with wild rice remains uncertain.
Source: Valerie Brady, Natural Resources Research Institute, 5013 Miller Trunk Highway, Duluth, Minnesota 55881; Contact info: http://www.nrri.umn.edu/staff/vbrady.asp; How used: estimating areas of various stands of aquatic vegetation.

Appendix C: Data and Summary Statistics for Lakes Included in Biomass Equations

How the Generic Biomass Equations were Determined

First, a word of caution: the biomass equations presented in this Handbook are not meant to exactly determine the weight or biomass. Rather, they are the best nondestructive approximation available that can be applied broadly to show trends over time within a site. Ways to use computed biomass are illustrated in the Case Study section. Comparisons between two water bodies in absolute amounts should be used with caution. More research is needed to further develop the statistical relationships between wild rice height, seed number, and biomass across different water bodies.

Minnesota: Wild rice plants were collected between August 22 and 25, 2011, from four lakes in the 1854 Ceded Territory in northeastern Minnesota: Cabin, Campers, Round Island and Stone lakes. The number of plants collected ranged from 13 and 21 per lake, respectively, for a total of 64 plants.

Wisconsin: Wild rice plants were collected between August 18 and September 17, 2014, from two lakes in northeastern Wisconsin, within 30 miles of Rhinelander: Aurora Lake (n=45), Cuenin Lake (n=53).

River wild rice was not represented in either Minnesota or Wisconsin, so it may be especially desirable to create new biomass equations if you are monitoring a river rice site.

Methods: Each plant was carefully uprooted from the sediment to retain all root material and measured for height. Plant roots were washed carefully in the lake water and then folded accordion-style and stored on ice in labeled plastic zippered bags. Plants were handled so as to preserve as many seeds as possible. Plants were thoroughly washed in the lab to remove all sediment and allowed to air dry in a drying room. Prior to weighing, plants were dried at 60°C for 24 hours.

Photo: GLIFWC

Plants were separated into 3 portions—roots, shoots, and seeds. Seeds were characterized as either viable or non-viable based on visual and physical inspection. Seed weight included both viable and non-viable seeds according to their proportions found in the sample. Total plant weight included roots, shoots, and seeds.

Biomass equations were computed using statistical software. Separate equations were developed for plant height-biomass and seed number-biomass. Lakes that were included in the equations showed statistical significance for the relationship represented by the equation. See SOP #5 for further explanation about how the biomass equations were computed.

Table 12. Characteristics for lakes used to create biomass equations

Lake Name	Aurora	Cabin	Campers	Cuenin	Round Island	Stone
ID	1592700 (WBIC)	38026000 (MNDNR)	38067900 (MNDNR)	1568800 (WBIC)	38041700 (MNDNR)	69004600 (MNDNR)
County **State**	Vilas WI	Lake MN	Lake MN	Oneida WI	Lake MN	St. Louis MN
Year wild rice plants were collected for biomass equations	2014	2011	2011	2014	2011	2011
Area (acres) [hectares]	94 [38]	67 [27]	56 [23]	28 [11]	54 [22]	230 [93]
Max depth (ft) [m]	4 [1.2]	3 [0.91]	3 [0.91]	4 [1.2]	4 [1.2]	3 [0.91]
Bottom	30% sand, 30% gravel, 0% rock, 40% muck	N/A	N/A	0% sand, 0% gravel, 0% rock, 99% muck	N/A	N/A
% Littoral area	100%	100%	100%	100%	100%	100%
Sulfate, as SO_4	N/A	2007-2012 range: 1.5 to 3.3 mg/L (MPCA)	N/A	N/A	2011-2012 range: 0.5 to 0.6 mg/L (MPCA)	2007-2012 range: 2.5 to 4.7 mg/L (MPCA)

WBIC = Water body ID; MNDNR = Minnesota DNR Lake ID

Sources: Minnesota Pollution Control Agency (MPCA) lake profile web pages; MN DNR Lake finder web pages; WI DNR lake pages

Resources for lakes included in the biomass equations

Aurora Lake

- Wisconsin Department of Natural Resources, Wisconsin State Natural Areas Program: Aurora Lake (no. 127) http://dnr.wi.gov/topic/lands/naturalareas/index.asp?sna=127
- Wisconsin Department of Natural Resources. (1999) Biotic inventory and analysis of the Northern Highlands-American Legion State Forest: A baseline inventory (1992-96) and analysis of natural communities, rare plants and animals, aquatic invertebrates, and other features in preparation for State Forest Master Planning, http://dnr.wi.gov/files/PDF/pubs/er/ER0093.pdf

Cabin Lake

- Minnesota Department of Natural Resources Lake Finder profile http://www.dnr.state.mn.us/lakefind/lake.html?id=38026000
- Minnesota Pollution Control Agency lake profile http://cf.pca.state.mn.us/water/watershedweb/wdip/waterunit.cfm?wid=38-0260-00

Campers Lake

- Minnesota Department of Natural Resources Lake Finder profile http://www.dnr.state.mn.us/lakefind/lake.html?id=38067900
- Minnesota Pollution Control Agency lake profile http://cf.pca.state.mn.us/water/watershedweb/wdip/waterunit.cfm?wid=38-0679-00

Cuenin Lake

- Wisconsin Department of Natural Resources, Cuenin Lake
  http://dnr.wi.gov/lakes/lakepages/LakeDetail.aspx?wbic=1568800

Round Island Lake

- Minnesota Department of Natural Resources Lake Finder profile
  http://www.dnr.state.mn.us/lakefind/lake.html?id=38041700
- Minnesota Pollution Control Agency lake profile
  http://cf.pca.state.mn.us/water/watershedweb/wdip/waterunit.cfm?wid=38-0417-00

Stone Lake (Lake ID 69004600)

- Minnesota Department of Natural Resources Lake Finder profile
  http://www.dnr.state.mn.us/lakefind/lake.html?id=69004600
- Minnesota Pollution Control Agency lake profile
  http://cf.pca.state.mn.us/water/watershedweb/wdip/waterunit.cfm?wid=69-0046-00

Table 13. Wild rice plant characteristics and water depths of lakes used for biomass equations

(T. Kjerland analysis of data collected by Vogt, 2011)

	Range of Values, 2011					
	Cabin Lake, MN			Campers Lake, MN		
Variable	Min	Median	Max	Min	Median	Max
Total Plant Height (inches)[m]	20 [0.51]	38 [0.97]	54 [1.4]	22 [0.56]	38 [0.97]	74 [1.9]
Shoot weight (g)	0.102	0.573	1.33	0.238	2.62	5.18
Root weight (g)	0.010	0.104	0.188	0.060	0.640	1.94
Seed weight (g)	0.000	0.036	0.155	0.007	0.203	0.808
Individual Plant Weight (g)	0.157	0.720	1.63	0.305	3.86	7.04
Density (Stalks per m^2)	2	6	86	2	32	110
# Potential Seeds per Plant	3	11	39	4	39	106
Water Depth at Sampling Date (inches)[m]	12 [0.30]	19 [0.48]	34 [0.86]	8 [0.20]	18 [0.46]	35 [0.89]
% Wild Rice Coverage, 1998-2013	47	89	100	0	86	100

	Range of Values, 2011					
	Round Island Lake			Stone Lake		
Variable	Min	Median	Max	Min	Median	Max
Total Plant Height (inches)[m]	28 [0.71]	47 [1.2]	63 [1.6]	38 [0.97]	55 [1.4]	66 [1.7]
Shoot weight (g)	0.150	1.87	4.21	1.03	2.45	12.7
Root weight (g)	0.013	0.232	0.986	0.060	0.490	1.82
Seed weight (g)	0.016	0.291	0.813	0.050	0.342	3.16
Individual Plant Weight (grams)	0.179	2.38	5.45	1.22	3.54	17.70
Density (Stalks per m^2)	14	152	294	2	26	162
# Potential Seeds per Plant	4	29	82	5	21	267
Water Depth at Sampling Date (inches)[m]	13 [0.33]	26 [0.66]	34 [0.86]	18 [0.46]	29 [0.74]	43 [1.1]
% Wild Rice Coverage, 1998-2013	31	84	100	21	52	75

	Range of Values, 2014					
	Aurora Lake, WI			Cuenin Lake, WI		
Variable	Min	Median	Max	Min	Median	Max
Total Plant Height (inches)[m]	40 [1.0]	61 [1.5]	79 [2.0]	31 [0.8]	51 [1.3]	61 [1.5]
Shoot weight (g)	1.38	4.30	26.2	0.692	2.93	13.4
Root weight (g)	0.357	1.04	8.11	0.169	1.57	7.84
Seed weight (g)	0.341	1.04	6.88	0.0249	0.260	1.21
Individual Plant Weight (grams)	2.55	7.43	37.3	1.03	4.67	21.8
Density (Stalks per m^2)	18	98	186	6	80	240
# Potential Seeds per Plant	8	53	312	14	48	216

	Range of Values, 2014					
	Aurora Lake, WI			Cuenin Lake, WI		
Variable	Min	Median	Max	Min	Median	Max
Water Depth at Sampling Date (inches)[m]	20 [0.51]	34 [0.86]	48 [1.2]	11 [0.28]	23 [0.58]	42 [1.1]
% Wild Rice Coverage, 1998-2013	na	na	na	na	na	na

GLOSSARY

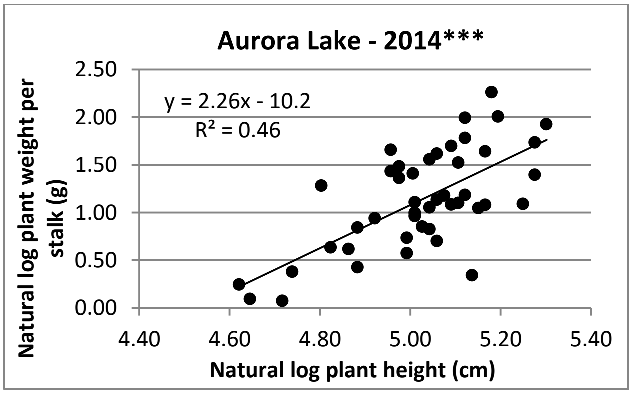
Median is the middle value of a set of numbers. The median and mean/average will be very similar when a set of numbers is normally distributed, but the median will be different, and more representative, when there is a great deal of "skewness" to the data. Wild rice density data tend to be skewed towards more plots of low density with only a few plots having high density.

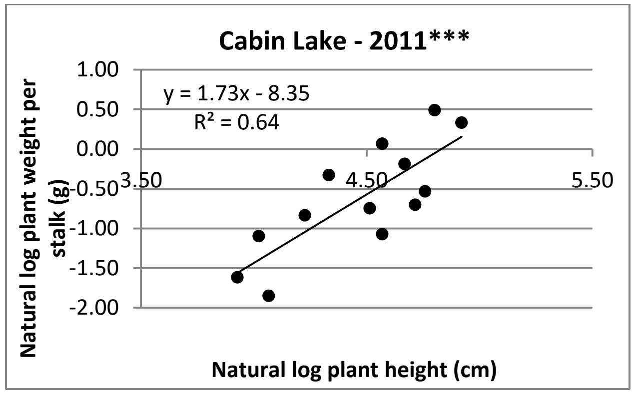
Helpful Tip: While these values provide a good ballpark estimate, it is possible that the population of wild rice plants you measure will show significantly different characteristics from those listed here. For example, other lakes may have higher values that differ by 10 times or more, on average (Kjerland, unpublished data).

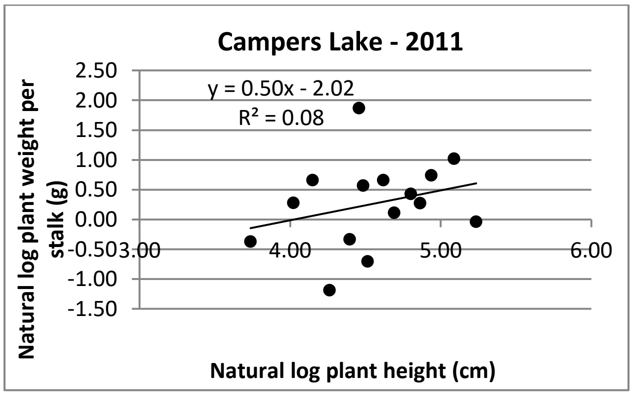
Equation 1: Plant Height – Weight

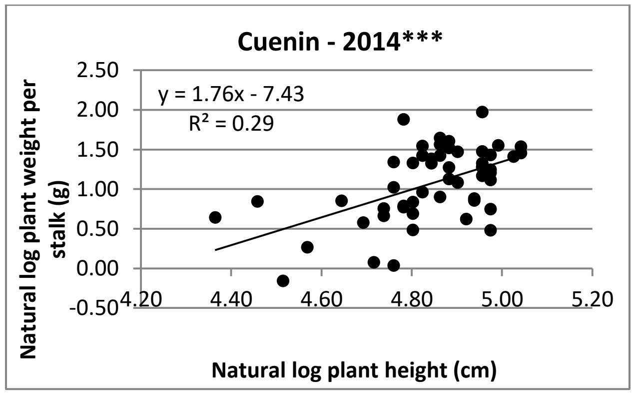
Note: Variables were log transformed

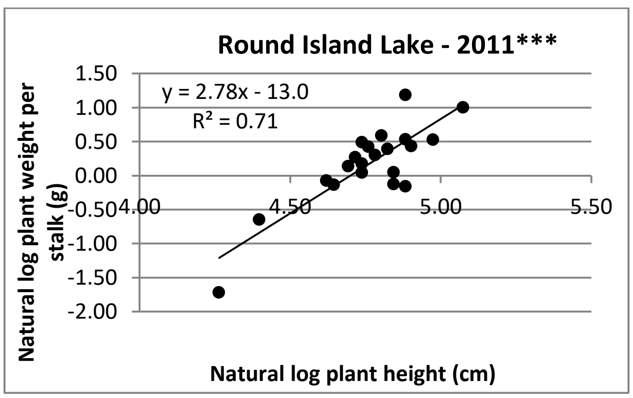
Statistical significance: * = p ≤ 0.05   ** = p ≤ 0.01   *** = p ≤ 0.001

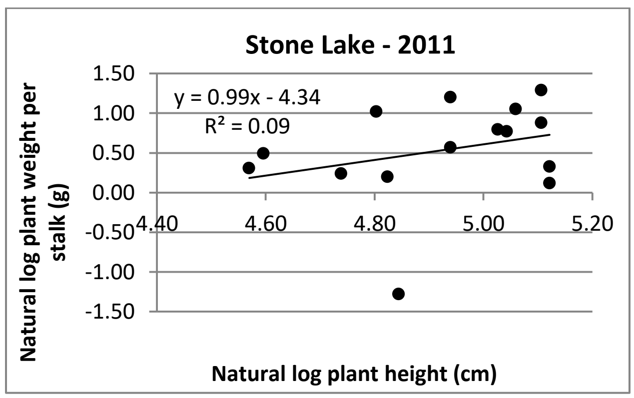








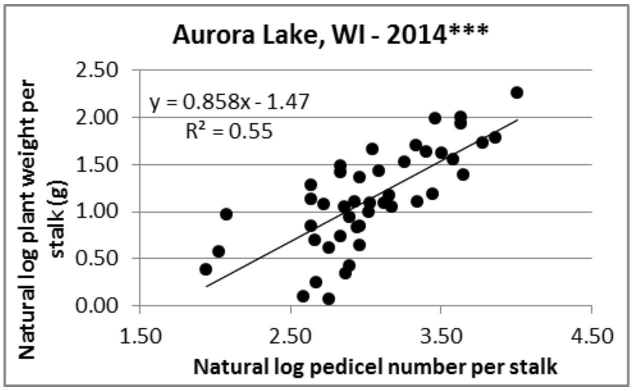


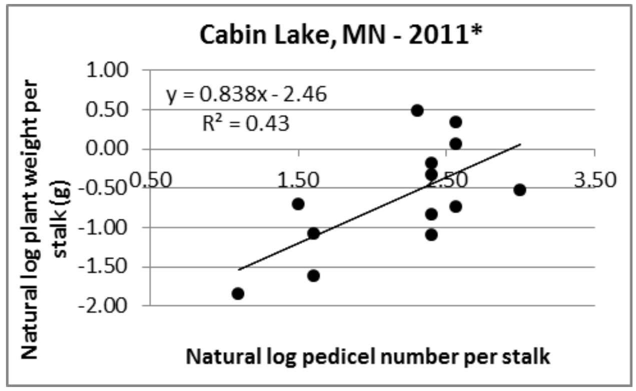


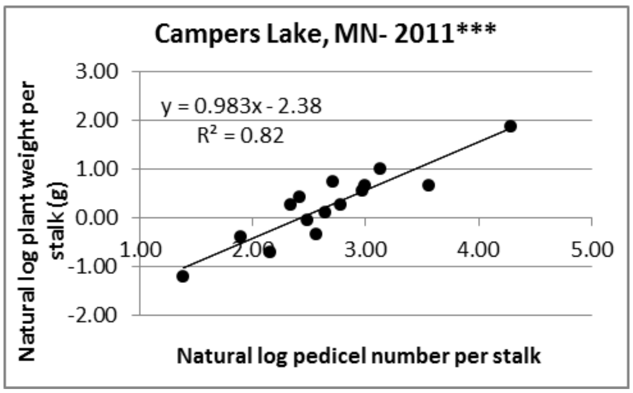
Equation 2: Number of potential seeds (pedicels) per stalk - Weight per stalk (g)

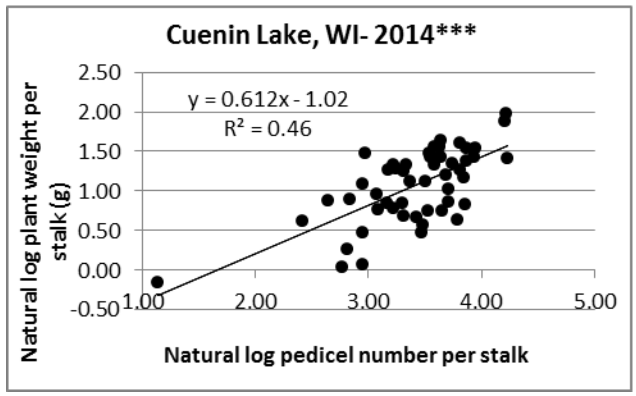
Note: Variables were log transformed

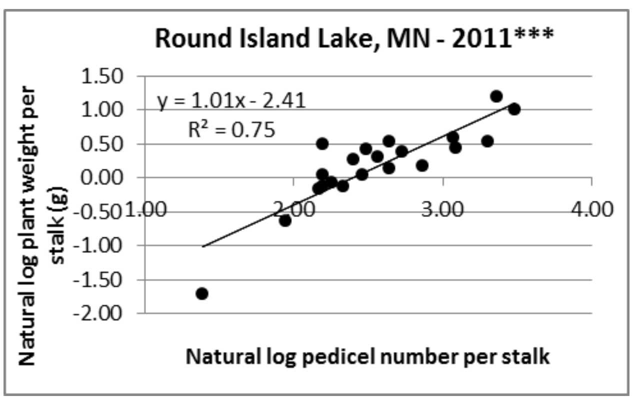
Statistical significance: * = $p \leq 0.05$ ** = $p \leq 0.01$ *** = $p \leq 0.001$

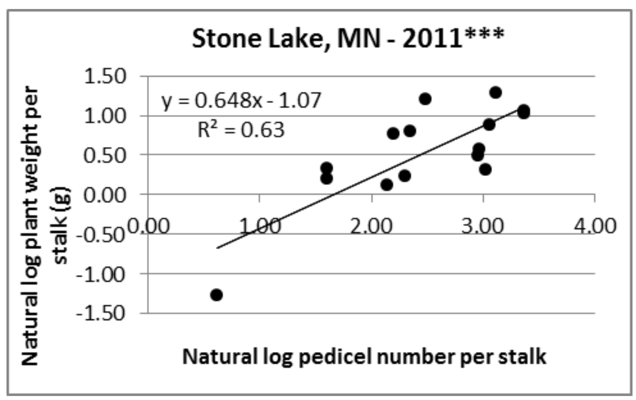












Appendix D: Water Quality and Sediment Sampling Methods

Modified from methods provided by Nancy Schuldt, Fond Du Lac Band of Lake Superior Chippewa

For more information on recommended parameters to measure and sampling frequency, see the section in this Handbook, "Related Environmental Variables,"

SURFACE WATER

Field measurements for surface water <u>every site visit</u>*:

- Electrical conductance (EC25)
- Dissolved oxygen (mg/L and % saturation)
- pH
- Temperature
- Turbidity (using field sensor or lab meter)
- Secchi transparency in lakes
  - In lakes with shallow, clear waters, use a secchi tube (transparency tube)
  - In deeper areas of lakes, use a secchi disk

**These are standard multi-sensor probe parameters, i.e. Hydrolab, YSI, etc.*

Laboratory analyses for surface water <u>every site visit</u> (surface grab sample):

- Alkalinity
- Total hardness
- Color (true and apparent) and Dissolved Organic Carbon if resources allow (color is low-cost, but less accurate proxy for dissolved carbon)
- Nitrogen
  - Ammonium [nitrate + nitrite],
  - Total Kjeldahl Nitrogen (TKN)
  - Total-N (has lower detection limit, therefore preferred over TKN)
- Phosphorus (Total, Ortho-P)
- Total suspended solids
- Chlorophyll *a*
- Sulfate

Laboratory analysis of <u>surface water</u> performed once annually per water body: One sample per year from each lake, stream, and river site should be analyzed for the following suite of toxic chemicals and heavy metals: unionized ammonia (only if NH_4-N is relatively high [$\geq$0.10 mgN/L], i.e. when pH>8.5, as a rule of thumb), chloride, aluminum, arsenic, cadmium, chromium, copper, lead, nickel, selenium, and zinc.

SEDIMENT

Laboratory analysis of <u>sediments</u> performed once annually per sample site (top 5 cm grab, using petite Ponar or Eckman dredge)

- Nitrogen (TN)
- Phosphorus (TP)
- % water (Total solids)
- Total volatile solids (a measure of organic matter, same as ash-free dry weight [AFDW])
- Iron (essential micronutrient)

SAMPLING PARAMETERS AND JUSTIFICATION

Chemical Parameters	Justification
***Field Measurements** - Water*	
Electrical Conductance (EC25)	General characteristic; indicator of overall mineral content
Oxygen, Dissolved & % Saturation	General characteristic; indicator of organic loading
pH	General characteristic
Secchi Transparency	General characteristic; trophic state indicator
Temperature	General characteristic
Turbidity*	Indicator of sedimentation/erosion, primary productivity

*Turbidity (may be measured either with a multi-sensor probe or with a lab instrument)

Laboratory Measurements - Water	
Alkalinity, Total	General characteristic; measure of acid buffering capacity
Chlorophyll a	A measure of algal density; trophic state indicator
Color, true and apparent	Measure of substances suspended and in solution
Dissolved Organic Carbon	Measure of refractory organic compounds (resistant to rapid microbial degradation) in surface runoff, seepage
Hardness, Total	A measure of mineral concentration
Nitrogen, Ammonium	Nutrient; potentially toxic to aquatic organisms
Nitrogen, Nitrate+Nitrite } **Most likely limiting nutrient (Walker, et al, 2010)**	Nutrient
Nitrogen, Kjeldahl, Total (TKN)	Nutrient (organic-N + ammonium-N, most is organic-N in natural, or unpolluted, waters)
Nitrogen, Total	Nutrient
Phosphorus, Ortho	Nutrient; trophic state indicator
Phosphorus, Total } **2nd most likely limiting nutrient**	Nutrient; trophic state indicator

Suspended Solids, Total	Indicator of sedimentation/erosion
Sulfate	Can be inhibitory to wild rice
Laboratory Measurements – Sediment	
Nitrogen, Total Kjeldahl	Nutrient
Phosphorus, Total	Nutrient
Total Solids/% Water	Required for dry-weight calculations
Total volatile solids	A measure of organic matter
Iron, Total	Essential micronutrient
Toxic Chemicals	
Ammonia, unionized	Potentially toxic to aquatic organisms
Chloride	Same
Arsenic, Total	Same
Cadmium, Total	Same
Chromium, Total	Same
Copper, Total	Same
Lead, Total	Same
Nickel, Total	Same
Selenium, Total	Same
Zinc, Total	Same

ANALYTICAL METHODS

Analytical methods change over time as science progresses and a variety of scientifically acceptable methods for measuring water quality and sediment exist (Elias et al., 2008). These methods have different detection limits and procedures for handling samples. The Resources section of this Handbook provides a list of reliable sources to use for determining the analytical methods to use.

SAMPLE CONTAINERS AND PREPARATION

The following is an example from Fond du Lac Band of Lake Superior Chippewa. Consult with your organization's Quality Assurance Project Plan (QAPP) for surface water to determine the appropriate procedures to use for preparing sample containers and handling samples.

All sample containers may be provided by the laboratory performing the analysis. Pre-cleaned containers may be purchased from commercial sources, or the containers may be cleaned and re-used. Unless the containers are pre-cleaned with a manufacturers certificate, the laboratory must verify the cleaning procedure by randomly selecting at least one of each type of container per month, filling it with deionized water and an appropriate preservative, waiting at least 24 hours, and analyzing the water for all analytes of interest. A record of these checks is to be maintained by the Laboratory Director. When containers are re-used, the following cleaning procedures are used:

General Chemistry: 1 liter wide-mouth plastic bottles; washed with detergent and rinsed three times with warm tap water, then at least three times with deionized water.

Chlorophyll: 1 liter amber glass or plastic bottles; prepared same as General Chemistry.

Metals: 250 or 500 mL wide-mouth plastic bottles; prepared same as General Chemistry, then rinsed with dilute HNO_3, tap water, dilute HCl, tap water, and finally at least three times with deionized water.

Nutrients: 250 or 500 mL wide-mouth plastic bottles; prepared same as General Chemistry, then rinsed with dilute HCl, tap water, and finally at least three times with deionized water.

Ortho Phosphorus: Same as Nutrients

Dissolved Organic Carbon: 50 ml amber glass bottles with TFE lined caps; soak 24 hours in 10% HCl acid bath, rinse with deionized water. Seal bottles with aluminum foil then combust at 400 ^{o}C for 1 hour.

Sediments collected by Ekman or Ponar dredge for nutrient/sediment characteristics analysis should be transferred immediately to labeled zippered plastic bags, and stored in a cooler until delivery to the contract lab for analysis.

MEASURING SUBSTRATE CLASS

To bring up substrate, use some sort of device to grab a small sample of the sediment from the shore side of the boat (Minnesota DNR, 2012). Record the code of the substrate class and Sample ID# on a data sheet designed to include the related environmental variables sampled.

The following table is from the Minnesota Sensitive Lakeshore Manual by the Minnesota Department of Natural Resources (2012, pp. 14). For more information on determining substrate classes, see the Minnesota DNR Lake Survey Manual (Minnesota DNR, 1993).

Table 14. Substrate class

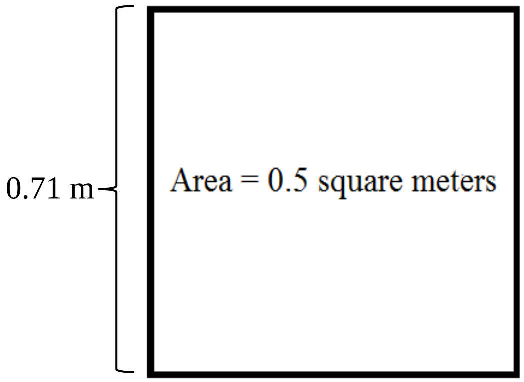
Substrate Group	Type	Code	Description
Hard Bottom	Boulder	BO	Diameter over 10 inches
	Rubble	RU	Diameter 3 to 10 inches
	Gravel	GR	Diameter 1/8 to 3 inches
	Sand	SA	Diameter less than 1/8 inch
	Sand/Silt	SS	Sand bottom overlaid with thin layer of silt
Soft Bottom	Silt	SI	Fine material with little grittiness
	Marl	MR	Calcareous material
	Muck	MU	Decomposed organic material

Appendix E: Instructions for Making a Square Quadrat Frame

How to make a quadrat frame with area equal to 0.5 m^2

Materials needed:

- 10' (foot) Plastic PVC pipe, ~1" in diameter
- 4 right-angle elbows (90 degree angle), fit to diameter of PVC pipe (if available, one elbow should be a different color for marking one corner of the quadrat)
- PVC solvent cement (glue)
- Saw capable of cutting PVC (ideally a fine-toothed saw, blade 3" – 4" in width)
- Measuring tape or yard stick
- Colored tape (optional, for marking one corner of the quadrat if colored PVC elbow unavailable)



Directions:

- Cut four (4) lengths of PVC pipe to 0.71 m (~28").
- Assemble the quadrat taking care to ensure that the interior dimensions exactly measure 0.71 m for the inside measurement of each side (0.71 m x 0.71 m ≈ 0.5 m^2).
- Apply solvent-cement/glue evenly to outside end of pipe and inside of right-angle elbow
- Insert pipe into elbow and turn ¼ turn to spread glue.
- Hold the pipe and fitting together for about 15 seconds (note: the glue dries very quickly)
- Lay out the frame on a flat surface, & continue attaching right-angle elbows to pipes until a square is formed.
- Mark one corner of the quadrat using colored tape, using a colored PVC elbow, or by making a small notch with the saw. This mark is needed for selecting the sample plant (the one nearest to this corner).
- Allow to dry flat.

Appendix F: Statistical Basis for Determining the Number of Sample Points Required

This section explains the statistical foundation for recommending 40 points as the minimum number to sample. The "Number of Sample Points Equation" is based on a study to clarify the most efficient techniques for estimating the biomass of aquatic plants (Downing and Anderson, 1985) across a range of temperate lakes and ponds.

The sample point number recommendations in this Handbook are also based on research showing size of a water body is not a factor in determining the frequency of aquatic plant species occurrence (Newman et al, 1998; MN DNR, 2012). In sampling for other plants that co-occur with wild rice, the sample point numbers recommended will also be valid.

Downing and Anderson tested five sizes of quadrats ranging from 100 cm^2 to 1 m^2.[22] The authors analyzed patterns of spatial distribution of biomass to determine the optimum number of sample plots. They looked at 22 aquatic plant studies from around the world with a total of 1200 sample plots in order to develop an equation for the number of samples required.

Number of Sample Points Equation

Please note: You don't need to know how to use this equation.

Number of sample points = $5.75\bar{x}^{-0.433}A^{-0.157}p^{-2}$

Where $\bar{x}$ = Mean standing biomass in g/m^2
A = area of the quadrat used in square meters
p = statistical precision desired

Source: Downing and Anderson (1985), p. 1866.

According to this study, the number of sample points required depends on the current year's (standing) biomass. Other information needed is the quadrat size and desired level of statistical precision. A quadrat size of 0.5 m^2 and a statistical precision of 20% of the mean are recommended in the Handbook methods. Figure 33 illustrates the rationale behind recommending a statistical precision of 20% of the mean, which is a widely accepted measure and results in a reasonable sampling effort.

Figure 33 shows average annual wild rice biomass on 10 water bodies in northeastern Minnesota (1998-2014) and the corresponding number of sample points required to measure biomass at two different levels of precision (Downing and Anderson, 1985; T. Kjerland analysis of data collected by Vogt,

[22] These are area measurements. The length of each side of a 0.5 m^2 quadrat is equal to 0.71 m.

2014). The blue dots represent the recommended level of precision—standard error at 20% of the mean. The red dots represent a more stringent standard error at 15% of the mean. The orange line represents 40 sample points.

Based on analysis of the natural growth patterns on these 10 water bodies, sampling 40 points per year will result in achieving a 20% standard error of the mean in most years (4 out of 5). More sample points will be needed in years when the rice is less abundant to achieve the same level of accuracy as in productive years. Less sample points will be needed in years when the rice is more abundant. See also, Table 2 on page 26.

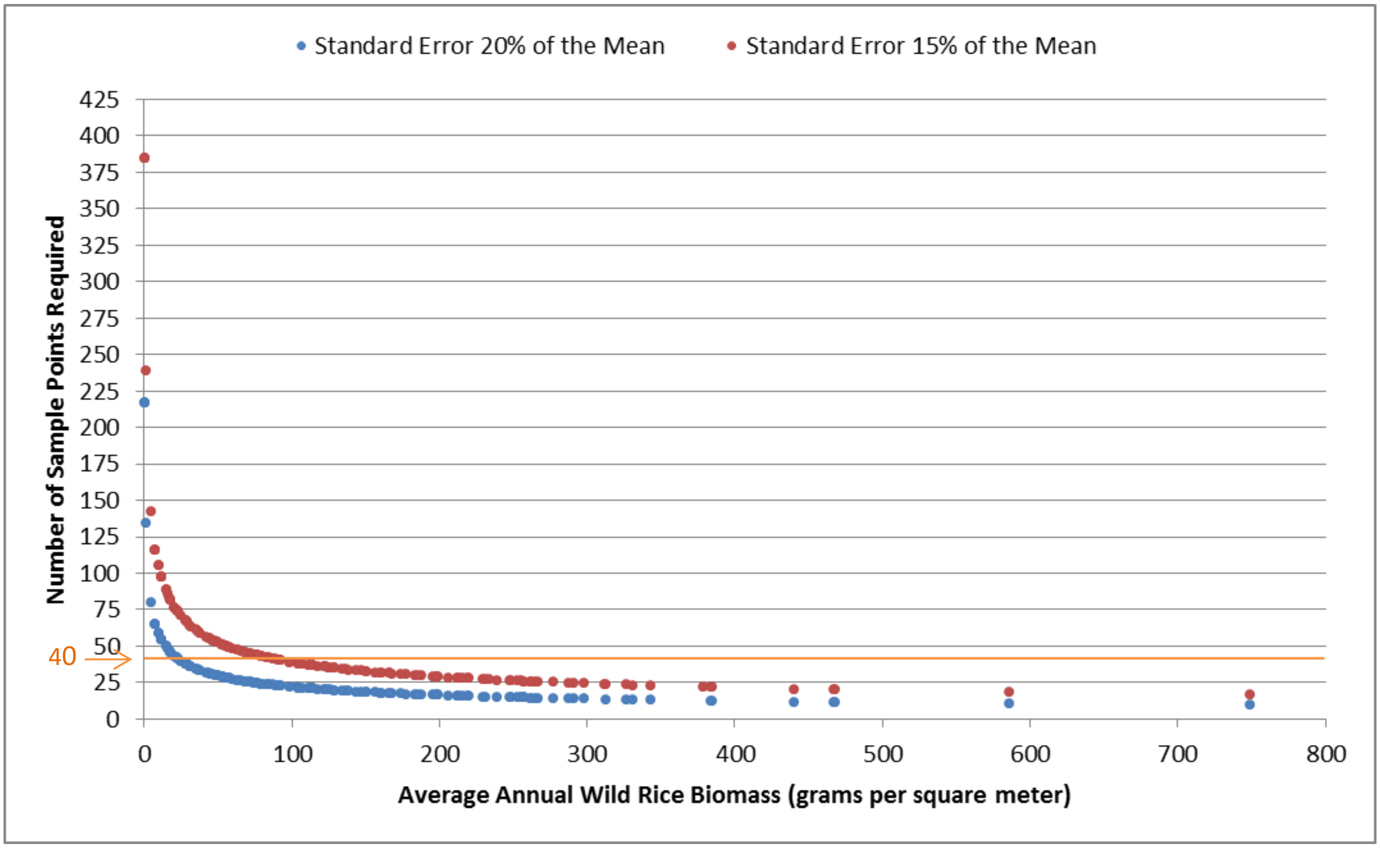


Figure 33. Illustration of the increasing number of sample points required as the level of statistical precision desired is raised from a standard error of 20% of the mean to a standard error of 15% of the mean