Minnesota Center for Environmental Advocacy

Clean Water Organizations' second (and final) set of exhibits.

> significant staff time and resources to implement. It is necessary and reasonable to focus the limited staff time and resources on the highest priority DWSMA areas. Through implementation of the proposed Rule in the DWSMAs, the MDA will build the Rule infrastructure and will learn important lessons, such as what land use practices worked, what elements contribute to a successful Local Advisory Team, and if there are parts of the Rule that are more or less difficult to enforce. These learnings can then be applied to a broader geographic area in the future, if circumstances warrant.

The MDA will implement the voluntary parts of the 2015 NFMP in townships up to level 2, including forming LATs and conducting groundwater monitoring. Based on the above, it is reasonable for the MDA to focus its regulatory efforts on DWSMAs and continue with the voluntary approach for townships that was outlined in the NFMP, based on available resources.

MDH's authority governing public water suppliers?
The state's Safe Drinking Water Act (SDWA) was adopted by the legislature in 1977 (Minn. Stat. §§ 144.381-144.387). It authorizes the MDH commissioner to promulgate rules which are no less stringent than federal regulations governing public water supplies (Minn. Stat. § 144.383(e)). This authority was granted by the legislature to allow the state, under the federal Safe Drinking Water Act of 1974 (Public Law 93-523 and amendments thereto), to assume primacy for enforcement of the USEPA safe drinking water regulations.

MDH collects data on public water supply wells which includes nitrate-nitrogen analysis. At a minimum, PWSs are required to submit annual samples. If the wells have exceeded 5.4 mg/L nitrate-nitrogen in the past, then quarterly testing is required in order to more closely monitor, evaluate and identify ways to reduce nitrate-nitrogen concentrations in their water supply.

For purposes of the proposed Rule, the MDA will use the nitrate-nitrogen data collected by the MDH in order to evaluate public water supply wells and their surrounding DWMSAs for mitigation levels. These monitoring results are an 'official record' of groundwater conditions that supply the public well. PWS monitoring has been conducted for many years and hence a relationship between communities and MDH is well established. Using this data for purposes of determining mitigation levels is reasonable because the public water supply monitoring program is firmly established and the additional testing requirement at 5.4 mg/L nitrate-nitrogen is an already established 'action level.' In addition, the value of 5.4 mg/L is used in Part 1 for DWSMAs, therefore it is reasonable to be consistent between both parts of the proposed Rule.

Subp. 2. DWSMA mitigation levels. – Evaluation of nitrate-nitrogen concentrations in groundwater

Nitrate-nitrogen concentration data from public wells
Minn. Stat. § 103H.251, subd. 1(a) directs the commissioner to evaluate the detection of pollutants from agricultural chemicals and practices in groundwater of the state. The statute does

not provide details on how this is done, therefore giving the MDA the discretion on how to conduct the evaluation of pollutants. For purposes of public water protection, it is needed for the proposed Rule to use public water supply wells to initially determine the nitrate-nitrogen concentrations in groundwater. This is reasonable because the MDH has conducted annual monitoring in these PWSs over the history of the wells; therefore, in many cases, there is reliable past data available on nitrate-nitrogen concentrations. Subsequent monitoring may continue to use the public well(s) monitoring data or a groundwater monitoring network may be established within the DWSMA for mitigation levels 2, 3 and 4. This approach will yield reliable, accurate results while allowing the MDA flexibility to monitor based on local conditions and allocate its resources appropriately.

Where did the mitigation level criteria come from?
The mitigation part of the NFMP and the proposed Rule is based broadly on a multi-level approach currently in use in the State of Nebraska (Central Platte NRD, 2016). The approach was modified in consideration of the requirements in the Groundwater Protection Act, conditions and data that are Minnesota-specific, and the existing MDH program. The NFMP advisory committee was presented with Nebraska's nitrate groundwater protection activities (including an in-person presentation from University of Nebraska staff) at advisory team meetings in 2011 and 2012. The advisory committee recommended that the MDA develop a phased approach which includes both groundwater monitoring and nitrogen fertilizer BMP adoption criteria, and voluntary and regulatory phases (now called levels). See also MDA, 2014.

There are four levels, two are voluntary and two are regulatory. Each mitigation level in the proposed Rule is designed to initiate actions commensurate with the level of contamination in the source water, or threatening the source water, in the public water supply well. DWSMAs that fall under Part 2 of the proposed Rule will be monitored and will move up or down according to changes in water quality or increases in residual soil nitrate below the root zone which can leach into the groundwater. Factors used for moving within levels include: past nitrate concentrations, the length of time of past public well monitoring, projecting future nitrate concentrations, residual soil nitrate below the root zone, and the adoption of nitrogen fertilizer BMPs. (These are discussed in greater detail below). A DWSMA will always start in a voluntary level and will only progress to a regulatory level if the voluntary approach is unsuccessful either because the nitrogen fertilizer BMPs are not being adopted or groundwater monitoring or soil sampling data indicates that nitrate levels are increasing. DWSMAs may only move up one mitigation level at a time. For example, a DWSMA will never go from mitigation level 1 to mitigation level 3 in a single cycle. (see also Subp. 10)

Initial designation of mitigation levels 1 and 2
The initial designation of mitigation levels 1 and 2 is necessary and reasonable for several reasons. The NFMP, published draft rule and proposed Rule follow the overall intent of and are necessary under the Groundwater Protection Act (Minn. Stat. chap. 103H). Prevention and

implementation must be conducted within a voluntary framework until there is adequate information to provide feedback that the voluntary efforts are not effective in addressing nitrate concerns. The evaluation of monitoring results of the public water supply wells will be used by the MDA to initially designate an area as mitigation level 1 or 2. Mitigation levels 1 and 2 are voluntary levels with no immediate regulatory components. These voluntary levels are meant to encourage farmers to adopt nitrogen fertilizer BMPs and other nitrogen management practices and make changes on their own, without regulation. The MDA will always start the process at either a mitigation level 1 or 2 based on monitoring results. This approach was supported by the NFMP advisory committee, comments received during the NFMP public comment period, request for comments on the proposed rule and the summer 2017 comment period for the draft rule as well. Farmers are always given the chance to voluntarily comply with the nitrogen fertilizer BMPs and other practices (as recommended by the LAT). If they choose not to voluntarily adopt nitrogen fertilizer BMPs for level 2 sites, the MDA will proceed to a regulatory level. For these reasons, the initial designation is reasonable.

The approach is designed to prevent and minimize nitrate-nitrogen concentrations in groundwater to the extent practicable and to prevent pollution from exceeding the health risk limits as directed in Minn. Stat. § 103H.275, subd. 1(c) by working with local farmers and their agronomists to evaluate, promote, and adopt practices that are able to reduce nitrate-nitrogen concentrations in groundwater. The approach starts in a voluntary step because, based on the NFMP advisory committee discussions, the approach likely will be more effective if it is voluntary. This will be done through the formation of a local advisory team (LAT). It was noted that if local farmers and their agronomists are actively consulted and become committed partners in trying to address local nitrate concerns, they will have a much greater potential for solving the problem than any other group. Most farmers live in or near the communities that are experiencing nitrate problems and are concerned about protecting water quality. They control the land and have the ability to manage and change the use of the land in a manner that will be far more effective and efficient in reducing nitrate leaching than is the likely outcome of a purely regulatory approach. The goal of the plan and proposed Rule is, in part, to create a formal approach and structure to facilitate that engagement process. However, the proposed Rule and the specific actions outlined in the proposed Rule are necessary in the event that the voluntary approach is not successful and to outline a clear set of expectations regarding what performance-based outcomes are required before a regulatory action is justified and necessary.

The mitigation process in the proposed Rule has been designed to increase the level of response activity as the water quality gets worse in a manner commensurate with the nitrate pollution as directed in Minn. Stat. § 103H.275, subd. 1(b). It is also designed to be integrated in a practical manner with existing MDH source water protection strategies and regulations. The use of monitoring data, regulatory boundaries, and action level criteria all are based to a large extent on the existing MDH source water protection program. It is necessary for the MDA to determine regulatory boundaries and action levels in order to create an effective proposed Rule. It is reasonable for the MDA to align our regulatory process and guidance with the existing program requirements in order to prevent the inefficient duplication of efforts and in order to take advantage of the extensive amount of effort which has already been dedicated to protecting public water supplies.

Subp. 3. Criteria for initial mitigation level designation

The initial level designation will be based on the nitrate-nitrogen concentration from public water supply wells. The initial level designations are designed to prioritize DWSMAs based on the risk to human health from elevated nitrate. The MDA will continue to work on education and implementation activities in mitigation level 1 DWSMAs and will continue to evaluate nitrate-nitrogen concentrations from the public water supply wells but will not establish monitoring networks in mitigation level 1 DWSMAs. Mitigation level 2 DWSMAs are areas where nitrate-nitrogen concentrations are at or exceed 8.0 mg/L or have been at or exceeded that concentration at any point during the previous 10 years, or are projected to exceed the 10 mg/L MDH HRL within the next ten years. Farmers and their agricultural advisors are provided the opportunity to engage in local work groups to decide and implement local solutions before regulations are necessary. This is a reasonable approach, using objective data and making progressive decisions based on that data.

Subp. 3. Criteria for initial mitigation level designation. A. (1) – Mitigation Level 1

For a mitigation level 1 designation, a threshold concentration of 5.4 mg/L nitrate-nitrogen was selected because it is the concentration under which the MDH, as the lead state agency implementing the federal Safe Water Drinking Act, (Minn. Stat. § 144.381-144.387) requires more frequent monitoring of a well because of the potential for increased health risk due to elevated nitrate-nitrogen concentrations.

Mitigation level 1 is voluntary. However, a mitigation level 1 designation provides notice to the local agricultural community and others within a DWSMA that the source water to the well and groundwater within the DWSMA have significantly elevated concentrations of nitrate-nitrogen and require immediate increased attention and care to nitrogen management practices. This is reasonable because it uses an existing and established guideline for action. For mitigation level 1 DWSMAs the MDA will seek to work with the local agricultural community to increase protective actions, including nitrogen fertilizer BMP adoption, and promotion and funding for implementation of AMTs, within the DWSMA.

Mitigation level 1 DWSMAs will continue to be monitored through the MDH's programs. If nitrate-nitrogen concentrations increase and meet the requirements for a mitigation level 2, the MDA will reevaluate and re-designate the mitigation level of the DWSMA.

Subp. 3. Criteria for initial mitigation level designation. A. (2). – Mitigation Level 2

A DWSMA will initially be placed in mitigation level 2 if the source water has met or exceeded a concentration of 8.0 mg/L nitrate-nitrogen at any time during the previous 10 years or if the projected trend of the source water nitrate-nitrogen concentrations will exceed 10 mg/L within 10 years. These criteria are necessary because some clear benchmarks are needed to determine when the nitrate concentrations are increasing such that increased actions are required commensurate with the nitrate contamination and to prevent the water quality from exceeding the MDH HRL as directed in the Groundwater Protection Act. They are reasonable because they are appropriate indicators that there is an increasing risk that the source water for the public water supply well may exceed the MDH HRL. They were selected specifically to provide for increased response actions before the source water for a well exceeds the MDH HRL.

The concentration of nitrate in groundwater can vary significantly in a well based on a number of factors. For shallow wells or wells constructed in areas with karst geology, the nitrate concentrations in groundwater can vary rapidly over short periods of time due to rapid travel times through the aquifer (Runkel et al, 2014, Steenberg et al, 2014). For deeper wells or wells in slightly less vulnerable aquifers concentrations tend to change at slower rates. Nitrate concentrations in groundwater can also change in response to changes in land use, for example, a significant increase or decrease in the number of acres planted to a high nitrogen using crop like corn, or because of adverse weather which can affect the rate of nitrate leaching. Because of the range of possible situations considering well construction, hydrogeology, land use and weather, the MDA selected indicators for a level 2 determination which are applied over a long period of time. A single detection of nitrate-nitrogen over 8 mg/L at any time over the last 10 years or a projected increase in nitrate-nitrogen concentration to over 10 mg/L over the next 10 years should provide sufficient notice that the source water is at risk and additional actions are needed to prevent the source water from exceeding the MDH HRL of 10 mg/L.

The criteria in the proposed Rule changed from the previous draft and the NFMP by reducing the benchmark from 9 mg/L nitrate-nitrogen over the previous 10 years to 8 mg/L nitrate-nitrogen over the previous 10 years. MDA concluded that this change was needed and reasonable to provide an increased margin-of-safety to take action before source water might exceed the MDH HRL. This change represents moving from an action level that was 10% below the MDH HRL to one that is 20% below the MDH HRL, for a single sampling event.

The proposed Rule requires that the projected increase in nitrate-nitrogen concentrations to greater than 10 mg/L over 10 years be based on a statistical analysis. The statistical trend analysis is reasonable because this is a standard practice already used to evaluate trends in data (generally and specifically water quality trends). Statistical analysis is a rigorous evaluation, using scientific methodology to arrive at results that are highly reliable. The analysis of monitoring data is described in this SONAR, 1573.0040, Supb. 5. Monitoring.

Moving to mitigation level 2 will initiate several actions to address the nitrate-nitrogen concentration concern. These include, most importantly, the formation of a LAT including local farmers and their agronomists to advise on appropriate nitrogen fertilizer BMPs and AMTs to reduce nitrate levels in groundwater. These actions are described in other places in this SONAR.

Subp. 3. Criteria for initial mitigation level designation. B. – Exceptions

The proposed Rule allows the Commissioner to make exceptions for increasing the mitigation level designations for non-municipal public water supply wells. These exceptions might be for one or more of the following reasons:

1. whether there has been a significant change in the amount of land used for agricultural production within a drinking water supply management area;
2. the severity of the nitrate-nitrogen concentration found in other wells in a drinking water supply management area;
3. the population affected by the groundwater contamination of nitrate-nitrogen; and
4. other factors expected to influence nitrate-nitrogen concentration.

Non-municipal community wells serve at least 25 year-round residents or 15 service connections used by year-round residents and are privately owned. They might include nursing homes, mobile home parks, or housing developments. There are about 260 such wells in Minnesota. They typically have much lower capacity (lower pumping rate) wells compared to municipal systems. Because of the low capacity wells, the DWSMA might be very small – on the order of a few hundred acres or less. Many of these systems do not currently have DWSMAs delineated by the MDH, but MDH staff have indicated they plan to develop DWSMAs for the systems that are located in areas with vulnerable groundwater (Steve Robertson, MDH Supervisor, personal communication).

Although these systems are small in scale, they may involve a significant amount of MDA staff work to implement the proposed Rule within them. These exceptions were included in the proposed Rule to allow the MDA to prioritize work with the larger systems which are the most contaminated and serve the largest population being addressed as a higher priority than smaller systems with a smaller served population and less nitrate-nitrogen contamination. In addition, the exceptions allow the commissioner to consider changes in land use that can be especially significant for small DWSMAs. An example would be a nursing home on the edge of a town where the land in the DWSMA is being developed and converted from cropland to residential housing. The exceptions also allow the MDA to consider other factors because of the potential for unusual situations that can occur but are difficult to fully predict.

This provision in the proposed Rule is necessary because it allows the MDA to prioritize work in a practical manner if there are insufficient staff resources to address all of the community water systems with elevated concentrations of nitrate-nitrogen at one time, or if actions in the DWSMA are unlikely to improve water quality because of changes in land use or for other reasons. It is reasonable because it is anticipating situations that might realistically occur, it will ensure that staff resources are used efficiently by working on those areas that pose the greatest risk first, and because the MDA has professional staff able to exercise good judgement when allowing exceptions to the mitigation level criteria for smaller non-municipal water systems.

Subp. 3. Criteria for initial mitigation level designation. C. – Point Sources of Pollution

As stated in the SONAR for 1573.0030, Subp. 2. F., in some cases, elevated nitrate levels within DWSMAs are due to point sources of nitrogen. Examples of point sources may include but are not limited to an improperly sealed well, animal feedlot or an agricultural chemical incident. This exclusion is needed and reasonable since it is clearly inappropriate to consider any mitigation actions, especially regulations, for nitrogen fertilizer if the source of the contamination in the public well is not related to the use of nitrogen fertilizer.

Subp. 3. Criteria for initial mitigation level designations. D. - Partial Exclusions Due to Low Risk

The commissioner may exclude part of a drinking water supply management area from a level designation if the commissioner determines that the area is not contributing significantly to the contamination of the public well in the drinking water supply management area. This provision in the rule is necessary to allow the commissioner to exempt parts of a DWSMA which are not contributing significantly to the groundwater contamination in the public well from the level determination and subsequent requirements in the rule.

DWSMAs vary in size from very small, less than a hundred acres, to relatively large, on the scale of tens of thousands of acres. For most DWSMAs the soils types and vulnerability to groundwater contamination are likely to be fairly uniform across the DWSMA and this exclusion will not be needed. But for large DWSMAs it is reasonable to expect that there will be areas with significantly different soils types, land features, and groundwater vulnerability such that some parts of the DWSMA may not be contributing significantly to high nitrate-nitrogen concentrations in the public well.

This provision is necessary to ensure that the commissioner does not implement surveys, install monitoring wells, promote practices, and potentially impose regulatory requirements and related costs in areas where these activities will not significantly help reduce nitrate-nitrogen concentrations in the public well. It is reasonable because the Groundwater Protection Act directs that Water Resource Protection Requirements should be practicable and consider factors such as economics, implementability and effectiveness, and implementing certain practices uniformly across a DWSMA including in areas where they may provide limited environmental benefits would not meet this requirement.

Subp. 4. Determination of nitrogen fertilizer best management practices and mitigation levels. A. – Determination of BMPs and LATs.

Determination of nitrogen fertilizer BMPs for each DWSMA?
The U of M nitrogen fertilizer BMPs are developed and promoted as general guidance for the majority of the soils, climate conditions and crops found in the each of the five BMP Regions. Frequently localized conditions can be considerably different requiring site specific recommendations. In many DWMSAs, the unique conditions are frequently much more conducive for nitrogen leaching. Many of the DWMSAs already identified having elevated nitrates are frequently those with significant acres comprised of coarse texture soils or thin mantles of loamy soils underlain by sands and gravels. For these reasons, the local advisory teams (LATs), in partnership with experts from the U of M and the MDA will be helpful in recommending the most appropriate practices.

A primary goal of the NFMP and the proposed rule is to create a process which encourages local farmers and their agronomists to learn about and adopt the most current and effective practices and technologies that will help reduce nitrate contamination in highly vulnerable groundwater areas. The use of LATs is intended specifically to accomplish that goal.

Local advisory team
When a DWSMA is designated as a mitigation level 2, it indicates that additional monitoring and education/promotion activities need to begin. After a DWMSA is designated in mitigation level 2 status, a very important step is the establishment of a local advisory team (LAT). The purpose of LATs will be to make recommendations to the commissioner about the appropriate nitrogen fertilizer BMPs and AMTs that should be used in the DWSMA While the formation of the LAT in a mitigation level 2 is not mandatory, it is desirable because the LAT can help develop and implement locally viable solutions to address elevated nitrate-nitrogen concentrations. The LAT will be critical to advising the MDA on designing educational aspects including field demonstrations, the Nitrogen Smart training program (U of M Extension/Minnesota Corn Growers) and other outreach approaches.

The LAT will consist of people who are from the area, including farmers, representatives of local groups/organizations, public water supply systems, and government staff and/or professionals who can provide technical or financial support. The majority of members will be local farmers and their crop advisors/consultants. The size and composition of the team will vary depending upon the size of the area, the nature of the problem and availability of local stakeholders; however, it will likely be no more than 15 -20 people. The MDA will develop guidance that outlines the roles and responsibilities of the LAT.

Local farmers and their crop advisors/consultants are critical in helping develop and implement appropriate activities to address elevated nitrate in their groundwater because they control the land use. The mitigation strategy is constructed specifically to involve the local agricultural community in problem solving with the opportunity to avoid regulations if voluntary actions are taken.

LAT decisions will not be determined by majority vote, but rather the team will seek consensus and common ground. The team will advise the MDA in an open process. All members' comments and recommendations will be considered. The MDA will be responsible for final determinations of potential regulatory actions and will seek to provide consistency in decision making for similar situations/areas.

In addition, the MDA believes LAT members know their local area the best, and therefore are best able to determine what will work locally. The MDA acknowledges that a 'one size fits all' approach is not ideal. Instead, the LAT is a reasonable and better alternative to find local solutions to address nitrate in groundwater. During the summer 2017 comment period, there were significant comments supporting the formation and use of LAT to address local nitrate in groundwater issues.

Subp. 4. Determination of nitrogen fertilizer best management practices and mitigation levels. B. – Notice.

Legal notice of proposed and established commissioner's orders is required in Minn. Stat. § 103H.275, subd. 2. Providing legal notice is a balance between providing adequate and appropriate notice to affected parties, but not creating an undue burden (time and expense) to the regulator in providing this notice. Use of a local legal newspaper is a reasonable alternative for the larger DWMSAs. Due to the limited number of producers in many of the smaller DWMSAs, the MDA will contact the landowners, operators, and dealerships directly if they are known. If not, the MDA will publish the water resource protection requirements in two consecutive issues of the legal newspaper.

In addition, it is reasonable to provide other options to provide notices of proposed Rule actions. The agency website is a reasonable option because this is a likely location where individuals impacted by the proposed Rule will go to find more information.

Supb. 5. Monitoring. A and B – Public wells and groundwater monitoring networks

The primary monitoring point for water quality in a water supply well is the raw (untreated) water pumped from the well. This is the source of nitrate-nitrogen concentration data that will be used to evaluate if the source water has exceeded the water quality thresholds used for mitigation level determinations and for assessing if nitrate concentrations are projected to exceed 10 mg /L within a 10-year period. It is reasonable to use this data for decision making since it is the actual water being provided for use by the public water supply system and it is the point where monitoring is conducted under the direction of the MDH.

Public wells

Historical nitrate data provided by the MDH from the water supply well(s) will be evaluated to estimate future nitrate concentration in the well(s). This analysis will use the most recent 10 years of nitrate-nitrogen concentration data provided by the MDH to project future nitrate-nitrogen concentrations. Using regression techniques, the future nitrate-nitrogen concentration in the well(s) will be projected to determine if the concentration is likely to exceed the MDH HRL within ten years.

When a groundwater monitoring network is established within a DWSMA, the groundwater nitrate-nitrogen concentration data will be evaluated after a minimum of three growing seasons or the estimated lag time, whichever is longer. A statistical analysis will be performed to assess change in the nitrate-nitrogen concentration by comparing pre-and post-implementation periods for nitrogen fertilizer BMPs. Changes will be assessed using the 90th percentile concentration from nitrate samples collected from the groundwater monitoring network. It is anticipated that the 90th percentile concentration will generally indicate changes in the nitrate-nitrogen concentration distribution sooner. The statistical significance of change in the 90th percentile concentration will be determined utilizing a 90% confidence level ($p < 0.10$).

It is necessary and reasonable to use statistical methods to evaluate changes in water quality data which sometimes includes considerable variability in the data. Statistical analysis will provide robust analysis of the groundwater nitrate-nitrogen concentration data (from public wells and the groundwater monitoring network – if applicable) to ensure confidence in the results. It is reasonable to consider and use statistical methods that have been developed for this purpose.

The MDA hired a national expert in statistical analysis of groundwater monitoring data to provide guidance on the groundwater monitoring network design and the interpretation of groundwater monitoring data. (Comments on statistics of the conceptual design, the five assumptions of network design, and the seven statistical questions in the Township Nitrate Monitoring Scope of Work, July 2017). Statistical analyses such as those suggested by Dr. Helsel provide a basis for evaluating change in nitrate-nitrogen concentration within the DWSMAs. Dr. Helsel outlines a variety of statistical analyses that can be used to evaluate changes in concentrations over time. These methods will be evaluated to determine which would be the most appropriate for the data being assessed.

Groundwater monitoring network

The MDA may also conduct monitoring to evaluate the effectiveness of nitrate reduction practices in two other ways, through the installation of a groundwater monitoring network within the DWSMA or through monitoring of residual soil nitrate below the root zone. Both of these approaches to monitoring can be used to determine if nitrate levels are increasing or decreasing in the DWSMA.

The MDA may install a groundwater monitoring network to evaluate if the nitrate-nitrogen concentrations are increasing or decreasing across the DWSMA. This is reasonable because a DWSMA is defined as the area that contributes water to a pumping well over a period of 10 years. That means it will take 10 years for groundwater to travel from the boundary of the DWSMA to the pumping well. As such, it would take a minimum of 10 years for changes in practices across the entire DWSMA to be reflected in the water quality in the pumping well. A groundwater monitoring network can be designed and installed to evaluate changes in water quality in the upper portion of the aquifer, at multiple locations within the DWSMA. This will reduce the amount of time required to measure changes in water quality associated with practices that have been implemented at the land surface. This approach is reasonable since the network will be specifically designed to provide an accurate assessment of changes in water quality across the agricultural areas of the DWSMA and will reduce the time required to evaluate those changes. The groundwater monitoring network data will not be used to determine if source water in the DWSMA meets water quality thresholds in the public water supply well, because it is not directly representative of the water supply well. The pumping well may be screened at different depths in an aquifer or in different aquifers and nitrate-nitrogen concentrations can change with increasing depth in an aquifer. Therefore the monitoring data in the public well is not directly comparable to the water quality measured in the shallowest portion of the aquifer.

The wells in the groundwater monitoring network will be constructed to evaluate the water quality in the upper portion of the shallowest aquifer. The groundwater monitoring network will specifically target row crop agricultural areas to assess changes in water quality as a result of changes in agricultural and land management practices within the DWSMA. The groundwater monitoring network will meet the minimum requirements for statistical analysis and may include a variety of well types (monitoring wells, temporary monitoring wells, domestic wells), provided each of the wells meet the specifications and requirements for the monitoring network. The requirements could include but are not limited to: well depth, construction, age, screen length, and well access.

If a groundwater monitoring network cannot be installed, changes in water quality can still be evaluated for regulatory decision making using water samples collected at the pumping well following a period of time equal to the lag time plus the groundwater travel time within the DWSMA.

Subp. 5 Monitoring C. – Residual soil nitrate tests

Residual Soil Nitrate Tests

Researchers routinely examine residual soil nitrate levels while developing and evaluating new nitrogen fertilizer management practices. If application rates exceed crop consumption or if other management changes (such as timing or source) result in reduced fertilizer recovery, the efficiency of the imposed practices can be evaluated through examining the nitrate levels remaining in the soil profile upon crop termination. Quantifying residual soil nitrate levels is an important metric because it is this fraction of the overall nitrogen inputs that has a high probability of escaping through the soil and eventually reaching groundwater supplies. Generally, soil scientists monitor the root zone or directly below the root zone using this technique.

Besides using standard groundwater monitoring approaches, the MDA also considered employing two soil sampling procedures used in Nebraska to evaluate changes in shallow "residual" soil nitrates levels: shallow residual soil nitrate monitoring and deep residual soil nitrate monitoring. In both Nebraska techniques, the idea is to determine if the potential for nitrogen loading is changing without having to wait for the groundwater to respond. Inorganic nitrogen is analyzed by depth increments providing valuable quantitative values on the nitrogen amounts in transport to the water table. Subsequent resampling provides critical information on the rate which the nitrogen is moving and if improvements over time are being achieved. The two different Nebraska approaches are described below.

Shallow Residual Soil Nitrate Monitoring

In a number of nitrate-impacted areas of Nebraska, farmers are required to provide three-foot soil samples annually from each field which grew either corn, potatoes or sorghum. Ferguson (2015) examined forty years of soil testing (0 to 3') results from the Central Platte Natural Resource District and determined that a strong correlation existed between the residual soil nitrate levels and nitrate-nitrogen concentrations of the underlying shallow groundwater in areas of coarse-textured soils. This is important because it provides strong evidence that Nebraska's approach for addressing elevated nitrate-nitrogen concentrations in groundwater is working and the timeframe for seeing measurable improvements is better understood.

Canadian researchers have also used nationwide residual soil nitrate information from shallow sampling over time to make policy decisions related to fertilizer use efficiencies and groundwater implications (Yang et al., 2007; Drury et al., 2007).

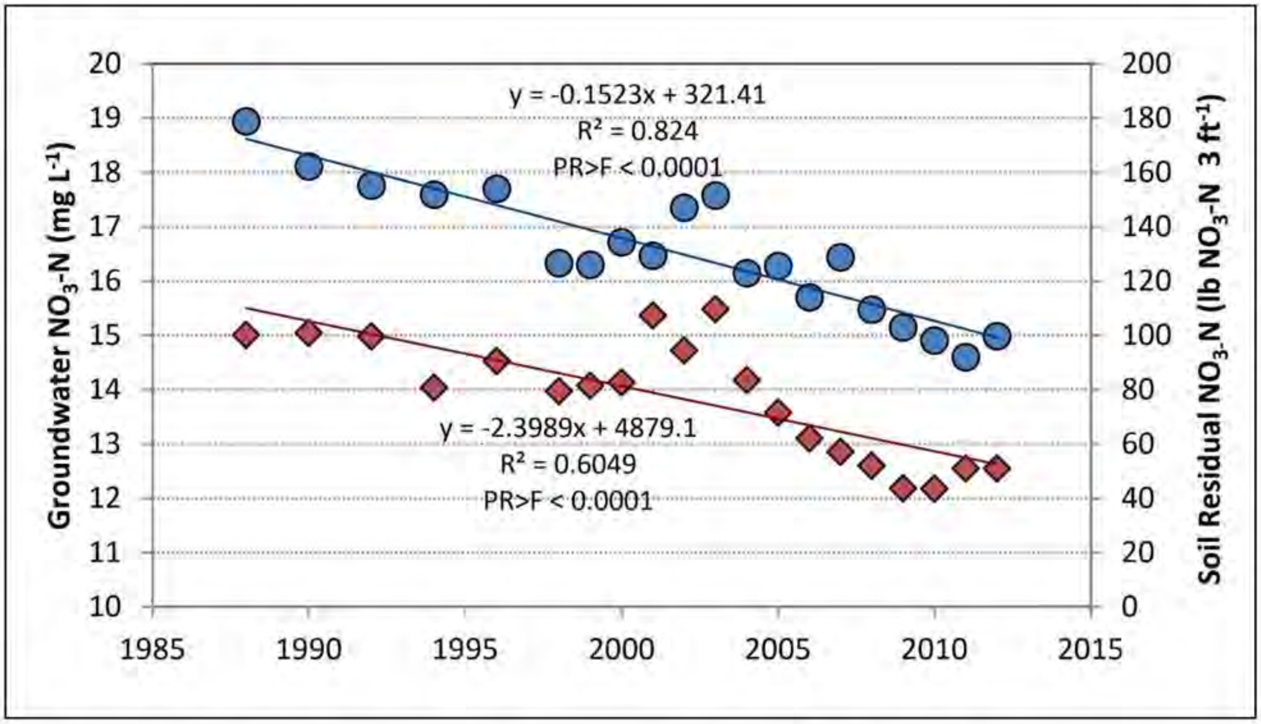

Figure VI-4. Relationship between nitrate-nitrogen in soil and shallow groundwater.

Deep Residual Soil Nitrate Monitoring

Some regions of Nebraska have very deep soils ranging from loams to clay loams. The estimated lag time (the travel time for nitrogen applied to the soil surface to the time it enters the groundwater) is frequently measured in decades. University of Nebraska scientists have experimented with the concept of using deep soil coring information (60 to 100 feet) in order to better understand the nitrogen inventory and the travel speed to groundwater. Routine groundwater monitoring in these types of environments can be greatly enhanced with the associated time lags.

Shields et al. (2017) summarized a number of previous related research projects which established a small number of study sites in the 1990s. The original researchers found that there were very high amounts of inorganic nitrogen (frequently over 1,000 lb. /acre) between the crop zone and the water table. Much of this excess nitrogen is believed to be from poor fertilizer and water management practices used in the 1970s. In the recent re-sampling, Shields determined that nitrogen was traveling at a rate of approximately 29 inches/year. **Error! Reference source**

not found. (Shields and Snow, 2017). Figure IX-5 illustrates a soil coring down to 80 feet at two different time intervals. After twenty years of nitrogen and water management outreach and regulations, this data suggests some drastic reductions in nitrate leaching losses.

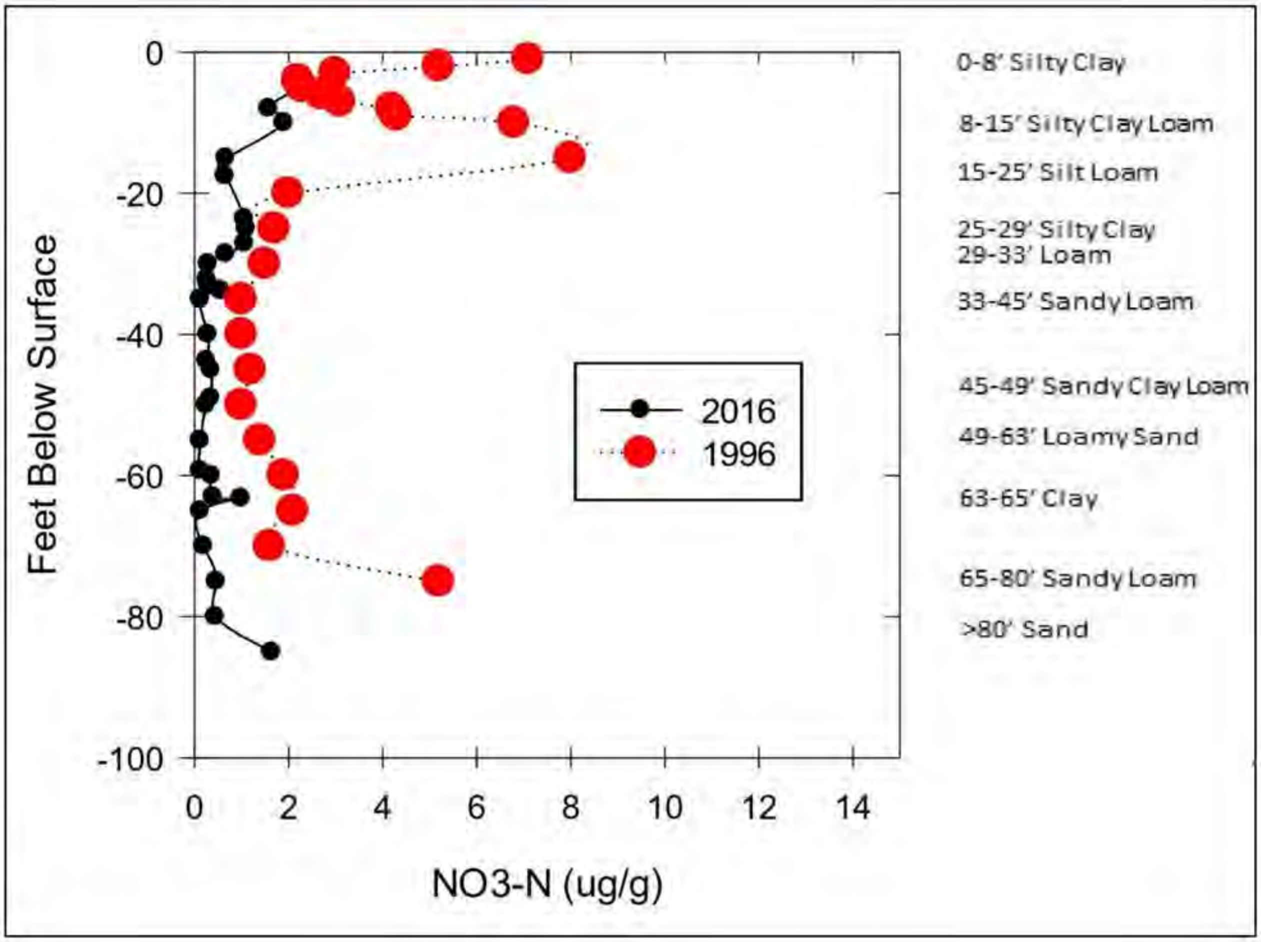

Figure VI-5. Deep soil nitrate coring and lag time to assess nitrogen and water management outreach and regulations.

Implications of the Residual Soil Nitrate Test for the proposed Rule

Use of the shallow residual soil nitrate test provided very good feedback for the Nebraska regulatory process. As previously mentioned, it worked in areas where the soils were coarse textured and the lag times where short because of shallow depth to groundwater. However, this method imposes some burdens: all Nebraska farmers in certain areas with elevated nitrates are required to provide shallow soil test results annually on fields receiving nitrogen fertilizer, and they are required to bear that additional cost. In addition, this testing requires access to a large number of acres. For this reason, the agency chose not to include this method in the rule, but it may be useful in some voluntary responses under the NFMP such as for townships with elevated nitrate.

The deep soil sampling method, the second approach used by the University of Nebraska, provides an accurate and useful approach and is included in the proposed Rule. In regions of the state where groundwater is located at much greater depths, it may be cost prohibitive to install monitoring wells. Similar to the Nebraska approach, deep soil samples would be obtained to establish a baseline inventory of the amount of inorganic nitrogen which has accumulated between the root zone and close proximity to the water table. Borings would be collected early in the Mitigation Level 2 process and then resampled on a predetermined sampling cycle. The number of sampling sites could be limited within the DWMSAs where this approach is used depending on available resources. MDA and the LATs would need to designate a small number of representative fields where the technique would be used.

This technique will provide useful metrics in terms of the initial levels of nitrogen currently in transport to the water table. The nitrogen levels should be reduced over time with improvements in nitrogen management practices. Once the resampling is conducted, the travel time of the nitrogen to groundwater can be quantified. The advantage of this approach is it is possible to determine if the implementation of BMPs and AMTs are effective by reducing the amount of nitrogen in the unsaturated profile without having to wait for extended lag times to actual reach (and ultimately impact) groundwater resources.

Subp. 6. Nitrogen fertilizer best management practices evaluation A.

BMP evaluation in mitigation level 2

According to Minn. Stat. § 103H.275, the MDA shall evaluate the nitrogen fertilizer BMPs based upon two components: 1) the evaluation of BMP implementation; and 2) the evaluation of BMP effectiveness. Each component must be evaluated individually, and their combined effect must be evaluated as well. Evaluation of either component will be a complex process. This section will discuss the tools used for assessing the implementation of nitrogen fertilizer BMPs.

The results of BMP implementation may not be discernible for a long period of time, as measured by the change in nitrate-nitrogen concentration of groundwater. Furthermore, changes in nitrate-nitrogen concentration observed over the course of a single year may or may not be related to BMP adoption. In view of these challenges, it is recognized that BMP adoption must be evaluated as well as BMP effectiveness in preventing or reversing the degradation of water quality.

On-Farm Nutrient Assessments: The ability of the MDA to document farmer adoption rates of voluntary nitrogen fertilizer BMPs is a critical component of the 1989 Minnesota Groundwater Protection Act (Minn. State. chap. 103H). The MDA has developed a diagnostic tool called FArm Nutrient Management Assessment Process (FANMAP) to get a clear understanding of existing farm practices regarding agricultural inputs such as fertilizers, manures and pesticides.

Although it is labor intensive, it provides a useful and accurate method of compiling data on BMP adoption. This approach was developed for DSWMAs and other small-scale water quality projects.

Results have been used to design focused water quality educational programs. Data collected in the program's infancy can be used as a baseline to assist in determining if the nitrogen fertilizer BMPs are being adopted. Over the past twenty years, hundreds of farmers have volunteered two to four hours of their time to share information about their farming operations. The complete compendium of FANMAP surveys is available on the MDA's FANMAP website (n.d. (b)).

Phone Surveys: The MDA has partnered with the NASS and U of M researchers to collect information about fertilizer use and farm management on regional or statewide scales. Partners have pioneered a survey tool for characterizing fertilizer use and associated management. Surveys are conducted over the phone.

Enumerators from NASS are highly skilled at obtaining critical information over the phone with minimal time and burden on the farmer. The first attempt using this technique was in 2010. NASS enumerators surveyed approximately 1,500 corn farmers from across the state to gather information about commercial fertilizer use on corn (Bierman et al. 2011). Statewide nitrogen use surveys for grain corn production are now conducted every other year in partnership with NASS. During the alternate year, surveys on other crops and practices are conducted.

Evaluation for purposes of the proposed Rule will be conducted after a minimum of three growing seasons after the publication of the nitrogen fertilizer BMPs. Since the proposed Rule is focused on DWSMAs, the FANMAP approach previously described will be the likely tool. To determine if proper nitrogen rates are used, it will be necessary to look back at past years practices for the purposes of crediting all sources of nitrogen that are applied. The survey will take into consideration all cropland except soybean (i.e. corn, alfalfa, wheat, etc.)

Time period for BMP adoption

The MDA will inform farmers of the selected nitrogen fertilizer BMPs (and AMTs if funded in mitigation level 3, or for mitigation level 4) prior to the beginning of a growing season and give them adequate time before implementation is required and evaluated by the MDA. The MDA determined that three growing seasons should be used because this is the length of the most common corn-soybean crop rotation. The corn-soybean rotation for the past several years has covered approximately 16 million acres which represents over ¾ of Minnesota's cropland acres.

It is reasonable that the MDA gives farmers time for implementing the nitrogen fertilizer BMPs (and AMTs if required) because after the selection and promotion of the nitrogen fertilizer BMPs, it may take some time for adoption. The MDA routinely finds that growers tend to use rates higher than the U of M recommendations in some parts of the rotations. Farmers will need time to experiment with these more conservative rates. In addition to farm management changes, there may be supplies (e.g., nitrogen fertilizer product availability), equipment (e.g., 'specialized' fertilizer application equipment), or other issues beyond the control of the farmer that may take time to resolve.

Exclude soybean acres

The MDA will not include soybean acres when evaluating compliance whether 80% of the cropland is following nitrogen fertilizer BMPs. Being a legume, soybeans fix their own nitrogen and therefore do not have a nitrogen recommendation except under unique circumstances. The proposed Rule is intended to apply to crops that apply nitrogen fertilizer; therefore it is reasonable that soybeans not be included. If soybeans were included, those acres would artificially increase the number of acres that followed the (non-existent for soybeans) nitrogen fertilizer BMPs. In addition (as noted above), soybeans are most often in rotation with corn, therefore those acres could be evaluated for compliance with required nitrogen fertilizer BMPs during the year corn is grown.

U of M research has shown that soybean loses appreciable amounts of nitrogen in comparison to other legume crops such as alfalfa. Beans frequently lose about 75% of the rate losses typically found under corn even though nitrogen fertilizer is seldom directly applied. Losses, in part, are due to the contributions from mineralized nitrogen along with lower crop water use (resulting in greater nitrogen flux). Alfalfa and other perennials are extremely effective in reducing nitrate losses through the root zone and when these crops are managed correctly, they can have extremely positive water quality benefits. For this reason, the introduction of these crops is considered an AMT and highly encouraged.

The MDA received some comments that suggested that it should not include soybeans in the 80% cropland calculation. Considering all of these factors, it is reasonable that the MDA does not include soybeans in the '80% cropland compliance'.

Justification for using 80% of cropland

Within any geographical region, it is reasonable to expect that some percentage of the agricultural landscape will experience climatic conditions or other conditions which will impede the producer's ability to manage nitrogen inputs in accordance to the nitrogen fertilizer BMPs and corresponding Fertilizer Guidelines (MDA, n.d. (g) Kaiser et al., 2011, 2016, Lamb 2015). For example, one of the consequences of climate change is more localized thunderstorms resulting in wide variations of rainfall within small distances. Large differences are frequently observed within the boundaries of an individual farm. Localized saturated conditions, as well as drought conditions, can have a profound impact on time management and the producer's ability to implement nitrogen management on these minor acres.

Additionally, making alterations to fertilizer management practices can also impact time management, labor costs, labor availability, and many associated equipment issues. For a variety of reasons, it is not realistic to assume that nitrogen fertilizer BMPs can be implemented across all acres for any particular growing season.

There was considerable discussion and eventual consensus across the NFMP Advisory Committee that this threshold level should not be 100%. A range of percentages were discussed and eventually the committee agreed that 80% would represent a balance between challenging producers to continue adopting the best available science yet reflecting that the forces of nature must always be considered.

Why is it needed and reasonable to allow periodic evaluations to monitor progress?
Periodic evaluations of nitrogen fertilizer BMP adoption will allow the agency to check on progress and compliance, and to make adjustments as needed. Over time, cropping systems and nitrogen fertilizer BMPs may change and the MDA will need to track these changes. In addition, evaluations indicate whether the practices needed to improve groundwater quality are in place. These periodic evaluations will allow the MDA to make sure that the desired nitrogen fertilizer BMPs/AMTs in mitigation levels 3 and 4 are being implemented. This type of feedback will also be informative for the LATs and other partners to evaluate the effectiveness of mitigation level 2 promotional activities. For these reasons, it is reasonable that the MDA conduct evaluations of nitrogen fertilizer BMP adoption.

The timeframes of these evaluations may be variable due to the mitigation level and DWSMA area as further discussed below.

Subp. 6. Nitrogen fertilizer best management practices evaluation. B – Evaluation criteria.
The proposed Rule has established several additional considerations when determining whether the nitrogen fertilizer BMPs (and AMTs) are being adopted. The MDA has determined that it is necessary for the rule to include additional circumstances that are relevant in determining compliance with the BMPs. These include:

> *Approved Alternative Management Tools (AMTs):* The AMTs are a replacement or improvement to the nitrogen fertilizer BMPs; therefore, it is reasonable that they be deemed in compliance with the nitrogen fertilizer BMPs. In the NFMP and in subsequent proposed Rule outreach activities, the MDA has repeatedly stated the goal of going beyond the nitrogen fertilizer BMPs and implementing AMTs. Therefore, in an effort to facilitate their use within the proposed Rule, the MDA will maintain a list of agency-approved AMTs so they are readily accessible for the MDA to promote and for farmers to implement. Therefore, it is needed to understand if farmers adopted approved AMTs in order to assess whether they are in compliance with the BMPs.
>
> *Minnesota Agricultural Water Quality Certification Program (MAWQCP):* A compliance determination for MAWQCP is needed because Minn. Stat. § 17.9891 states that enrollment in MAWQCP is deemed in compliance with any state regulation. This

includes the proposed Rule. In addition, in order to get certified under the MAWQCP, the nitrogen fertilizer BMPs as well as other fertilizer management practices will have been adopted on the certified acres.

Lack of Information: If a regulated party does not provide the MDA any information, or provides inadequate information, that party will be determined to not be in compliance with the proposed Rule. The MDA expects regulated parties to be forthcoming during compliance checks, and noncooperation by providing inadequate information will result in an assumption that nitrogen fertilizer BMPs have not been adopted. This is reasonable because the proposed Rule begins in a voluntary level, providing farmers adequate opportunity to comply before regulation. In the regulatory levels, it is reasonable to expect continued cooperation in compliance with regulatory requirements. In addition, determination of noncompliance is reasonable because it is equitable to all regulated parties in an area to require all to comply with the same regulatory requirements.

Waiver from non-compliance due to an agricultural emergency – In some cases, events will occur that are beyond the control of a farmer (e.g., weather events). The proposed Rule needs to account for agricultural emergency events, so that farmers are not deemed noncompliant due to an event that is unpreventable. It would not be uncommon for agricultural emergencies to impact more than one farmer in an area as well. Therefore, an exception for agricultural emergencies is needed and reasonable.

MPCA-approved and implemented manure management plan that include the required BMPs: Manure management plans are in place for feedlots of a defined size throughout Minnesota. These plans require proper management of manure based on the nutrient content including nitrogen. The plans provide a formal process for reviewing and approving the proper management of nutrients. In the comment process, the MDA received several recommendations that MDA use this existing process for approval of any required BMPs and practices so that farmers do not need two reviews of their practices. This provision has been included in the rule in response to those recommendations. A manure management plan that includes any required practices for the land in the DWSMA and has been approved by the MPCA or their designee will be considered to be implementing the required practices under the rule. This is reasonable, because a manure management plan requires that land application of manure be done in a manner that protects surface and groundwater. Therefore, including MPCA approve management plans is reasonable because feedlot rules (Minn. R. chap. 7020) require that nutrient applications be based on crop needs. This includes nitrogen from all sources including manure, fertilizer, crop credits and other sources; however, in addition the proposed Rule requires that the manure management plan is determined to be implemented (by MPCA staff or designee) as well. This is needed and reasonable because the plan must be implemented to reflect that actual manure (and associated nitrogen) management activities protective of water quality are being done.

Subps. 7-9. DWSMA mitigation levels. – Mitigation level 2, 3 and 4 designation review

The proposed Rule provides for a systematic process to determine the appropriate mitigation level. This process considers a review of water quality monitoring data and residual soil nitrate data below the root zone (if available) for all mitigation levels. In addition, for a mitigation level 2 site, it considers a survey on the adoption of designated nitrogen fertilizer BMPs.

The criteria for determining a site to be at a specific mitigation level are clearly defined. A site will move up a mitigation level if the criteria for a specific mitigation level are met. If the criteria for a mitigation level are no longer met because water quality is improving, then the site will be moved down.

The criteria for initial mitigation level 1 and mitigation level 2 determinations were previously discussed in Subp. 3. The criteria for moving a mitigation level 2 site to mitigation level 3 are if the recommended set of nitrogen fertilizer BMPs are not being adopted on 80% of the crop land acres (excluding soybean) or if water monitoring data or residual soil nitrate testing data indicates that nitrate-nitrogen concentrations are increasing.

The development of mitigation level criteria is needed to provide for a consistent approach and for ensuring that the goals of the regulation (reductions of nitrate-nitrogen concentrations in groundwater) are met. These mitigation level criteria are reasonable for two reasons. First, one of the primary goals of the Groundwater Protection Act is to ensure the adoption of nitrogen fertilizer BMPs. The criteria of 80% adoption of the recommended nitrogen fertilizer BMPs was selected because it means that most of the agricultural land with high nitrogen using crops in the DWSMA will be adopting the most important nitrogen fertilizer BMPs to ensure that nitrogen fertilizer is used appropriately and in a manner that will minimize nitrate leaching to groundwater. As is discussed elsewhere in the SONAR, the required percent of BMP adoption is not 100% because there are frequently practical limitations to 100% adoption of some practices and the Groundwater Protection Act clearly directs that any regulatory requirements must be practicable.

The 80% of cropland acres surveyed does not apply to soybean acres. This is reasonable because they do not generally receive significant applications of nitrogen fertilizer. In the case of soybean, it is generally grown in rotation with corn and proper crediting for nitrogen for soybean will be considered during other parts of the crop rotation. Other crops such as alfalfa and perennial crops are included in the assessment of cropland. This is reasonable because growing certain other crops such as perennials can have a significant beneficial effect on reducing nitrate losses. If these crops were not included in the assessment of cropland it might cause an unintended consequence of discouraging their adoption.

The other criteria for moving to mitigation level 3, and also for moving to mitigation level 4 for sites in mitigation level 3, is if nitrate-nitrogen concentrations in groundwater or in residual soil nitrate below the root zone are increasing. These criteria are intended to ensure that, at a minimum, the agricultural practices within the DWSMA are sufficiently protective to prevent water quality from getting worse and from eventually exceeding the HRL for nitrate-nitrogen of 10 mg/L. If nitrate-nitrogen concentrations are continuing to increase that indicates additional implementation actions beyond the widespread voluntary adoption of nitrogen fertilizer BMPs are necessary. In mitigation level 3 the commissioner – in consultation with a local advisory team – would require landowners to implement best management practices and may require other practices such as testing, educational programs and AMTs if they are funded. These actions would represent a significant increase in implementation activities to address the issue.

The timeline for review and possible redetermination of a mitigation level may vary depending upon the lag time for each DWSMA. The approach is to reevaluate the appropriate mitigation level after not less than three growing seasons or the estimated lag time, whichever is longer, following when the recommended practices are first published for mitigation level 2 or when the order is finalized and published for mitigation levels 3 and 4. The monitoring data and mitigation level will then be reviewed not less than every three years thereafter. The exception to this approach is if residual soil nitrate testing below the root zone is conducted in which case the timeline for evaluating these tests will be highly dependent upon the characteristics of the site and the procedures employed in the testing. Soil residual nitrate tests would be conducted in cases where the lag time is measured in decades. In such instances it is not feasible to wait until after the lag time and soil residual nitrate tests offer an alternative method to tracking the amount of nitrate moving to groundwater. However, these procedures will require an initial and one or more follow-up series of soil tests. In most cases the timeframe for evaluating these tests will be several years between tests at a minimum. For purposes of the rule it states that the time interval for review of residual soil nitrate tests will be not less than three years. Use of this test to assess changes in nitrate-nitrogen concentration is reasonable because it provides a more rapid alternative to groundwater monitoring in areas where there are very long lag times (which can be decades) or where it is very expensive to install monitoring wells. However, residual soil nitrate testing is highly resource intensive and still relatively new therefore it is anticipated that its application will be very limited. (see SONAR Supb. 5. Monitoring, Residual Soil Nitrate Monitoring).

Lag Time

Lag time is the period of time for nitrate to travel from the point of application on or near the land surface, through the unsaturated zone and reach the aquifer being monitored. This lag time can vary significantly in different locations across Minnesota from periods of less than a year in extremely vulnerable aquifers to decades or longer in some deeper aquifers. It is necessary to account for the lag time when evaluating if changes in land management practices are having an effect on water quality in an aquifer. The lag time can be estimated in several ways, including through models or calculations that estimate these travel times and/or through the use of a variety of tracers. Tracers are chemicals which are used in the environment at a known point in time so that when they are first detected in an aquifer they provide an estimate of the travel time to that aquifer. There are a number of commonly used tracers including the first use of a specific pesticide, pharmaceutical or compound linked to atmospheric deposition. The Minnesota Geologic Survey (MGS), the United States Geologic Survey (USGS) and the MN DNR have all provided technical advice, research publications, and conduct or support ongoing research to estimate travel times to different aquifers in Minnesota (Runkel et al, 2014, Steenberg et al, 2014, Puckett and Cowdery, 2002). The following references provide information on tracers. https://water.usgs.gov/lab/references/group/

These timelines provide clear guidance on expectations to the public regarding the MDA's process for review of water quality data, and expectations on when changes in water quality can reasonably be anticipated based on changes in practices. It is necessary to have some guidance in the proposed Rule on the evaluation process including timelines for moving to regulation or, if water quality improves, when regulatory requirements may be dropped. The timelines proposed in the proposed Rule are reasonable for several reasons. Three growing seasons is based on the three-year timeline that is frequently used for a crop rotation. This will provide a reasonable timeframe for all of the farmers in the DWSMA to learn about, evaluate and adopt any changes in practices that are necessary. During this time the MDA and partners in the agricultural community and local government will actively promote the nitrogen fertilizer BMPs, and at the same time discuss and encourage the adoption of AMTs. It is important to note that one of the primary goals of the NFMP is to educate on and promote the most effective and current agricultural practices that can minimize nitrate losses. The AMTs, which are described elsewhere in the SONAR, are intended to provide a highly flexible approach to engaging and sharing information across the entire agricultural community in Minnesota on new or proven strategies and technologies the can help reduce nitrate losses in vulnerable groundwater areas. Anyone can suggest AMTs and if they are suitable, they will be listed on the MDA website and may be considered for use in DWSMAs. The MDA is currently funding agricultural educator positions with U of M Extension specifically to promote nitrogen fertilizer BMPs and AMTs in targeted high-risk areas including DWSMAs. The three-year adoption period, especially in mitigation level 2, will be an important time for working with the local advisory committee, local farmers and agronomists to promote both the nitrogen fertilizer BMPs and AMTs in the DWSMA. This is reasonable and supports the goal of promoting practices that can improve water quality in the DWSMA.

As previously discussed, consideration of the lag time from when a change in practices will have an effect on groundwater quality is necessary and reasonable because we cannot know if changes in practices are having the desired effect until after the lag time (see 1573.0040, Supb. 5. Monitoring).

The timeline for mitigation review states that it will be "not fewer than" three cropping seasons or the lag time for water sampling, whichever is longer, or "not fewer than" three years for residual soil nitrate tests. The phrase "not fewer than" has been used because it is necessary and reasonable to use a longer timeline in some situations. For example, it is necessary to align the survey of BMP adoption in the DWSMA with the monitoring data, so they are assessed together. If the BMP adoption survey takes longer than anticipated, then it will be necessary to delay the review of the mitigation level until it is completed. In addition, there might be other factors which require a delay in the survey of BMP adoption. There could be extreme weather events such as a drought or extremely late planting due to heavy rainfall or late spring planting under which the Commissioner may allow wide spread exceptions to BMP adoption. In those years the MDA would postpone surveys until following a normal cropping year. The timelines for use of residual soil nitrate tests will vary by the test and may also be modified during periods of extreme weather. When working with agricultural systems, it is necessary to have some flexibility to adjust to weather conditions. An approach that provides this flexibility is reasonable and necessary to efficiently align different testing and survey methods into a single review cycle and to adjust or correct for extreme weather events.

The proposed Rule allows the commissioner to grant a one-time delay moving a mitigation level 2 or mitigation level 3 site up a mitigation level for a period equal to three growing seasons or the lag time, whichever is longer, or for a time period equal to the time used for the reviewing the level determination for residual soil nitrate tests, if the responsible parties have demonstrated progress in addressing nitrate in groundwater within the DWSMA. This provision has been included in the proposed Rule to recognize situations in which actions in the DWSMA have already been implemented that are comparable to, or go beyond, the actions that would likely be required in a mitigation level 3 or mitigation level 4 order. In this case the order would be unnecessary and even counter-productive. This provision might be applied in a situation where it took several years to implement practices that are much more extensive than mitigation level 2 nitrogen fertilizer BMPs or mitigation level 3 water resource protection requirements, such as a change in the cropping system to a perennial crop. This delay in implementation might be because it took a long time to obtain funding to implement the new practice, which is quite common when implementation funds are limited as they generally are. But since the new practices will have been implemented, it is appropriate to provide additional time to evaluate how effective they are. This provision in the proposed Rule is necessary because if the increased actions taken are effective the order would be unnecessary. Further, it might actually be counter-productive to issue the order because any regulatory action tends to provoke a defensive response from some members of a regulated community and an order that might reasonably be viewed as clearly unnecessary might offend and discourage further voluntary cooperative efforts. It is important to note that a goal of the Groundwater Protection Act and the NFMP is to address nitrate concerns through a voluntary approach and only move to a regulatory approach if the voluntary approach is not successful. This provision allows the commissioner to encourage and reward a strong voluntary response to elevated nitrate in the DWSMA.

The proposed Rule also allows the commissioner to make exceptions to increasing a mitigation level due to changes in land use. Some DWSMAs are very small and changes in land use might have a dramatic effect on water quality. In some cases there may be limited cropland left in a DWSMA. An example might be a DWSMA on the edge of an area where land is being converted from agriculture to suburban development.

The commissioner could not use the exceptions to increase the mitigation level faster than the other parts of the proposed Rule allow. However, the commissioner may make exceptions to the criteria and not increase a mitigation level based on a reduced risk of nitrate contamination to groundwater.

This provision in the proposed Rule is necessary because it allows the MDA to use resources efficiently and to be able to respond to situations where the source for elevated nitrate in a public well has been removed or greatly diminished even though, because of lag times and travel times within the DWSMA, it may take many years for high nitrate-nitrogen concentrations in the well to fall. It is reasonable for MDA to include provisions in the proposed Rule which allow flexibility for quickly adjusting to changes in nitrogen sources so that limited resources are not wasted.

A mitigation level 3 site will be moved to mitigation level 4 if nitrate water monitoring data or residual soil nitrate testing data shows nitrate-nitrogen concentrations are increasing as described above, or if the nitrate-nitrogen concentration in the sampling data from the public well exceeds 9 mg/L three times over the previous 10 years. The criteria indicate that the source water to the public well is at great risk of exceeding the nitrate-nitrogen MDH HRL of 10 mg/L and additional implementation activities than are required for mitigation level 3 are needed to prevent this from occurring. For mitigation level 4, the proposed Rule allows the commissioner, in consultation with the LAT, to order the implementation of any actions that are allowed under the Groundwater Protection Act. For a mitigation level 4 order the commissioner, in consultation with the LAT, would conduct a detailed site-specific assessment of the site, and then select practices that are likely to reduce nitrate-nitrogen concentrations in the source water to below the MDH HRL in consideration of the requirements in the Groundwater Protection Act. It is important to note the commissioner must consider economic and other practical factors for any requirements in the order. The specific statutory language (Minn. Stat. § 103H.275, subd. 2) regarding what the commissioner could require in the order is the following:

> *"The water resource protection requirements must be based on the use and effectiveness of best management practices, the product use and practices contributing to the pollution*

> *detected, economic factors, availability, technical feasibility, implementability, and effectiveness."*

It is necessary to have clear criteria of when the concern for high nitrate-nitrogen concentration in groundwater or threatening groundwater justify moving to the highest regulatory requirements allowed by the Groundwater Protection Act and the proposed Rule. It is reasonable for the proposed Rule to adopt these specific criteria for moving to a mitigation level 4 because the criteria are reasonable indicators that there is a significant risk that the source water will exceed the MDH HRL if additional actions are not implemented than are currently being conducted under mitigation level 3.

If the criteria for a given mitigation level are no longer met, then a site will be moved to a lower mitigation level. The criteria for a specific mitigation level do not change. For a mitigation level 4 site it would be moved down one mitigation level to a mitigation level 3 site, and a mitigation level 3 order would be prepared in accordance with the mitigation level 3 requirements in the proposed Rule. For a mitigation level 3 site it would be moved down to mitigation level 1. This is because the water quality goal of not exceeding 8 mg/L nitrate-nitrogen over 10 years is the same for mitigation level 2 and 3. In addition, the site cannot have increasing nitrate-nitrogen concentrations as previously discussed.

It is necessary to have clear guidance in the proposed Rule for when a site will be removed from regulatory requirements. It is reasonable to use the same set of criteria for moving a site up or down since the criteria are based an increasing concern that nitrate-nitrogen concentrations are threatening to exceed the MDH HRL for source water in a public well, and if this concern no longer true, then regulatory requirements should be reduced. It is important to recognize that the water quality criteria are based on the nitrate-nitrogen concentrations observed over period of 10 years. It is felt that this is a sufficiently long period to provide confidence that the changes are likely to continue to be sustained over the long term

Subp. 10. DWSMA mitigation levels. - Limitation on change in designation

It is needed and reasonable for a DWSMA to only increase one mitigation level at a time in order to give regulated parties certainty about regulation. No less than every three growing seasons or the lag time, whichever is longer, DWSMAs with a mitigation level of 2 or higher will be reevaluated. If nitrate-nitrogen concentrations are increasing, the regulated party knows that they will only move up one mitigation level until the next re-evaluation cycle. This proposed Rule provides certainty for the responsible party and allows some certainty for the regulated party regarding the process of increasing mitigation levels.

E. 1573.0050 Water Resource Protection Requirements Order

Subp. 1. Commissioner's water resource protection requirements order

The MDA is required to lay out the procedures for notice to be given to persons affected by the water resource protection requirements order under Minn. Stat. § 103H.275, subd. 2(d). This provision of the proposed Rule is reasonable to identify who is subject to the water resource protection requirements order when it is issued for a DWSMA. Minnesota farms can be operated by an owner, a tenant, or other arrangements. Where neighboring DWSMAs are the same mitigation level and the cropping systems are similar, meaning that the implemented nitrogen fertilizer BMPs would be the same or similar, it is necessary and reasonable to use the MDA's limited resources to address these areas with one LAT and one mitigation level. This can reduce complications for those farmers that operate on land in more than one DWSMA and will not provide any additional regulations for those farmers that only operate in one DWSMA.

Subp. 1. Commissioner's water resource protection requirements order. A. – Mitigation level 3 and 4 DWSMAs

To address the most serious groundwater concerns, it is necessary and reasonable for the commissioner to issue a water resource protection requirements order, as described in Minn. Stat. § 103H.275, subd. 2(c), for DWSMAs that meet the requirements of mitigation levels 3 and 4 as described in this SONAR 1573.0040 Drinking Water Supply Management Areas; Mitigation Level Designations.

The water resource protection requirements in the proposed Rule are necessary to achieve the purpose of the Groundwater Protection Act, which is to ensure that groundwater is "maintained in its natural condition." Minn. Stat. § 103H.001.

Under the Groundwater Protection Act, the commissioner of agriculture is charged with, among other things, promoting the implementation of BMPs to prevent or minimize pollution from agricultural chemicals "to the extent practicable." Minn. Stat. § 103H.275, subd. 1. The commissioner of agriculture may issue water resource protection requirements if "the implementation of best management practices has proven to be ineffective." Minn. Stat. § 103H.275, subd. 1(b). Thus, if BMPs have not been implemented or if they have been implemented and found to be ineffective, the commissioner may issue water resource protection requirements. The proposed Rule addresses both the "implementation" factor and the "ineffectiveness" factor.

Implementation: Under the proposed Rule, the commissioner will issue water resource protection requirements if nitrogen fertilizer BMPs have been implemented on less than 80% of the cropland in the affected DWSMA. If nitrogen fertilizer BMPs are implemented on less than 80% of the cropland in the affected DWSMA, it is expected that nitrate-nitrogen concentrations in groundwater will continue to rise, making it necessary for the commissioner to issue a water resource protection requirements order. The use of 80% is a reasonable measurement to determine if nitrogen fertilizer BMPs have been implemented.

Ineffective: Under the proposed Rule, the commissioner also will issue a water resource protection requirements order if the nitrogen fertilizer BMPs have been proven ineffective. This will be assessed by measuring whether nitrate-nitrogen concentrations are increasing.

This is reasonable because, before moving to any water resource protection requirement, the MDA intends to use voluntary mitigation levels 1 and 2 to alert farmers to groundwater conditions, encourage farmers to voluntarily adopt the nitrogen fertilizer BMPs, and employ farmer-led strategies to protect groundwater. Farmers will have adequate time to implement the measures voluntarily, and adequate time will be allowed to take into account the travel time of the affected groundwater. It is also reasonable because the commissioner will assess whether the criteria have been met through scientifically accepted methods for testing for nitrate in groundwater (see 1573.0040 Drinking Water Supply Management Areas; Mitigation Level Designations). If the nitrate-nitrogen concentrations meet those objective criteria, it will be necessary for the commissioner to adopt water resource protection requirements in order to prevent the nitrate-nitrogen concentrations from becoming a broader public health issue by exceeding the MDH HRLs. It is also reasonable and satisfies the provisions of Minn. Stat. § 103H.275, subd. 2(c) because the water resource protection requirements order will be site-specific for each affected DWSMA.

Subp. 1. Commissioner's water resource protection requirements order. B. – Presence of groundwater monitoring networks or residual soil nitrate testing

It is necessary for the rule, as part of the mitigation level decision, to account for the time it takes for changes in agricultural or land management practices on the land surface to have an effect on water quality in the aquifer or in the public well. As noted in 1573.0060, subp. 5, the Commissioner may construction a groundwater monitoring network or conduct residual soil nitrate testing to evaluate if the water quality within a DWSMA is getting worse for purposes of designating a mitigation level. The groundwater monitoring network will be designed to evaluate water quality for groundwater considering the unique hydrogeology in each DWSMA. The installation of a monitoring network and use for mitigation level decisions is reasonable because it will provide a rapid and technically defensible assessment of changes in groundwater quality. The monitoring data from the monitoring network will be a direct reflection of the effectiveness of changes in agricultural or land management practices in reducing nitrate-nitrogen contamination in the aquifer. Residual soil nitrate testing below the root zone provides similar information on the increase or decrease of nitrate levels in soils below the root zone. Nitrate in soil below the root zone will not be taken up by the crop and is available for migration to the groundwater, and provides a useful indicator of future nitrate leaching into the aquifer.

For all aquifers there is a lag time before changes in agricultural or land management practices have a beneficial or harmful effect on water quality in the underlying aquifer. This is because it takes time for nitrate to migrate below the root zone of the crop where nitrate may be taken up by the plant, and through an unsaturated zone below the ground surface before it reaches an aquifer. An aquifer is a geologic formation that yields usable quantities of groundwater. This lag time can vary substantially from less than a year to decades or longer depending upon the depth to groundwater and ability of the soil or bedrock to rapidly conduct water (the hydraulic conductivity) (Adams, 2016, Struffert et al, 2016).

The DWSMA is a two-dimensional estimate of the area within an aquifer that would provide groundwater to a pumping well within a period of 10 years. The DWSMA is based on horizontal travel times within an aquifer (i.e. movement of nitrate once it has reached groundwater) and does not generally consider the lag time for nitrate or another contaminant to travel downward to reach the aquifer. The installation of a groundwater monitoring network or conducting residual soil nitrate testing will assess the changes in water quality across the entire DWSMA at once, without waiting 10 years for groundwater from the most distant part of the DWSMA to reach the public water supply well. Therefore it is reasonable, in areas where a groundwater monitoring network is installed or residual soil nitrate testing is conducted, for the order to apply to the entire DWSMA.

Subp. 1. Commissioner's water resource protection requirements order. C. – for areas where a groundwater monitoring network is not installed or residual soil testing is not conducted

It is necessary for the rule, as part of the mitigation level decision, to account for the time it takes for changes in agricultural or land management practices to have an effect on water quality in the public well. As described in subpart 1 (B), a DWSMA is calculated based on the two dimensional area in an aquifer that will provide water to a pumping well over a period of 10 years without consideration of lag time. In contrast to the situation described in subpart 1 (B), if a groundwater monitoring network is not installed, or residual soil nitrate testing is not conducted, then the monitoring information will not be available to assess the entire DWSMA at one time until a period equal to the lag time plus 10 years to account for the horizontal travel time across the entire DWSMA. However, the effectiveness of practices on water quality can be evaluated for those parts of the DWSMA that are having an impact on water quality in the public well based on estimated lag and horizontal travel times.

This provision in the rule provides that an order in a DWSMA may only apply to that part of the DWSMA for which practices on the land surface would impact water quality in the public well, considering both the lag time for nitrate to reach the aquifer and the horizontal travel time for water in the aquifer to reach the well. This is reasonable, because it ensures that the order will only apply to those fields where practices are impacting water quality in the public well based on a detailed assessment of the estimated travel time for nitrate-nitrogen to travel from the place of application to the well.

Subp. 1. Commissioner's water resource protection requirements order. D. – Prioritizing issuance

Minnesota's agricultural economy and its geology are very diverse and using a water resource protection requirements order is necessary as they allow the MDA to tailor groundwater improvement solutions to fit an affected area. The MDA has limited staff and resources, and the criteria described in part 1573.0040, Subp. 3 (A) of the proposed Rule allows the commissioner to prioritize the areas of greatest concern in order to use these resources most efficiently. Using the criteria described in the proposed Rule to prioritize water resource protection requirements orders are reasonable as it allows for areas with high groundwater nitrate concentrations that affect the largest populations to be prioritized over areas where nitrate-nitrogen concentrations are low and/or where there are higher levels of nitrogen fertilizer BMPs are adopted.

Subp. 1. Commissioner's water resource protection requirements order. E. – Contents and application

Due process requires notice of a government action that may affect a private interest and provides a meaningful opportunity to be heard. The content of the water resource protection requirements order are needed and reasonable in order to inform the responsible parties in the DWSMA of the basis for its designation of a mitigation level 3 or 4. Including the information described in the proposed Rule is reasonable to sufficiently inform a responsible party why the DWSMA had been designated a mitigation level 3 or 4. This information includes letting responsible parties know of their mitigation level; providing responsible parties with the evidence as to why the mitigation level has been designated for their area;, informing regulated parties about the boundaries of the DWSMA that the order applies to, when the water resource protection requirements order will be effective, and their rights to contest the case. It is needed for the MDA to provide the responsible parties with the data that lead to the mitigation level designation. This data can help farmers understand that there is a groundwater problem in their DWSMA. It is reasonable and will help the regulated parties in that DWSMA understand the steps the MDA will take to work with the local area to reduce the concentration of nitrate-nitrogen in groundwater.

Subp. 1. Commissioner's water resource protection requirements order. F. – DWSMA partial exclusions

This provision in the rule is necessary to allow the commissioner to exempt parts of a DWSMA which are not contributing significantly to the groundwater contamination in the public well from certain requirements in the rule, and to allow MDA to consider other factors that may make implementation of a specific practice impracticable because of the unsuitability of the location for the specific practice.

An important consideration when working with agricultural systems is that one size or set of practices does not fit all landscapes and cropping systems. DWSMAs vary in size from very small, less than a hundred acres, to relatively large, on the scale of tens of thousands of acres. For most DWSMAs, the soils types and vulnerability to groundwater contamination are likely to be fairly uniform across the DWSMA and this exclusion will not be needed. But for large DWSMAs, it is reasonable to expect that there will be areas with significantly different soils types and groundwater vulnerability such that some parts of the DWSMA may not be contributing significantly to high nitrate-nitrogen concentrations in the public well.

In addition for large DWSMAs there may be differences in soils types, land features, or groundwater vulnerability such that the practices that are highly desirable for one area may not be as beneficial or even practicable to implement across the entire DWSMA. This is especially important for level three orders that may require more complex AMTs (if fully funded) and for level four orders that can require any practices allowed under the Groundwater Protection Act. These practices could be much more difficult to implement then standard fertilizer BMPs and may not be suitable for all of the land area in a large DWSMA or their implementation in some parts of the DWSMA may provide little or no improvement in nitrate-nitrogen concentrations in the public well.

This provision is necessary to ensure that the commissioner does not impose requirements and related costs on individuals in areas where they will not significantly help reduce nitrate-nitrogen concentrations in the public well. It is reasonable because the Groundwater Protection Act directs that Water Resource Protection Requirements should be practicable and consider factors such as economics, implementability, and effectiveness; implementing certain practices uniformly across a DWSMA including in areas where they may provide limited environmental benefits would not meet this requirement. It is necessary to be able to exclude parts of a DWSMA from a water resource protection requirements order so that they are not overly broad and do not include persons whose practices are not contributing significantly to the contamination. It is also reasonable to include only those responsible persons whose actions can affect the groundwater in the DWSMA.

Subp. 1. Commissioner's water resource protection requirements order. G. – Exclusion.

This requirement is addressed under in the SONAR under 1573.0040, **Error! Reference source not found.**

Subps. 2-4 and 6. Commissioner's water resource protection requirements order – Notice, contested case hearings, final order effective date and judicial review

These provisions are necessary and reasonable because they provide due process and follow the requirements set forth at Minn. Stat. § 103H.275, subd. 2

Minn. Stat. § 103H.275, subd. 2(d) requires the MDA to provide procedural due process to persons affected by a commissioner's order. Procedural due process requires notice of a government action that may affect a private interest, and a meaningful opportunity to be heard. The MDA considered the question of how much process is due in issuing a water resource protection requirements order. *"[T]he requirements of due process must be measured according to the nature of the government function involved and whether or not interests are directly affected by the government action." Barton Contracting Company, Inc., v. City of Afton*, 268 N.W.2d 712, 715 (Minn. 1978). The MDA believes it is reasonable and necessary to provide sufficient notice of its proposed action and ample, meaningful opportunity for affected farmers to be heard. The process for issuing a water resource protection requirements order was drafted to follow the process outlined in the Public Waters Inventory because it involved similar due process challenges that are shared by the MDA (Minn. Stat. § 105.391). The procedural due process described in the public waters inventory has been upheld by the Supreme Court of Minnesota in *Application of Christenson*, 417 N.W.2d 607 (Minn. 1987).

Minn. Stat. 103H.275, subd. 2(d) authorizes the MDA to provide notice by personal service, publication, or other appropriate methods. While personal service will be the first priority, in large DWSMAs, the MDA may encounter significant difficulty and administrative burden in identifying potentially affected operators. In many cases, the landowner and the operator are different entities. Landowners may be living out of state and, while it might be possible to identify all landowners through tax records, not all landowners and operators are the same entity. It is possible that the task of comparing maps with land records to determine owners and addresses would only provide the MDA with partial information. The MDA would still not be aware of the operator on the land. Under these circumstances, providing published notice is the most efficient and effective way to provide notice to the actual operator of affected farmland. As the rule on the public waters inventory states, *"To provide personal notice to all interested persons in the public water inventory process throughout the state would be a nearly impossible administrative task."* For large DWSMAs, notifying each individual landowner and operator of that land could similarly be a nearly impossible administrative task.

The USDA Farm Service Agency (USDA-FSA) collects data about operators on agricultural land for federal grants and funding purposes. However, this information is federal and not available to the MDA.

The proposed Rule incorporates many procedural safeguards to prevent erroneous designation or mandatory practices that may a farmer may object to: there are required informational meetings, multiple publications in legal newspapers, public hearings, and notice to other governmental agencies, cities, counties and the township board. Judicial review pursuant to Minn. Stat. §§ 14.63-14.69, is also available to any person or entity subject to a final order. All of these measures are reasonable and necessary to provide meaningful opportunities to be heard about proposed action to interested parties.

Subp. 5. Commissioner's water resource protection requirements order. – Amended orders

A water resource protection requirements order may need to be amended for a variety of reasons. Research and agricultural practices are always changing and the LAT may recommend that new or additional nitrogen fertilizer BMPs or other practices are needed. An amendment process for the water resource protection requirements order is needed to order to update water resource protection requirements orders. The proposed Rule is reasonable as it outlines the amendment process, which requires due notice similar to the original issuance of a water resource protection requirements order, and will allow affected parties to seek beneficial changes.

Subp. 7. Commissioner's water resource protection requirements order. – Recording

This provision is needed and reasonable so that all affected persons will have notice of specific water resource protection requirement orders and amendments.

F. 1573.0060 Requirements for Water Resource Protection Requirements Orders

All water resource protection requirements orders will be site-specific for each DWSMA, and will be designed with input from a LAT and technical support from the MDA. This is needed so that the water resource protection requirements require a set of activities that are appropriate for the specific cropping systems, soils, hydrogeology, and the climate of the area. The one exception is a record keeping requirement applied to all orders for fertilizer-related records, which is reasonable and necessary in order determine if the required practices in the order have been adopted. This is also necessary to determine proper crediting for the nitrogen contribution or estimated losses due to agricultural practices that may include nitrogen or result in increased or decreased leaching losses of nitrate to groundwater. Many agricultural practices can have an influence on nitrate leaching and losses through runoff or atmospheric loss.

All responsible parties must comply with the requirements described in the proposed Rule and the final water resource protection requirements order. Minn. Stat. § 103H.275, subd. 2(f) states that a person who violates a water resource protection requirements order is subject to the orders under Minn. Stat. chap. 18D, which gives the MDA authority to enforce rules. This section of the proposed Rule is needed and reasonable because it gives the regulated party and the public knowledge and notice of the MDA's statutory authority.

G. 1573.0070 Water Resource Protection Requirements Order Contents

Subp. 1. Mitigation level 3.

This subpart outlines the categories of what might be included in the water resource protection requirements order. The order under mitigation level 3 may include nitrogen fertilizer BMPs formally approved by the MDA under Minn. Stat. § 103H.151 and any of the specific related practices that are listed under 1573.0070. Setting forth the practices that can be included in a mitigation level 3 order is necessary and reasonable to provide a transparent, consistent, and structured process for selecting technically defensible practices for a mitigation level 3 order. The general list of practices listed under 1573.0070 is reasonable and necessary because it is the result of a lengthy development process starting with the development of the NFMP and continuing into the development of the proposed Rule. It includes suggestions from a stakeholder advisory committee and input from three public comment periods - one on the NFMP and two discretionary comments periods on the draft rule. It includes activities that are widely accepted as being important to properly manage nitrogen fertilizer under different cropping systems and in different settings. It also includes an option for an education requirement which was an option strongly recommended by the advisory committee and has been generally supported as an important option by many commenters.

The nitrogen fertilizer BMPs that can be considered by the MDA for the order have been approved by the MDA under Minn. Stat. § 103H.151. This requirement is reasonable because it is based on the process for developing and approving nitrogen fertilizer BMPs, which is science-based and formal, with a public comment period. Nitrogen fertilizer BMPs are developed based on guidance in Minn. Stat. § 103H.005, subd. 4. They are developed with direct input from U of M scientists and consider economics and other practical considerations. In most cases, adopting the nitrogen fertilizer BMPs will increase a farmer's profitability. They are also flexible and can be amended through the above-stated process to address new studies, new practices, and other considerations such as climate change. Many of the practices are specific to the different regions across Minnesota. Because of the differences in nitrogen fertilizer BMPs for different soils and different regions, not all nitrogen fertilizer BMPs may be suitable for all locations. Therefore, some judgement in the selection of appropriate nitrogen fertilizer BMPs is needed and is an important part of the order development process. The nitrogen fertilizer BMPs are the foundation of good nitrogen management, which in turn is the most important step in minimizing nitrate losses. There is extensive research and many publications on their environmental and economic benefits. For all these reasons considering a requirement for appropriate nitrogen fertilizer BMPs in a mitigation level 3 order is both necessary and reasonable.

The MDA considered other options when drafting the list of water resource protection requirements for mitigation level 3. One of these options includes a fixed list of all possible options that could be considered a nitrogen fertilizer BMP now or in the future. The MDA concluded that this would not be a feasible requirement, as there is continuing research and advancement that may lead to updates of the nitrogen fertilizer BMPs. Practices that may be included on the list now may be outdated in a few years. In addition, new developments should be expected in the future that will likely be included on the recommended nitrogen fertilizer BMP list. Including these in the proposed Rule would make them static and would not allow the proposed Rule to follow future nitrogen fertilizer BMPs. It is necessary and reasonable for the list to be broad enough to cover practices that may be developed in the future, but specific enough so that LATs and responsible parties know what regulations could potentially become eligible nitrogen fertilizer BMPs included in the water resource protection requirements order. The water resource protection requirements order will be developed based on the recommendations of the LATs using the options included under 1573.0100 as the basis for the recommendations. All interested parties will have the opportunity to review the water resource protection requirements order before it goes into effect under the process described in 1573.0080.

Alternative management practices may be required for mitigation level 3 DWSMAs if there is a source of funding available to help offset the costs of implementing the practice. In mitigation level 4, alternative management practices that meet the requirements listed under Minn. Stat. § 103H. 275, subd. 2(a) shall be considered for inclusion in a water resource protection requirements order regardless of whether or not funding is available. As described in this SONAR Section I, 1573.0090 Alternative Management Tools; Alternative Protection Requirements, these practices will go above and beyond the nitrogen fertilizer BMPs and are locally optimized practices that will have been shown to reduce nitrate-nitrogen concentrations in groundwater. In the proposed Rule, AMTs are defined as “specific practices and solutions approved by the commissioner to address groundwater nitrate problems.” In areas with highly vulnerable groundwater, the use of nitrogen fertilizer at the recommended rate, timing, source and placement of the nitrogen fertilizer BMPs may not be enough to decrease the amount of nitrate leaching into groundwater to meet water quality goals. In these areas, the MDA will work with the LAT on locally developed solutions for addressing groundwater nitrate problems that are implemented on a site-specific basis. AMTs are needed because they are practices and activities designed to reduce nitrate leaching. AMTs represents an advanced level of groundwater protection that go beyond traditional nitrogen fertilizer BMPs.

Mitigation level 3 DWSMAs are areas where nitrates have exceeded or are projected to exceed the MDH HRLs within the next 10 years. These areas will affect large populations around the state and regulatory action is being taken to ensure the nitrogen fertilizer BMPs are being adopted. It is necessary for the MDA to be able to require the stronger practices of AMTs to reduce nitrate at this level. However, the MDA acknowledges that there may be additional costs associated with implementing AMTs and given that economic factors are one of the considerations the MDA must consider under Minn. Stat. § 103H.275, subd. 2(a), it is reasonable that these factors will only be required if there is additional funding available.

Mitigation level 3 DWSMA may include requirements for AMTs if funded. This is reasonable because farmers may need incentives to implement AMTs. AMTs may not be profitable, and funding could bridge this gap. Use of funding is reasonable, to ensure that farmers can implement these practices even during periods of very low crop prices. Sources of funding exist from Federal, state, and often also local sources (Lenhart et al., 2017). Funding would currently be available for some of the AMTs being considered, subject to funding levels and priorities within the local area.

Rules that include funding requirements to implement conservation practices to improve water quality are being applied in Wisconsin (Wisc. Stat. § 281.16; Wisc. R. NR 151.09(4)).

Subp. 2. Mitigation level 4.

A commissioner's order for a mitigation level 4 may contain any of the requirements for mitigation level 3, requirements for rate for nitrogen fertilizer, and any practices that meet the definition of water resource protection requirements in Minn. Stat. § 103H.005, subd. 15 (with two exceptions, see below, Subp. 3. Exceptions.) that meet the criteria set forth in Minn. Stat. § 103H.275, subd. 2(a). This is the highest mitigation level and it is reasonable that it would contain the most stringent requirements. It is necessary and reasonable to include these more stringent water resource protections requirements because DWSMAs will have had a minimum of six growing seasons to implement nitrogen fertilizer BMPs and will have had a minimum of three growing seasons under a mitigation level 3 water resource protection requirements order, yet specific indicators show that nitrate levels are not improving.

It is necessary and reasonable for the commissioner to implement more stringent water resource protection requirements in mitigation level 4, because the criteria set forth in the proposed Rule for moving to mitigation level 4 will be the indicators that nitrogen fertilizer BMPs have proven to be ineffective, which is the trigger for implementing more stringent water resource protection requirements under Minn. Stat. § 103H.275, subd. 1(b).

It is necessary and reasonable to include in a mitigation level 4 order any practice that meets Minn. Stat. § 103H.275, subd. 2(a) factors, rather than limiting the commissioner's authority (except as described below in Subp. 3. Exceptions.) to specific, enumerated practices at this time, because agricultural methods, scientific knowledge, treatment methods, and technology will have advanced significantly by the time a DWSMA gets to mitigation level 4, and it would be unreasonable to limit the commissioner's authority to what technology exists at the time a proposed Rule is passed. The commissioner will need to meet the statutory requirements set forth in Minn. Stat. § 103H.275, subd. 2(a) that require that any water resource protection requirements must be *"based on the use and effectiveness of best management practices, the product use and practices contributing to the pollution detected, economic factors, availability, technical feasibility, implementability, and effectiveness."* The MDA must consider these conditions in order to require a practice under mitigation level 4. In considering economic factors in mitigation level 4, it is reasonable and necessary to consider economic impacts both to affected farmers as well as to area residents who must bear the costs of treatment of public water supplies that have been contaminated with nitrate.

The proposed Rule states that the commissioner shall not restrict the selection of the primary crop in mitigation level 4. This part of the proposed Rule is needed and reasonable to clarify for farmers that the water resource protection requirements order will not dictate the main crop they should grow. Requiring farmers to grow the primary crop could put a huge burden on a farmer and have a significant effect on their livelihood. It is probable other crops that could be grown would not be as profitable as the primary crop. Also, other crop options may need other management than the primary crop; therefore farmers would need to alter their management. It would be unreasonable for the commissioner to prevent farmers from selecting which crop to raise in order to earn their livelihoods. The proposed Rule also states that the commissioner cannot require a nitrogen fertilizer application rate lower than the bottom of the rate range in U of M recommended nitrogen fertilizer BMPs. This is reasonable and necessary because requiring a rate that is lower than the bottom of the range would have the effect of restricting the primary crop raised by a farmer.

Subp. 3. Exceptions.

It is needed and reasonable for exceptions to the water resource protection requirements order to be allowed on a site-specific basis as there can be factors that can affect whether nitrogen fertilizer BMPs can be implemented. Weather plays an important role in agriculture, more so than many other industries. In the case of a severe weather event, where there has been damage to large amounts of a crop or a damaging storm that requires crops to be put in late, or other situations where the BMPs can't be followed, it is needed and reasonable for the MDA to grant an exception from a requirement of the water resource protection requirements order to a targeted area or even individual farmer.

H. 1573.0080 Minnesota Agricultural Water Quality Certification Program Exemption

Minn. Stat. § 17.9897 (a)(1) states that once a producer is certified, the producer *"retains certification for up to ten years from the date of certification if the producer complies with the certification agreement, even if the producer does not comply with new state water protection* *laws or rules that take effect during the certification period."* Proposed Rule language was added in order to provide certainty for those producers that are certified that they are deemed to be in compliance with the proposed Rule, for the length of their certification.

Agricultural producers certified in the Minnesota Agricultural Water Certification Program (MAWCP) shall be deemed to be in compliance with the proposed Rule so long as they are consistent with the Certification Agreement signed by the commissioner. As stated in Minn. Stat. § 17.9891 *"whereby a producer who demonstrates practices and management sufficient to protect water quality is certified for up to ten years and presumed to be contributing the producer's share of any targeted reduction of water pollutants during the certification period."* In order to be certified and meet the intent of the statute, producers need to be addressing the groundwater resource concern in areas subject to the proposed Rule. This means that they will be not only implementing the nitrogen fertilizer BMPs but exceeding them with conservation practices and management appropriate to their operation that reduces the risk of nitrate loss to both groundwater and surface water. It is necessary to include this exemption because it is required by Minn. Stat. § 17.9897.

I. 1573.0090 Alternative Management Tools; Alternative Protection Requirements

Alternative management tools (AMTs) are practices and activities designed to reduce nitrate leaching. AMTs represent an advanced level of groundwater protection that go beyond traditional nitrogen fertilizer BMPs. The MDA recognizes that implementation of nitrogen fertilizer BMPs may not be adequate to decrease the amount of nitrate leaching into groundwater to meet water quality goals in some areas or situations. In areas where groundwater is vulnerable, the MDA encourages farmers to consider AMTs to meet water quality goals.

In many cases AMT practices are developed and used by farmers and implemented in ways that are optimized for local conditions and opportunities. The tools are designed to be flexible and can be adjusted or tailored to local conditions to a greater extent than BMPs. The MDA will continue to work toward providing technical and financial resources regarding the effectiveness of these alternatives. The MDA will work with the local agricultural community to encourage and incentivize their use. The general benefits of AMTs have been documented in scientific studies.

At the present time, the AMTs fall into the following categories:

- Alternative cropping systems, including low nitrogen input crops or continuous cover,
- Advanced nitrogen fertilizer management, including variable rate application and use of advanced nitrogen requirement prescription tools,
- New technologies that can increase nitrogen use efficiency, including the use of advanced crop sensor technology,

- Enrollment in the Minnesota Agricultural Water Quality Certification Program (MAWQCP).

The AMTs are needed for the following reasons:

- Because the nitrogen fertilizer BMPs are relatively static and require a long process to change, the MDA needs AMTs to recognize new practices and technology that are developed to reduce nitrogen leaching as they evolve.
- The nitrogen fertilizer BMPs may not have sufficient flexibility to work under all conditions or situations. The AMTs provide this additional flexibility.
- Nitrogen fertilizer BMPs may not be sufficient to meet water quality goals in all areas or in all situations. The AMTs represent an advanced level of groundwater protection and are designed to go above and beyond the BMPs and improve water quality faster.
- AMTs allow the MDA to support and recognize a regulated party who wishes to implement practices that exceeds the nitrogen fertilizer BMPs.
- Including AMTs as an option in the proposed Rule will allow farmers to be recognized for practices and activities they have adopted that go beyond the nitrogen fertilizer BMPs.
- Including AMTs as an option in the proposed Rule will engage the agricultural community in problem solving and will provide an effective approach for the agricultural community to propose workable solutions and new technologies that can improve water quality on both the local and state level.
- Maintaining a list of approved AMTs will provide a rapid and effective means for sharing information on new and effective methods to address nitrate concerns.

Thus, it is needed and reasonable for the MDA to include AMTs in the proposed Rule.

Subp. 1. Alternative Management Tools. A and B.

The MDA will maintain a list of approved AMTs and make this list available on the website. This list will be updated on a regular basis as AMTs are evaluated and approved. The list of alternative management practices is needed to inform responsible parties of the recognized AMTs available to them. Publishing this list on the MDA's website and updating it annually is reasonable as it informs regulated parties of options available to them to reduce the risk of nitrate leaching into groundwater. If the regulated party is subject to a water resource protection requirements order this list will inform them of other practices that could be implemented and allow them to still meet the requirements of the water resource protection requirements order.

Subp. 1. Alternative Management Tools. C.

The list of AMTs on the MDA's website will state whether these practices can be used in addition to nitrogen fertilizer BMPs or if they can be substituted for a nitrogen fertilizer BMP. Substitutions are necessary as in some cases, an AMT might go above and beyond a particular

BMP and implementation of that BMP is no longer necessary, or the tool may be incompatible with the BMP. In some cases the AMT might be most effective when used in combination with a nitrogen fertilizer BMP. Keeping records of the practices used where an AMT was substituted for another required practice will allow for the AMTs to be counted during the evaluation of nitrogen fertilizer BMPs.

Subp. 1. Alternative Management Tools. D.

This proposed Rule is needed and reasonable because if a producer wants to go above and beyond the nitrogen fertilizer BMPs, the MDA supports this. In many cases, AMTs can be tailored to the local conditions to a greater extent than the nitrogen fertilizer BMPs.

Subp. 2. Alternative protection requirements.

Minn. Stat. § 103H.275, subd. 2(e) requires the MDA to allow persons subject to water resource protection requirements to be able to suggest alternative protection requirements. Therefore, it is needed and reasonable for the proposed Rule to lay out the process by which a responsible party could apply to the MDA for an alternative protection requirement.

J. Effective Date.

The effective date is necessary to give affected parties time to implement the necessary changes in their organizations before the restrictions go into place. January 1, 2020 is a reasonable start date as the MDA heard from several comments during the summer 2017 comment period that some of the larger affected parties can purchase fertilizer as much as a year ahead of time,. With the proposed Rule expected to be adopted in early 2019, giving that additional year to use the existing stock seemed reasonable. The proposed effective date is also reasonable because the MDA plans to use the fall of 2019 to conduct education and outreach to affected parties.

VII. References

Abatzoglou, J. T. 2013. Development of gridded surface meteorological data for ecological applications and modelling. Int. J. Climatol., 33: 121–131.

Adams, R. 2016. Pollution Sensitivity of Near-Surface Materials. Minnesota Department of Natural Resources, St Paul, MN. 16 p. Online at https://files.dnr.state.mn.us/waters/groundwater_section/mapping/mha/hg02_report.pdf Last accessed on April 4, 2018.

Adams, R. J. Barry and J. Green. 2016. Minnesota Regions Prone to Surface Karst Feature Development. Minnesota Department of Natural Resources, St Paul, MN. Online at http://files.dnr.state.mn.us/waters/groundwater_section/mapping/gw/gw01_report.pdf . Last accessed on April 4, 2018.

Agricultural Nutrient Subcommittee (also referenced as Montgomery et al., 2001), In Minnesota's Nonpoint Source Management Program Plan, 2001. Chapter 9. Minnesota Pollution Control Agency, St. Paul, MN.

ASCE-EWRI, 2005. The ASCE Standardized Reference Evapotranspiration Equation. ASCE, Reston, Virginia. 147 p.

Bergemann, S. (2018) Farm Journal - Survey Shows Cover Crops Boost Yield, Reduce Weeds. Online at https://www.agweb.com/article/survey-shows-cover-crops-boost-yield-reduce-weeds-naa-sonja-begemann/

Bierman, P. M., J. E. Crants, and C. J. Rosen. 2015. Evaluation of a Quick Test to Assess Polymer-Coated Urea Prill Damage. Agron. J. 107:2381-2390.

Bierman, P., Rosen, C.R., Venterea, R., and Lamb, J. 2011. Survey of Nitrogen Fertilizer Use on Corn in Minnesota. Report, 27 pp. University of Minnesota and USDA-ARS. St. Paul. MN. Online at http://www.mda.state.mn.us/protecting/cleanwaterfund/~/media/C0D97703C7A84E74936431110A5FE897.ashx. Last accessed on April 4, 2018.

Böhlke, J. K., R. Wanty, M. Tuttle, G. Delin, and M. Landon. 2002. Denitrification in the recharge area and discharge area of a transient agricultural nitrate plume in a glacial outwash sand aquifer, Minnesota, Water Resour. Res., 38(7).

Boryan, C., Z. Yang, R. Mueller and M. Craig. 2011. Monitoring US agriculture: the US Department of Agriculture, National Agricultural Statistics Service, Cropland Data Layer Program. Geocarto International, 26:341-358.

Breckenridge, A., 2015, The Tintah-Campbell gap and implications for glacial Lake Agassiz drainage during the Younger Dryas cold interval: Quaternary Science Reviews, 2015, v.117, pp. 124–134.

Burow, K. R., B. T. Nolan, M. G. Rupert, and N. M. Dubrovsky. 2010. Nitrate in groundwater of the United States, 1991–2003, Environ. Sci. Technol., 44, 4988–4997.

Carlson, B., J. Vetsch, and G. Randall. 2017. Nitrates in Drainage Water in Minnesota. University of Minnesota Extension. 8 pp. Online at https://www.extension.umn.edu/agriculture/water/water-quality/nitrates-in-drainage-water/docs/nitrates-in-drainage-water-MN.pdf Last accessed on April 4, 2018.

Central Platte NRD. 2016. Rules & Regulations -Central Platte Natural Resources District's Groundwater Quality Management Requirements. Commodity Crop Growers in the Central Platte NRD must adhere to the following regulations. Available online http://cpnrd.org/wp-content/uploads/2015/11/Rules-Regs_Chart_8-2016.pdf Last accessed April 5, 2018.

Charles, D. 2013. Fertilized World. Natl. Geographic, May 2013. Online at http://ngm.nationalgeographic.com/2013/05/fertilized-world/charles-text Last accessed April 3, 2018.

Davis, D. M., P. H. Gowda, D. J. Mulla, and G. W. Randall. 2000. Modeling Nitrate N Leaching in Response to Nitrogen Fertilizer Rate and Tile Drain Depth or Spacing for Southern Minnesota, USA. J. Environ. Qual. 29:1568-1581.

Drury, C. F., Yang, J.Y., De Jong, R.D., Yang, X.M., Huffman, E.C., Kirkwood, V. and Reid, K. 2007. Residual soil nitrogen indicator for agricultural land in Canada. Can. J. Soil Sci. 87: 167-177. Online at https://www.researchgate.net/publication/273686917_Residual_soil_nitrogen_indicator_for_agricultural_land_in_Canada

Erickson, B. and Widmar, D.A., 2015. Precision agricultural services dealership survey results. Purdue University, West Lafayette, IN. 37 pp. Online at http://agribusiness.purdue.edu/files/resources/2015-crop-life-purdue-precision-dealer-survey.pdf Last accessed April 4, 2018.

EPA Science Advisory Board. 2011. Reactive Nitrogen in the United States: An Analysis of Inputs, Flows, Consequences, and Management Options. EPA-SAB-11-013.

Exner, M.E., A.J. Hirsh and R.F. Spalding. 2014. Nebraska's Groundwater Legacy: Nitrate Contamination Beneath Irrigated Cropland, Water Resour. Res. 50, 4474-4489.

Exner, M. E., and R. F. Spalding (1979), Evolution of contaminated groundwater in Holt County, Nebraska, Water Resour. Res., 15, 139–147.

Ferguson, R.B., 2015. Groundwater quality and nitrogen use efficiency in Nebraska's Central Platte River Valley. J. Environ. Qual., 44, 449-459.

Fernandez, F. 2017. Everything You Need to Know Before Applying N this Fall. University of Minnesota Extension, Minnesota Crop News. Online at http://blog-crop-news.extension.umn.edu/2017/09/everything-you-need-to-know-before.html Last accessed April 5, 2018.

Feyereisen, G. W., B. N. Wilson, G. R. Sands, J. S. Strock, and P. M. Porter. 2006. Potential for a Rye Cover Crop to Reduce Nitrate Loss in Southwestern Minnesota. Agron. J. 98:1416-1426.

Frear, C. 2014. The Reactive Nitrogen "Wicked Problem"-critical nutrient, disastrous pollutant. Washington State University, Center for Sustaining Agriculture and Natural Resources. Online at http://csanr.wsu.edu/the-reactive-nitrogen-wicked-problem/ Last accessed April 3, 2018.

Gelderman, R., P. Carson and J. Gerwing. 1987. Fertilizing for Grass Seed Production. South Dakota State University, Agricultural Experiment Station. Paper 272. Online at https://openprairie.sdstate.edu/agexperimentsta_circ/272/ Last accessed April 4, 2018.

Gordon, S. 2016. What Karst is, and How it Affects Wisconsin's Drinking Water. Wiscontext. Online at https://www.wiscontext.org/what-karst-and-how-it-affects-wisconsins-drinking-water Last accessed April 4, 2018.

Gormly, J. R., and R. F. Spalding. 1979. Sources and concentrations of nitrate-nitrogen in ground water of the central Platte region, Nebraska, Ground Water, 17.

Groten, J. T. and E. C. Alexander. 2013. Karst Hydrogeologic Investigation of Trout Brook, Dakota County, Minnesota. University of Minnesota, Water Resources Science. 64 pp.

Hamilton, A.V., D.A. Mortensen, and M.K. Allen. 2017. The state of the cover crop nation and how to set realistic future goals for the popular conservation practice. J Soil Water Cons. 72, 111A-115A.

Hopkins, B. G., C. J. Rosen, A. K. Shiffler, and T. W. Taysom. 2008. Enhanced Efficiency Fertilizers for Improved Nutrient Management: Potato (Solanum tuberosum). Crop Manag. 7.

Huggins, D. R., G. W. Randall, and M. P. Russelle. 2001. Subsurface Drain Losses of Water and Nitrate following Conversion of Perennials to Row Crops Joint publication of the USDA-ARS and the Minn. Agric. Exp. Stn. . Agron. J. 93:477-486.

IPNI, 2018. Nitrate Leaching. Nitrogen Notes Number 3. International Plant Nutrition Institute, Atlanta GA. 4 pp. Online at http://www.ipni.net/publication/nitrogen-en.nsf/0/FDEE48CFF7600CE585257C13004C7BB0/$FILE/NitrogenNotes-EN-03.pdf Last accessed April 4, 2018.

International Plant Nutrition Institute (IPNI) 2013. Modules and Case Studies for the 4R Plant Nutrition Manual CHAPTER 3 - RIGHT SOURCE A Publication of the International Plant Nutrition Institute (IPNI). Online at http://anz.ipni.net/article/ANZ-3006 Last accessed April 4, 2018.

Jokela, W. E., and G. W. Randall. 1989. Corn Yield and Residual Soil Nitrate as Affected by Time and Rate of Nitrogen Application. Agron. J. 81:720-726.

Kaiser, D.E., J. A. Lamb and R. Eliason. 2011. Fertilizer Guidelines for Agronomic Crops in Minnesota. University of Minnesota Extension, Publication no BU-0640-S.

Kaiser, D. E, F. Fernandez, J. A. Lamb, J.A. Coulter, and B. Barber. 2016. Fertilizing Corn in Minnesota. University of Minnesota Extension publication no #3790-C. Online at http://www.extension.umn.edu/agriculture/nutrient-management/nutrient-lime-guidelines/fertilizing-corn-in-minnesota/docs/fertilizing-corn.pdf Last accessed April 5, 2018

Kaiser, D.E., F. Fernandez, J.A. Lamb, J.A. Coulter 2016 Fertilizing Corn in Minnesota. 2016a. University of Minnesota Extension publication no # AG-FO-3790-D. Online at http://www.extension.umn.edu/agriculture/nutrient-management/nutrient-lime-guidelines/fertilizing-corn-in-minnesota/docs/fertilizing-corn.pdf

Katz, B. G. 2012. Nitrate Contamination in Karst Groundwater. Encyclopedia of Caves 2nd ed, 564-568.

Lamb, J., G. Randall, G. Rehm and C. Rosen. 2008. Best Management Practices for Nitrogen Use in Minnesota. University of Minnesota Extension. Publ. no 08560. 8 pp. Online at https://www.extension.umn.edu/agriculture/nutrient-management/nitrogen/docs/08560-generalMN.pdf Last accessed on April 4, 2018.

Lamb, John A., Carl Rosen, Phyllis Bongard, Daniel Kaiser, Fabian Fernandez, and Brian Barber. 2015. Fertilizing Corn Grown on irrigated Sandy Soils. University of Minnesota Extension, AG-NM-1501. 8 pp. Online at https://www.extension.umn.edu/agriculture/nutrient-management/nitrogen/docs/08560-generalMN.pdf Last accessed on April 4, 2018.

Lazarus, W.F., D. Mulla and D. Wall. 2014. A spreadsheet planning tool for assisting a state agency with cost-effective watershed scale surface water nitrogen planning. J. Soil and Water Conservation. Vol. 69, No. 2.

LCC. n.d. Minnesota's Legacy Funds. Legislative Coordinating Commission, St. Paul, MN. Online at http://www.legacy.leg.mn/about-funds Last accessed April 5, 2018.

Lenhart, C., B. Gordon, J. Peterson, J. Eshenaur, L. Gifford, B. Wilson, J. Stamper, L. Krider and N. Utt. 2017. Agricultural BMP Handbook for Minnesota, 2nd Edition. Minnesota Department of Agriculture, St. Paul, MN. 262 pp.

MAWRC. n.d. Events and Workshops. Minnesota Agricultural Water Resources Center, Eagan, MN. Online at https://mawrc.org/events/ Last accessed April 5, 2018.

MDA. 2012. Summary of Groundwater Nitrate-Nitrogen Data. Minnesota Department of Agriculture, St Paul, MN. 63 pp. Available online at http://www.mda.state.mn.us/chemicals/pesticides/maace/~/media/Files/chemicals/maace/2012-03nitraterpt.pdf. Last accessed April 6, 2018

MDA. 2014. Response to Comments on the draft Nitrogen Fertilizer Management Plan. Minnesota Department of Agriculture, St Paul, MN. Online at http://www.mda.state.mn.us/chemicals/fertilizers/nutrient-mgmt/nitrogenplan/~/media/Files/chemicals/nfmp/commentsresponse.pdf Last accessed April 5, 2018.

MDA. 2015. Minnesota Nitrogen Fertilizer Management Plan. Minnesota Department of Agriculture. St Paul, MN. 143 pp. Online at http://www.mda.state.mn.us/chemicals/fertilizers/nutrient-mgmt/~/media/Files/chemicals/nfmp/nfmp2015.pdf Last accessed April 3, 2018.

MDA. 2017. 2016 Water Quality Monitoring Report. Minnesota Department of Agriculture, St Paul, MN. 270 pp. Available online at http://www.mda.state.mn.us/chemicals/pesticides/maace/~/media/Files/chemicals/maace/2016wqmrpt.pdf. Last accessed April 6, 2018

MDA. 2018 (a). Nitrate Testing for Private Wells Results as of March 22, 2018. Minnesota Department of Agriculture, St Paul, MN. 2 p. Available online at http://www.mda.state.mn.us/chemicals/fertilizers/nutrient-mgmt/~/media/Files/chemicals/nfmp/nfmp2015.pdf. Last accessed April 3, 2018.

MDA. 2018 (b). Township Testing Program Update-March 2018. Minnesota Department of Agriculture, St Paul, MN. 3 p.

MDA. n.d. (a) Conservation Practices Minnesota Conservation Funding Guide. Minnesota Department of Agriculture, St Paul, MN. Available online http://www.mda.state.mn.us/protecting/conservation/practices/covercrops.aspx Last accessed April 4, 2018.

MDA. n.d. (b). Farm Nutrient Management Assessment Program (FANMAP). Minnesota Department of Agriculture, St Paul, MN. Online at http://www.mda.state.mn.us/protecting/soilprotection/fanmap.aspx Last accessed April 5, 2018.

MDA. n.d. (c). Fertilizers. Minnesota Department of Agriculture, St Paul, MN. Online at https://www.mda.state.mn.us/chemicals/fertilizers.aspx Last accessed April 5, 2018.

MDA. n.d. (d). Fertilizer as Source of Nitrate in Groundwater. Minnesota Department of Agriculture, St Paul, MN. Online at http://www.mda.state.mn.us/chemicals/fertilizers/nutrient-mgmt/nitrogenplan/fertsourcenitrategw.aspx Last accessed April 5, 2018.

MDA. n.d. (e). Irrigation Specialist Position. Minnesota Department of Agriculture, St Paul, MN. Online at http://www.mda.state.mn.us/protecting/cleanwaterfund/gwdwprotection/irrigationspecialist.aspx Last accessed April 5, 2018.

MDA. n.d. (f). Minnesota Agricultural Water Quality Certification Program. Minnesota Department of Agriculture, St Paul, MN. Online at http://www.mda.state.mn.us/awqcp Last accessed April 5, 2018.

MDA. n.d. (g). Nitrogen Fertilizer Best Management Practices. Minnesota Department of Agriculture, St Paul, MN. Online at http://www.mda.state.mn.us/nitrogenbmps Last accessed April 5, 2018.

MDA. n.d. (h). Nutrient Management Initiative Program in Minnesota. Minnesota Department of Agriculture, St Paul, MN. Online at http://www.mda.state.mn.us/nmi Last accessed April 5, 2018.

MDA. n.d. (i). Nutrient Management Survey. Minnesota Department of Agriculture, St Paul, MN. Online at http://www.mda.state.mn.us/protecting/cleanwaterfund/gwdwprotection/nutrientmgmtsurvey.aspx Last accessed April 5, 2018.

MDA. n.d. (j). Root River Field to Stream Partnership (RRFSP). Minnesota Department of Agriculture, St Paul, MN. Online at http://www.mda.state.mn.us/protecting/cleanwaterfund/onfarmprojects/rootriverpartnership.aspx Last accessed April 5, 2018.

MDA. n.d. (k). Soil & Plant Amendment Registration. Minnesota Department of Agriculture, St Paul, MN. Online at https://www.mda.state.mn.us/licensing/licensetypes/amendment.aspx Last accessed April 5, 2018.

MDA. n.d. (l). Soil Temperature Network. Minnesota Department of Agriculture, St Paul, MN. Online at https://app.gisdata.mn.gov/mda-soiltemp/ Last accessed April 5, 2018.

MDA. n.d. (m). Water Quality and Irrigation Research at Rosholt Farm. Minnesota Department of Agriculture, St Paul, MN. Online at http://www.mda.state.mn.us/protecting/cleanwaterfund/gwdwprotection/rosholtfarm.aspx Last accessed April 5, 2018.

MDA. 2015. Minnesota Nitrogen Fertilizer Management Plan. Minnesota Department of Agriculture. St Paul, MN. 143 pp. Online at http://www.mda.state.mn.us/chemicals/fertilizers/nutrient-mgmt/~/media/Files/chemicals/nfmp/nfmp2015.pdf. Last accessed April 3, 2018.

MDA. (various years) Clean Water Fund Research Program. Online at http://www.mda.state.mn.us/protecting/cleanwaterfund/research/projects.aspx Last accessed April 4, 2018.

MDA Conservation Practices Minnesota Conservation Funding Guide. Online at http://www.mda.state.mn.us/protecting/conservation/practices/covercrops.aspx Last accessed April 4, 2018.

MDA and NASS. 2014. Fertilizer and Manure Selection and Management Practices Associated with Minnesota's 2010 Corn and Wheat Production. Minnesota Department of Agriculture and USDA NASS, St Paul, MN. 193 pp. http://www.mda.state.mn.us/protecting/cleanwaterfund/gwdwprotection/~/media/Files/protecting/cwf/%202010cornnitromgmt.pdf Last accessed April 4, 2018.

MDA and NASS. 2015a. Commercial Nitrogen and Manure Applications on Minnesota's 2012 Corn Crop Compared to the University of Minnesota Nitrogen Guidelines. Minnesota Department of Agriculture and USDA NASS, St Paul, MN. 254 pp. Online at https://www.mda.state.mn.us/sitecore/shell/Controls/Rich%20Text%20Editor/~/media/Files/protecting /cwf/2012umnitrocorn.pdf Last accessed April 4, 2018.

MDA and NASS. 2015b. Survey Results of Nitrogen Fertilizer BMPs on Minnesota's 2013 Corn Acres. Minnesota Department of Agriculture and USDA NASS, St Paul, MN. 61 pp. Online at http://www.mda.state.mn.us/protecting/cleanwaterfund/gwdwprotection/~/media/Files/protecting/cwf/%202013fertbmpcorn.pdf Last accessed April 4, 2018.

MDA and NASS. 2016. Commercial Nitrogen and Manure Fertilizer Selection and Management Practices Associated with Minnesota's 2012 Corn Crop. Minnesota Department of Agriculture and USDA NASS, St Paul, MN. 355 pp. Online at https://www.mda.state.mn.us/sitecore/shell/Controls/Rich%20Text%20Editor/~/media/Files/protecting/cwf/2012nitrocorn.pdf . Last accessed April 4, 2018.

MDA and NASS. 2017. Commercial Nitrogen and Manure Fertilizer Selection and Management Practices Associated with Minnesota's 2014 Corn Crop. Minnesota Department of Agriculture and USDA NASS, St Paul, MN. 267 pp.

MDF. n.d. Welcome to Discovery Farms Minnesota. Discovery Farms Minnesota, Eagan, MN. Online at https://discoveryfarmsmn.org/ Last accessed April 5, 2018.

MDH, 2014. Minnesota Well Management News Fall 2013/Winter 2014. Minnesota Department of Health, St. Paul, MN.

MDH. 2015. Minnesota Drinking Water 2015 Annual Report for 2014. Minnesota Department of Health, St. Paul, MN. 33 pp. Online at http://www.health.state.mn.us/divs/eh/water/com/dwar/report2014.pdf . Last accessed April 5, 2018.

MDH. 2017. Minnesota Drinking Water 2017 Annual Report for 2016. Minnesota Department of Health, St. Paul, MN. 32 pp. Online at http://www.health.state.mn.us/divs/eh/water/com/dwar/report2016.pdf . Last accessed April 5, 2018.

MDH. n.d. Nitrate in Drinking Water. Minnesota Department of Health. St. Paul, MN. Online at http://www.health.state.mn.us/divs/eh/water/contaminants/nitrate.html#MinnesotaWater Last accessed April 4, 2018.

MDNR. n.d. County Geologic Atlas Program. Minnesota Department of Natural Resources, St. Paul, MN. Online at https://www.dnr.state.mn.us/waters/groundwater_section/mapping/index.html Last accessed April 4, 2018.

MDNR. 2017. County Geologic Atlas Program. Minnesota Department of Natural Resources, St. Paul, MN. Online at https://www.dnr.state.mn.us/waters/groundwater_section/mapping/index.html Last accessed April 4, 2018.

MDH. 2018. Nitrate in Drinking Water. Minnesota Department of Health. St. Paul, MN. Online at http://www.health.state.mn.us/divs/eh/water/contaminants/nitrate.html#MinnesotaWater Last accessed April 4, 2018.

MDNR. 2018. Final Spring/First Fall Freeze & Frost Date Probabilities. Minnesota Department of Natural Resources, State Climatology Office. Online at https://www.dnr.state.mn.us/climate/summaries_and_publications/freeze_date.html Last accessed April 4, 2018.

MEQB. 2015. 2015 EQB Water Policy Report. Minnesota Environmental Quality Board, St. Paul, MN. 44 pp. Online at https://www.eqb.state.mn.us/sites/default/files/documents/WaterReport_091715_FINAL_R.pdf . Last accessed April 5, 2018.

Meersman, T. 2015. Crop crops provide benefits but are a tricky proposition for Minnesota farmers. Star Tribune http://www.startribune.com/cover-crops-provide-benefits-but-are-a-tricky-proposition-for-minnesota-farmers/352456631/ Last accessed on April 4, 2018.

Miao, Y., D. J. Mulla, J. A. Hernandez, M. Wiebers, and P. C. Robert. 2007. Potential Impact of Precision Nitrogen Management on Corn Yield, Protein Content, and Test Weight. Soil Sci. Soc. Am. J. 71:1490-1499.

MNopedia. 2017. Precision Agriculture. Minnesota Historical Society, St Paul, MN. Online at http://www.mnopedia.org/thing/precision-agriculture Las accessed on April 4, 2018.

MPCA. 2005. Applying Manure in Sensitive Areas. Minnesota Pollution Control Agency, St Paul, MN. 12 pp. Online at https://www.pca.state.mn.us/sites/default/files/feedlots-manureapplication.pdf . Last accessed on April 4, 2018.

MPCA. 2013. Nitrogen in Minnesota Surface Waters. Minnesota Pollution Control Agency, St Paul, MN. Document number: wq-s6-26a2013.

MPCA. 2014. The Minnesota Nutrient Reduction Strategy. Minnesota Pollution Control Agency. St Paul, MN. 348 pp. Document number: wq-s1-80.

Mulla, D. J. 2013. Twenty five years of remote sensing in precision agriculture: Key advances and remaining knowledge gaps. Biosystems Engineering Volume 114, pages 358-371.

Mulla, D. J., J. S. Strock 2008. Nitrogen Transport Processes in Soil. In: J. S. Schepers, W. R. Raun, editors, Nitrogen in Agricultural Systems, Agron. Monogr. 49. ASA, CSSA, SSSA, Madison, WI. p. 361-400.

Nangia, V., P. H. Gowda, D. J. Mulla, and G. R. Sands. 2008. Water Quality Modeling of Fertilizer Management Impacts on Nitrate Losses in Tile Drains at the Field Scale J. Environ. Qual. 37:296-307.

Oquist, K.A., J. S. Strock and D. J. Mulla 2007 Influence of Alternative and Conventional Farming Practices on Subsurface Drainage and Water Quality J. Environ. Qual. 36: 4: 1194-1204.

Puckett, L. J., and T. K. Cowdery. 2002. Transport and Fate of Nitrate in a Glacial Outwash Aquifer in Relation to Ground Water Age, Land Use Practices, and Redox Processes. J. Environ. Qual. 31:782-796.

Puckett, L. J., A. J. Tesoriero, and N. M. Dubrovsky. 2011 Nitrogen Contamination of Surficial Aquifers—A Growing Legacy Environmental Science & Technology 2011 45 (3), 839-844.

Puckett, L. J., T. K. Cowdery, D. L. Lorenz, and J. D. Stoner. 1999. Estimation of Nitrate Contamination of an Agro-Ecosystem Outwash Aquifer Using a N Mass-Balance Budget. J. Environ. Qual. 28:2015-2025.

Randall, G. W. 1984. Efficiency of Fertilizer Nitrogen Use as Related to Application Methods. In: R. D. Hauck, editor, Nitrogen in Crop Production, ASA, CSSA, SSSA, Madison, WI. pp. 521-533.

Randall, G. W., and D. J. Mulla. 2001. Nitrate Nitrogen in Surface Waters as Influenced by Climatic Conditions and Agricultural Practices. J. Environ. Qual. 30:337-344.

Randall, G.W., D.R. Huggins, M.P. Russelle, D.J. Fuchs, W.W. Nelson, and J.L. Anderson. 1997. Nitrate Losses through Subsurface Tile Drainage in Conservation Reserve Program, Alfalfa, and Row Crop Systems. J of Environ Qual. 26:1240-1247.

Randall, G. W., and J. A. Vetsch. 2005 (a). Corn Production on a Subsurface-Drained Mollisol as Affected by Fall versus Spring Application of Nitrogen and Nitrapyrin Agron. J 97: 2: 472-478.

Randall, G. W., and J. A. Vetsch. 2005 (b). Nitrate Losses in Subsurface Drainage from a Corn–Soybean Rotation as Affected by Fall and Spring Application of Nitrogen and Nitrapyrin J. Environ. Qual. 34: 2: 590-597.

Randall, G. W., J. A. Vetsch, and J. R. Huffman. 2003 (a). Corn Production on a Subsurface-Drained Mollisol as Affected by Time of Nitrogen Application and Nitrapyrin. Agron. J. 95:1213-1219.

Randall, G.W., J. A. Vetsch and J. R. Huffman, 2003 (b). Nitrate Losses in Subsurface Drainage from a Corn–Soybean Rotation as Affected by Time of Nitrogen Application and Use of Nitrapyrin J. Environ. Qual 32: 1764-1772.

Randall, G. W., and M. J. Goss. 2001. Nitrate losses to surface water through subsurface tile drainage. In: Follett, R.F. and J. L. Hatfield. Nitrogen in the environment: sources, problems, and management. Elevier Sci. B.V., Amsterdam. pp. 95-122.

Randall, G., Rehm, G., and Lamb, J. 2008 (a). Best Management Practices for Nitrogen Use in Southeastern Minnesota. Minnesota. University of Minnesota Extension publication #08557. Online at http://www.extension.umn.edu/agriculture/nutrient-management/nitrogen/docs/08557-southeastMN.pdf Last accessed April 4, 2018.

Randall, G., Rehm, G., Lamb, J. and Rosen, C. 2008 (b). Best Management Practices for Nitrogen Use in South-Central Minnesota. University of Minnesota Extension publication #08554. Online at http://www.extension.umn.edu/agriculture/nutrient-management/nitrogen/docs/08554-southcentralMN.pdf Last accessed April 4, 2018.

Rehm, G., Lamb, J., DeJong Hughes, J., Randall, G. 2008 (a). Best Management Practices for Nitrogen Use in Southwestern and West-Central Minnesota. University of Minnesota Extension publication #08558. Online at http://www.extension.umn.edu/agriculture/nutrient-management/nitrogen/docs/08558-swwcMN.pdf Last accessed April 4, 2018.

Rehm, G., Lamb, J., Rosen, C., and Randall, G. 2008 (b). Best Management Practices for Nitrogen Use on Coarse Textured Soils. University of Minnesota Extension publication #08556. Online at http://www.extension.umn.edu/agriculture/nutrient-management/nitrogen/docs/08556-coarsesoilsMN.pdf Last accessed April 4, 2018.

Rehm, G. M. Schmitt, R. Eliason, .UM recommended Soil nitrate test. (No year). Online at http://www.extension.umn.edu/agriculture/nutrient-management/nitrogen/using-the-soil-nitrate-test-in-mn/index.html Last accessed April 4, 2018.

Reitema, K. D., D. E. Clay, S. A. Clay, B. H. Dunn and C. Reese. 2016. Does the U.S. Cropland Data Layer Provide and Accurate Benchmark for Land-Use Change Estimates? Agron. J., 108:266-272.

Rosen, C. and Bierman, P. 2008. Best Management Practices for Nitrogen Use: Irrigated Potatoes. University of Minnesota Extension publication #08559. Online at http://www.extension.umn.edu/agriculture/nutrient-management/nitrogen/docs/08559-potatoesMN.pdf Last accessed April 4, 2018.

Runkel, A.C., J.R. Steenberg, R.G. Tipping, A.J. Retzler.. (2014). OFR14-02, Geologic controls on groundwater and surface water flow in southeastern Minnesota and its impact on nitrate concentrations in streams. Minnesota Geological Survey. Available online https://conservancy.umn.edu/handle/11299/162612 Last accessed April 5, 2018

Rupert, M. G. (2008). Decadal-scale changes of nitrate in ground water of the United States, 1988–2004, J. Environ. Qual., 37, S-240-S-248.

Russelle, M. P., J. F. S., Lamb, B. R. Montgomery, D. W. Elsenheimer, B. S., Miller and C. P. Vance. 2001. Alfalfa Rapidly Remediates Excess Inorganic Nitrogen at a Fertilizer Spill Site. J. Environ. Qual., 30, 30-36.

Schmidt, J. P., M. A. Schmitt, G. W. Randall, J. A. Lamb, J. H. Orf, and H. T. Gollany. 2000. Swine Manure Application to Nodulating and Nonnodulating Soybean. Agron. J. 92:987-992.

Schmitt, M. A., C. C. Sheaffer, and G. W. Randall. 1996. Preplant Manure on Alfalfa: Residual Effects on Corn Yield and Soil Nitrate. J. Prod. Agric. 9:395-398

Schoeneberger, P.J., D. A. Wysocki and E. C. Benham. 2012. Field Book for Describing and Sampling Soils, Version 3.0. Natural Resources Conservation Service, National Soil Survey Center, Lincoln, NE. 300 pp.

Shields, J. and Snow, D. 2017. Central Platte Natural Resource District Vadose Zone Nitrate Study. Progress report by the Water Sciences Laboratory, University of Nebraska. Online at http://cpnrd.org/wp-content/uploads/2015/11/2016-Vadose-Progress-Report.pdf

Shields, J., Snow, D. and Ray, C. 2017. Integrating the vadose zone into nitrate contamination of groundwater in Nebraska. University of Nebraska. Online at https://www.watersmartinnovations.com/documents/poster_sessions/2017/P-36.pdf

Sims, A., Rehm, G., and Lamb, J. 2008. Best Management Practices for Nitrogen Use in Northwestern Minnesota. University of Minnesota Extension publication #08555. Online at http://www.extension.umn.edu/agriculture/nutrient-management/nitrogen/docs/08555-northwestMN.pdf Last accessed April 4, 2018.

Soil Survey Staff, Natural Resources Conservation Service, United States Department of Agriculture. Web Soil Survey. Online at https://websoilsurvey.sc.egov.usda.gov/ Last accessed April 4, 2018.

Sousa, M.R., J.P. Jones, E.O. Frind and D.L. Rudolph. 2013. A simple method to assess unsaturated zone time lag in the travel time from ground surface to receptor. J Contaminant Hydr, 144: 138-151

Steenberg, J.R., R.G. Tipping, A.C. Runkel. (2014). OFR14-03, Geologic Controls on Groundwater and Surface Water Flow in Southeastern Minnesota and its Impact on Nitrate Concentrations in Streams: Local Project Area Report. Minnesota Geological Survey. Available online https://conservancy.umn.edu/handle/11299/162613 Last accessed April 5, 2018

Struffert, A. M., J. C. Rubin, F. G. Fernández, and J. A. Lamb. 2016. Nitrogen Management for Corn and Groundwater Quality in Upper Midwest Irrigated Sands. J. Environ. Qual. 45:1557-1564.

UC Davis. 2012. Addressing Nitrate in California's Drinking Water. University of California Davis, Center for Watershed Science. 92 p. Online at http://groundwaternitrate.ucdavis.edu/files/138956.pdf Last accessed April 5, 2018.

UM. 2007. Cost of Nitrate Contamination of Public Water Supplies. University of Minnesota, Department of Soil, Water and Climate. 12 pp. Online at http://www.house.leg.state.mn.us/comm/docs/CostofNitrateContaminationtoPublicSuppliers2007.pdf Last accessed April 5, 2018.

UM. n.d. Cover Crops. University of Minnesota, Forever Green. Online at https://www.forevergreen.umn.edu/crops-systems/cover-crops Last accessed April 5, 2018

UM Extension – Soil Management and Health. Online at https://www.extension.umn.edu/agriculture/soils/cover-crops/ Last accessed April 4, 2018.

UM Extension. n.d. Nitrogen Smart. University of Minnesota Extension, Minnesota Crop Events. Online at https://www.extension.umn.edu/agriculture/crops/events/nitrogen-smart/ Last accessed April 5, 2018.

UNDESA. 2014. International Decade for Action 'Water for Life' 2005-2015. United Nations Department of Economic and Social Affairs. Online at http://www.un.org/waterforlifedecade/quality.shtml Last accessed April 3, 2018.

USEPA. 1998. National Primary Drinking Water Regulations. US Environmental Protection Agency, Washington, DC. Online at https://www.gpo.gov/fdsys/granule/CFR-1998-title40-vol14/CFR-1998-title40-vol14-part141 Last accessed April 5, 2018.

USDA NASS. n.d. (a). Census of Agriculture. USDA National Agricultural Statistics Service, Washington, DC. Online at https://www.agcensus.usda.gov/ Last accessed on April 5, 2018.

USDA NASS. n.d. (b) CropScape – Cropland Data Layer. USDA National Agricultural Statistics Service, Washington, DC. Online at [https://data.nal.usda.gov/dataset/cropscape-cropland-data-layer] Last accessed on April 5, 2018.

USDA NRCS. 2007. Nutrient Management Practice Standard 590. USDA Natural Resources Conservation Service. 12 pp. Online at https://efotg.sc.egov.usda.gov/references/public/MN/590mn.pdf Last accessed on April 4, 2018.

Venterea, R. T., C. R. Hyatt, and C. J. Rosen. 2011. Fertilizer Management Effects on Nitrate Leaching and Indirect Nitrous Oxide Emissions in Irrigated Potato Production. J. Environ. Qual. 40:1103-1112.

Vetsch, J. A., and G. W. Randall. 2004. Corn Production as Affected by Nitrogen Application Timing and Tillage. Agron. J. 96:502-509.

Walters, D.T. and G.L. Malzer. 1990. Nitrogen management and nitrification inhibitor effects on nitrogen-15 urea: II. Nitrogen leaching and balance. Soil Sci. Soc. Am. J. 54:122-130.

Wilson, M. L., C. J. Rosen, and J. F. Moncrief. 2009. Potato Response to a Polymer-Coated Urea on an Irrigated, Coarse-Textured Soil. Agron. J. 101:897-905.

WI DATCP. 2015. Wisconsin Nutrient Management Update and Quality Assurance Team Review of 2015's Nutrient Management Plans. Wisconsin Department of Agriculture, Trade, and Consumer Protection. Madison, WI. 6 pp. Online at https://datcp.wi.gov/Documents/NMUpdate2015.pdf Last accessed April 4, 2018.

WI GCC. 2017. Nitrate report to the Legislature. Wisconsin Groundwater Coordinating Council. Madison, WI. 6 pp. Online at https://dnr.wi.gov/topic/groundwater/documents/gcc/gwquality/nitrate.pdf Last accessed April 4, 2018.

Yang, J.Y., De Jong, R.D., Drury, C. F., Huffman, E.C., Kirkwood, V. and Yang, X.M., 2007. Development of a Canadian agricultural nitrogen budget model and the evaluation of various policy scenarios. Can. J. Soil Sci. 87: 153-165. Online at https://www.researchgate.net/publication/223762872_Residual_soil_nitrogen_in_soil_landscapes_of_Canada_as_affected_by_land_use_practices_and_agricultural_policy_scenarios

Yost, M.A., J.A. Coulter, and M.P. Russelle, 2015. Managing the rotation from alfalfa to corn. University of MN Extension. 12 pp. Online at http://corn.agronomy.wisc.edu/Management/pdfs/L001.pdf Last accessed on April 4, 2018.

Yost, M. A., T.F. Morris, M.P. Russelle and J. A. Coulter, 2014 Second-Year Corn after Alfalfa Often Requires No Fertilizer Nitrogen Agron. J 106: 2: 659-669.

Zvomuya, F., C.J. Rosen, M.P. Russelle, and S.C. Gupta. 2003. Nitrate leaching and nitrogen recovery following application of polyolefin-coated urea to potato. J. Environ. Qual. 32(2):480-489.

VIII. Appendixes

1. Fertilizing Corn Grown on Irrigated Sandy Soils
2. Best Management Practices for Nitrogen Use in Minnesota
3. Best Management Practices for Nitrogen on Coarse Textured Soils
4. Best Management Practices for Nitrogen Use: Irrigated Potatoes
5. Best Management Practices for Nitrogen in Southeastern Minnesota
6. Best Management Practices for Nitrogen Use in South-Central Minnesota
7. Best Management Practices for Nitrogen Use in Southwestern and West-Central Minnesota
8. Best Management Practices for Nitrogen Use in Northwestern Minnesota
9. Nitrogen Fertilizer Management Plan
10. Potential Nitrogen Sale Reduction

Toxicological Basis for Nitrate and Nitrite USEPA RfDs Lack Scientific Merit: Submission to USEPA in Response to Call for Comments on Revisions to Nitrate and Nitrite Reference Dos...

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Errata – Corrections included to: RESPONSE TO USEPA ON RFD ANNOUNCEMENT FINAL 12/11/2023

December 18, 2023

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Center for Public Health & Environmental Assessment
U.S. Environmental Protection Agency
1200 Pennsylvania Avenue, NW
Washington, D.C. 20460

Docket Number: EPA–HQ–ORD–2017–0496 for nitrate/nitrite

Dear Director Cascio:

USEPA recently announced that the IRIS toxicological basis for nitrate and nitrite RfDs is under review. USEPA does not intend to review the hematological basis for the RfDs.

"Given input received during scoping, the IRIS assessment will include evaluation of noncancer and cancer human health hazards associated with ingested nitrate and nitrite. Although all health effects will be considered for hazard identification, the assessment will take a different approach for hematological outcomes. A hematological hazard has already been established through the known association between methemoglobinemia and nitrate/nitrite (Ward et al., 2005; Walton, 1951). Therefore, EPA will not re-consider the hematological domain during hazard identification. Instead, any new studies identified for methemoglobinemia and supporting hematological endpoints will be examined for information on the quantitative relationship with nitrate/nitrite and the potential to support dose-response analysis." EPA-HQ-ORD-2017-0496-0010

Research for our upcoming contracted book with CRC Press (in preparation), currently titled *Nitrate and Nitrite Impacts on Groundwater, Drinking Water, and Public Health, Deriving New Health Protective Standards*, finds that errors, omissions and misrepresentations by USEPA of the cited basis for the RfDs negate USEPA's claims to fully understand the hematological basis of Infant Acquired Methemoglobinemia (IAM).

1. Selection of LOAELs is incorrect. USEPA apparently performed a limited literature review of IAM case statistics available in the peer review literature. Numerous other papers exist that demonstrate that the LOAEL range is much lower than USEPA acknowledges.
2. Walton (1951), the cited basis for the RfDs, leads to other papers from the United States that demonstrate LOAELs as low as 0.4 ppm nitrate-N from likely the best laboratory for such residue analysis in the United States during the 1940s.
3. USEPA eliminated IAM cases below 11 ppm nitrate-N for arbitrary reasons. One reason appears to be that USEPA mistranslated German language papers demonstrating IAM cases below 11 ppm nitrate-N (USEPA claims no such translations exist). Another

reason is concern that less than 11 ppm nitrate-N IAM cases were influenced by other nitrate exposures that were common around the world at that time and still occur today. USEPA's flawed conceptual model assumes that infants only ingest nitrate via contaminated infant formula. In reality, the historical international literature demonstrates that infant nitrate exposures via ingestion of supplemental water and feeding of vegetable broths was common around the world and in the United States and is still the case. Rather than additional nitrate exposures being uncommon and a concern for defining exposure concentrations leading to infant cyanosis, such exposures occur via normal feeding practices. This means that IAM cases under 11 ppm nitrate-N, discarded for these reasons, can now be included in the LOAEL distribution leading to RfD calculation. Thus, overwhelming evidence demonstrates that the RfD range should start at 0.4 ppm nitrate-N not 11 ppm nitrate-N.

4. That the majority of IAM cases are above 0.4 ppm nitrate-N is irrelevant to selecting the lowest valid IAM case concentration to serve as the LOAEL for RfD calculation. Thus, 0.4 ppm nitrate-N is the correct value for calculating the RfD for nitrate and nitrite.
5. Uncertainty is improperly addressed in the current RfD derivations. USEPA uses no intraspecies uncertainty factor for nitrate or nitrite. There is no scientific justification to assume that all infants are the same in their response to nitrate ingestion exposure from contaminated milk formula or any other liquid food. USEPA could ask any parent or physician, much less toxicologist, to determine that a UF=1 for intraspecies uncertainty is absurd on its face.
6. Data quality is impossible to determine for the cited principal studies. Walton (1951) and Bosch et al. (1950) are not peer reviewed studies according to the publishers of these papers. Data cited in these papers is not part of any epidemiological study according to the authors. The data in Walton (1951) is derived mostly from another paper that itself is based on a questionnaire. There is no way to address the data using USEPA data quality guidelines to verify and validate the data. Rather than there being no uncertainty in these two studies (much of Bosch et al. is included in the Walton paper), the data in these papers is highly uncertain, perhaps of unbounded uncertainty, and there can be no confidence in the papers themselves because they lack materials and methods and there is no possible way to verify the reliability of the data sets used in calculating the nitrate RfD, LOAEL or NOAEL, or derived nitrite values. USEPA has failed to apply its own data quality requirements to these papers thus creating RfDs that lack scientific merit and are scientifically indefensible.
7. USEPA's mechanistic basis for the RfDs (e.g., infant gastrointestinal tracts produce insufficient acid secretions that allow nitrosating bacteria to grow, produce nitrite, and cause IAM case induction) is based on outdated science and is likely obtained from non-peer reviewed papers. In fact, any paper before 1975-1980 is suspected of not being peer reviewed. USEPA's stable of RfDs have many chemical files that are constituted on papers that are not proven peer reviewed and may in fact be based on outdated science from non-peer reviewed papers. USEPA and the regulated community will need to review this problem to determine if these chemicals require rewriting of their basis to meet modern data quality standards and actual peer reviewed science.
8. USEPA's use of uncertainty factors (UFs) and modifying factors (MFs) for nitrate and nitrite RfDs appears to be designed to negate any acknowledgement that uncertainties

exist. The assertion that all human epidemiology morbidity and mortality data are without blemish is unsupportable and refuted by the aldicarb human study.

9. USEPA has never produced a scientifically defensible dose-response curve that provides any predictability for IAM case induction and, if induced, the severity of the IAM case. These are basic toxicological outputs that, if not possible to create, clearly indicate a lack of USEPA's most fundamental understandings of the cause/effect relationship and dose-response relationship of the chemical(s) under review. Given USEPA's spurious claim that it essentially has perfect institutional knowledge of the IAM paradigm (e.g., by use of a cumulative UF equal to 1), it should be able to produce these relationships. It cannot. In fact, our findings indicate that USEPA's knowledge of the hematological basis for the RfDs is broken and cannot be fixed by trying to rehabilitate its non-peer reviewed cited principal studies whose data cannot be verified and validated by applying the spackle of supporting studies that themselves have unverified and unvalidated data and may not be peer reviewed. Thus, no uncertainty becomes high uncertainty and perhaps unbounded uncertainty. High confidence in the studies becomes no confidence in the studies. UF = 1 becomes cumulative UFs of as high as 1,000X. No data gaps for modifying factors becomes 10X. In fact, there are not enough UF and MF categories to describe and compensate for all the problems with the papers and data used by USEPA to calculate its nitrate and nitrite RfDs. Of course, this means that any MCLs based on any RfDs citing to the current principal studies are also fatally flawed and must be immediately reduced in concentration to account for data problems with the source documents or withdrawn.
10. USEPA leaves no margin of safety between the 11 ppm nitrate-N lowest LOAEL and the selected 10 ppm nitrate-N NOAEL. This implies a steep dose-response curve akin to a cliff. At 10 ppm nitrate-N, infants are safe and at 11 ppm nitrate-N infants are at acute toxic risk. If USEPA is correct that there is no intraspecies variation, then all infants are at equal risk of IAM induction. Yet, the IAM case data doesn't bear this out. USEPA has yet to explain this phenomenon that would, in part, be explained by intraspecies variability in the infant population. It would appear that a 10X intraspecies variability factor is needed.
11. Using drinking water source nitrate concentrations as the delivered dose/concentration to infants is mathematically incorrect. Infants displaying nitrate induced cyanosis ingested diluted source water containing some fraction of the contaminated source water nitrate concentration. A correction factor is needed to reduce the equivalent delivered concentration for use in RfD calculation that would reduce the RfD (and MCL) 10-fold at most. This correction needs to be done immediately as this critical error demonstrates that nitrate is far more toxic than previously admitted by USEPA.
12. USEPA has an incorrect conceptual model of IAM induction. International literature demonstrates that IAM induction likely is the result of nutrient/microbial ingestion from contaminated water and not just nitrate. This means that mixture risk assessment is required, not just single chemical risk assessment evaluations. USEPA's chemical mixtures guidelines demonstrate that USEPA understands that mixtures pose different risks than single chemical exposures. IAM is the result of chemical/biological mixtures. Therefore, sole use of nitrate as a surrogate for the mixture that leads to nitrite toxicosis is toxicologically untenable and does not rise to the level of risk assessment science that models real world exposures rather than hypothetical assumption-based exposures.

13. There are logical reasons to increase or decrease the RfDs and any MCLs based on their use, regardless of source (e.g., USEPA's nitrate and nitrite MCLs are based on Office of Drinking water unique RfDs that are different from the IRIS RfDs either in narrative or numerical basis (see Nitrate/Nitrite Criteria Document for details and to compare with current IRIS nitrate and nitrite RfDs). Increases or decreases in numerical values are currently impossible because USEPA denies the existence of errors, omissions, and misrepresentations in nitrate and nitrite RfDs (and MCLs) even though the author of this submission has provided this information to USEPA over the last two years in various forms. Thus, it would appear that USEPA is disingenuously putting forth the discredited notion that the current hematological basis for the RfDs is understood and need not be revisited in an attempt to bury this new knowledge that has been presented to them concerning the lack of scientific basis of their current RfDs. Because of this position, there is really no way to know if any population or subpopulation of humans is adequately protected by the RfDs when linked to MCLs and whether the enormous regulatory burdens linked back to the RfDs are justified. All communities need USEPA to formulate nitrate and nitrite RfDs that represent good science and not stealth risk management decisions that have no place in RfD formulation or represent just plain bad risk analysis products.
14. In the 1970s and again in the 1980s, USEPA Assistant Administrator Kimm noted in official USEPA documents that USEPA frequently did not know the actual exposure concentrations associated with IAM cases. Furthermore, USEPA has never identified which, if any, IAM exposure concentrations are reliable. Assistant Administrator Kimm impeached USEPA's principal studies and likely supporting studies a decade or so before the first IRIS nutrient RfD was written. This means that USEPA knew or should have known the data sets were unreliable. USEPA needs to use maximalized UFs and MFs to account for data unreliability. Not knowing which, if any, of the cited principal studies' IAM case statistics are usable means that the current UF of 1 is untenable and, perhaps, the RfDs should be withdrawn.
15. USEPA states that nitrite is an acute toxicant. IAM cases follow days, weeks, or months of intermittent or continuous exposure to nutrient contaminants in source drinking water. The RfDs do not explain how an acute toxicant turns into a longer-term exposure toxicant without accumulating and/or causing long term subclinical hypoxia and anoxia and potentially associated developmental effects. This is a critical question that might explain developmental effects in infants yet to be linked with a cause. Without opening up the hematological basis for the RfDs, USEPA will not investigate the potential links between developmental disorders and hematological toxicity of nitrate and nitrite and mixtures of nutrients and microbes linked to IAM cases.
16. "Through the IRIS Program, EPA provides high quality science-based human health assessments to support the Agency's regulatory activities and decisions to protect public health." Given the evidence presented in this submission, it appears that for nitrate and nitrite RfDs USEPA has never provided "...high quality science-based human health assessments to support the Agency's regulatory activities and decisions to protect public health." This assertion is proven if even one of the claims in this submission is found scientifically valid. For example, the admissions of Mr. Kimm support this assertion.

17. USEPA has opened the door to inclusion of the historical hematological basis for the IRIS nitrate and nitrite RfDs by referring back to the principal studies in narrative and tables in previous six-year reviews. Therefore, it seems too late to close the door now.
18. Given that the nitrate and nitrite MCLs are not linked to the IRIS RfDs (according to the USEPA Nitrate/Nitrite Criteria Document), what is the point of this review?

It should be noted that USEPA was invited to peer review work product for the book in preparation but curtly refused to agree to any interactions with the authors except via PIO requests for information that were unproductive. Despite USEPA's desire to remain ignorant of our interim book findings, the Agency was apprised of these findings via multiple communications.

USEPA's unprofessional approach to having their science products reviewed in a collegial manner was a great disappointment that culminated with ignoring our findings and moving forward with a nitrate and nitrite RfD review process that excludes the fatally flawed IRIS RfD explanation for the hematological processes that result in a case of IAM.

For all these reasons and more that will be presented in our book, USEPA needs to reopen the hematological basis for the nitrate and nitrite RfDs. USEPA's nitrate and nitrite RfDs have been demonstrated to lack scientific and procedural rigor. Their narrative basis is flawed because much of it is based on assumptions that do not match real world exposures or modern science that replaced outdated or disproven science.

USEPA needs to move its RfDs from dalliances with past papers and hypotheses, starting as early as the 1920s for the mechanistic basis of IAM and infant physiology and biochemistry to the third decade of the 21st century. It needs to replace the musings and hypotheses turned into paradigm (starting in the 1940s and coalesced into doctrine in the 1970s) to instead practice modern peer review science and assure data quality.

In closing, I would like to thank USEPA for training me in the writing and reviewing of RfDs, MCLs and risk assessment products during and after my time as Wisconsin's State Toxicologist and State Groundwater Toxicologist.

This document and USEPA's response will serve, in part, as USEPA peer review previously denied. USEPA is again invited to participate in the peer review of our book chapters as they become available.

Thank you for the opportunity to comment on your FR notice.

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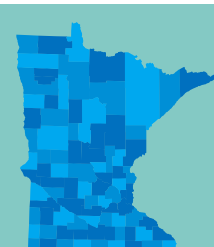
Surface Water

October 2022

Aquatic Life Water Quality Standards Draft Technical Support Document for Nitrate

MINNESOTA POLLUTION CONTROL AGENCY



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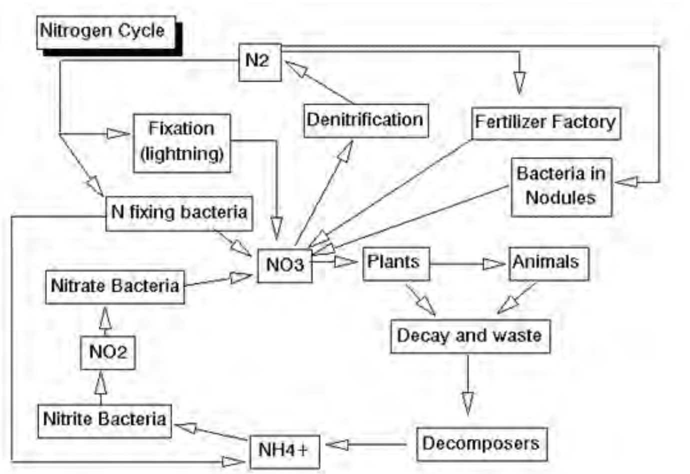
Contents

Introduction

Nitrate is a common chemical found in surface waters and groundwater from both natural and anthropogenic sources. Nitrate is formed as part of the breakdown of organic wastes, production by nitrogen-fixing plants, and through industrial production. Sources of excess nitrate in the environment can be linked to human activities on the landscape that result in the release of nitrogen to surface and ground waters. These include point sources such as wastewater discharge and non-point sources such as agricultural practices. Forest fires, decay of organic matter, and volcanic discharges are some natural sources that release nitrate to the environment. Nitrogen cycling in the environment results in nitrogenous compounds, such as ammonia, that may covert into the more stable and conservative nitrate ion (NO_3^-).

Figure 1. Illustration of the nitrogen cycle (McShaffrey, n.d.)



Natural sources of nitrate to surface waters in the state vary; however, when nitrate concentrations in surface water samples from “reference” areas (i.e., areas with relatively little human impact) are compared to samples from areas of greater human impact, the reference areas exhibit much lower nitrate concentrations. Nitrate concentrations in these reference areas are typically below 1 mg/L (Heiskary and Wilson, 2008). In surface water, nitrate is the predominant form of total nitrogen, reported as milligrams (mg) nitrate-nitrogen per liter (L) (alternatively, mg nitrate-N/L or mg N:NO3/L), in concentrations above about 4 mg nitrate-N/L. This concentration of nitrate is within the range of concentrations reported for effects to aquatic organisms.

Concern regarding the toxicity of nitrate to aquatic organisms was brought to the attention of the Minnesota Pollution Control Agency (MPCA) through comments made by the Minnesota Department of Natural Resources and the Minnesota Center for Environmental Advocacy during the 2008 triennial standards review and reported from monitoring studies in Minnesota surface waters. In addition, the Minnesota State Legislature in 2010 approved funding for the MPCA to develop aquatic life standards for nitrogen and nitrate. Development of a nitrate aquatic life standard is part of the effort to address these concerns and directives; information on how that path has evolved since 2010 is provided later in this document.

Nitrogen has multiple forms and environmental impacts, which are being addressed in multiple ways.

Nitrate, nitrite, and ammonia all may impact aquatic life. In addition to developing water quality standards (WQS) to protect aquatic life from nitrate, MPCA is also revising the water quality standard (WQS) for ammonia concurrently with the development of this nitrate standard.

Nitrite is another form of nitrogen that has been shown to exert toxicity to aquatic organisms at much lower concentrations compared to nitrate. The nitrite ion, however, is not stable in environments concurrent with the presence of most aquatic organisms considered in the context of natural communities. There may be cases of high nitrite present in places like wastewater ponds, but those are not considered as waters of the state. The ephemeral nature of nitrite under conditions of oxygen, particularly streams and rivers, does not allow it to build up to concentrations known to be toxic to aquatic organisms. Therefore, nitrite is not being considered in development of this aquatic life standard.

Nitrogen can also contribute to nutrient over-enrichment or eutrophication, leading to algae growth and, eventually, oxygen depletion. The MPCA is also engaged in implementing a nutrient reduction strategy for the State that includes goals for total nitrogen in surface waters. This nutrient reduction strategy aims to reduce Minnesota's contribution to eutrophication and "dead zones" in areas such as the Gulf of Mexico. The contribution of nitrogen to eutrophication, either locally or regionally, is not being considered in development of this aquatic life standard. Efforts to develop a total nitrogen budget center on addressing contributions of nitrogen to protect against adverse effects downstream in the Mississippi River basin. However, this effort differs from the need to develop a nitrate toxicity standard to protect aquatic life in any given lake or stream.

Finally, nitrogen (nitrate and nitrite) can also cause human health impacts if present in sufficiently high enough concentrations in drinking water. The surface WQS for Minnesota's Class 1 waters come from the Federal Safe Drinking Water Act, with the Maximum Contaminant Levels set at 10 mg/L for nitrate, and a 1 mg/L for nitrite. The Class 1 WQS are also currently under revision in a separate process.

Still, elevated concentrations of nitrate have been documented in surface waters throughout the state, from both point and non-point sources (Omernik et al, 2016). A comprehensive assessment of these data is beyond the scope of this document, but current trends in the data clearly indicate that increased nitrate concentrations are associated with areas of higher human activity on the landscape.

Currently, there is little guidance for protection of United States waters from the effects of nitrate toxicity to aquatic organisms. The importance of nitrate toxicity to aquatic organisms has been a concern to aquaculture management for many years. In the ambient environment, the role of nitrate, along with the more toxic forms of nitrogen, ammonia and nitrite, is a subject of greater scrutiny. This document will present the technical discussion of nitrate toxicity to aquatic organisms and will propose draft water quality standards (acute and chronic) necessary for the protection of aquatic life for nitrate.

How and why water quality standards are developed?

Minnesota's WQS are designed to protect the beneficial uses of the state's groundwater and surface waters. In surface waters, protection encompasses normal growth and reproduction of aquatic animal and plant populations (aquatic life), human recreational uses (recreation), consumption of aquatic biota (aquatic consumption), and sources of drinking water (domestic consumption) in some waters.

WQS consist of three parts: 1) the beneficial use classification of the water; 2) narrative and numeric criteria that describe the needed conditions in the water, including concentrations of pollutants, below which are considered protective of the beneficial use;[1] and 3) mechanisms designed to avoid degradation of water quality (antidegradation). This document focuses on numeric standards for protection of the aquatic life community from nitrate toxicity in Class 2 surface waters.

Development of nitrate standards relies on sound scientific studies that provide the data needed to characterize and quantify how nitrate affects aquatic organisms, in this case, freshwater invertebrates and invertebrates. Toxicity data used to develop numeric criteria were evaluated based on national U.S. Environmental Protection Agency (EPA) guidance (EPA, 1985), requirements in Minn. R. chs. 7050 and

[1] *The numeric criteria setting an acceptable level of pollution is usually referred to as "the standard" in Minnesota, while EPA and other states use the word "criteria"*

7052, methods outlined by the American Society for Testing and Materials (ASTM, 2009), and a number of EPA testing methods. The key steps in developing the planned new numeric water quality criteria for nitrate involved:

1. A thorough search of the scientific literature by using electronic and printed databases. This search was performed for literature published through June 2021. In this case, the search terms “nitrate”, “toxicity” and “freshwater” served to provide the bulk of literature considered for review.
2. Reviewing these articles to screen out those that were outside of the scope of interest and to determine the usefulness of reported endpoints. For example, articles were found that reported toxicity of silver nitrate or used terrestrial organisms. Neither of these fit the scope of assessing the toxicity of the nitrate ion in freshwater aquatic systems.
3. Tabulating pertinent toxicity endpoints to be used in the calculation of draft acute and chronic standards.

Articles were reviewed and critiqued based on the information reported. Occasionally, correspondence with the author was needed to clarify issues or obtain additional information. Information from the literature was retrieved from a search of academic databases. Primary literature search databases included were the (EPA) ECOTOX database, MPCA library resources, University of Minnesota library, Scirus (www.scirus.com), and Google Scholar (scholar.google.com). Other sources and references included scientific papers shared between fellow colleagues or those gleaned from reviews of printed material. Scientific studies were assessed for quality based on guidance provided by the EPA and published ASTM methods of testing protocol (ASTM).

Updates to Technical Support Document

Since the initial effort by MPCA in 2010 to develop nitrate water quality standards for aquatic life, considerable additional aquatic toxicity information has been completed and published in the scientific literature. Appropriate laboratory performance, review and documentation of aquatic toxicity tests sufficient to provide the technical underpinnings for developing WQS takes much time and effort. EPA worked along with the MPCA to garner support for additional toxicity testing to supplement the existing aquatic species evaluated for acute and chronic endpoints. Central to this effort was the addition of new test methods for species like freshwater mussels, a group of macroinvertebrates important to a large area of the United States, including Minnesota. Mayflies are another important group of macroinvertebrates that have been difficult to use in laboratory aquatic toxicity tests. Test methods for a species of mayfly (*Neocloeon triangulifer*) were developed over a number of years and this species is now suitable for toxicity testing. The EPA worked with other federal and academic institutions to develop these new test methods over several years prior to performing the actual toxicity tests. Completion of these test methods and toxicity endpoints reported for these test species fills a critical knowledge gap about the sensitivity of these important taxonomic groups to nitrate in the aquatic environment (EPA, 2010). In addition, the toxicity endpoints derived from these tests fulfilled important requirements of the EPA for developing water quality criteria. The compendium of scientific literature used to develop a water quality standard for nitrate is the result of research studies on nitrate toxicity performed by public, private and academic institutions throughout the United States.

EPA provided support for research and expertise in toxicity test method development and experimental design. Some of these studies were recently completed in 2020 and published in 2021 in the scientific literature. The EPA also manages a large database (ECOTOX) of toxicity test endpoints reported from the published literature. The assemblage of reported toxicity values provides an extensive search of the scientific literature that are used in the development of numeric water quality criteria. There is no one report or publication that provides any cumulative summary of nitrate toxicity testing conducted with the assistance of the EPA. We hope that this technical support document will serve as a source that demonstrates the importance of these investigative endeavors.

Aquatic life criteria development

Numeric water quality criteria consist of a Final Acute Value (FAV), a Maximum Standard (MS) and a Final Chronic Value (FCV). Methods used to calculate both acute and chronic criteria values follow the EPA document titled "*Guidelines for Deriving Numerical National Water Quality Criteria for the Protection of Aquatic Organisms and Their Uses"* (EPA, 1985). These values are interrelated and calculated on the assumption that provides for protection of 95% of aquatic communities. Much of this assumption is because not all aquatic organisms present in the environment can be feasibly tested for their sensitivity to environmental contaminants. Therefore, calculation of numeric water quality criteria relies on toxicity endpoints observed through laboratory tests exposures using organisms that are either cultured for this purpose or collected from the field and tested. These organisms are used to represent both the specific species and organisms related taxonomically. The EPA guidance requires a minimum dataset representing eight taxonomic categories, referred to in this document as minimum data requirements (MDR). Overall, these MDRs represent an approximation of the assemblage of North American aquatic organisms that depend on adequate water quality for their survival, growth, and reproduction. The use of either cultured or field collected organisms must follow consistent methodology that assures for the soundness of outcomes in the tests performed.

Toxicity information used for development of the numeric criteria for nitrate was provided through reports from scientific studies published in the open literature. Results of studies were reviewed from 110 references cited in the scientific literature, and most studies considered were from work published over the past twenty years. All studies considered for use in this criteria development are listed in Table 5 and Table 6, for acute and chronic endpoints, respectively. Studies considered for use in numeric criteria development were those performed using sodium nitrate as a toxicant. Other carrier salts reported for the nitrate ion are calcium and potassium. Few studies reported results using calcium nitrate and based on the recent work by EPA assessing chloride toxicity, the potassium ion exerts its own level of toxicity that would confound effects of toxicity endpoints if used together with nitrate. The literature contains much information about the toxicity of ammonium nitrate, which is a common agricultural fertilizer, but these too were not included, because ammonia is a much more toxic chemical. The Minnesota water quality chronic standard for ammonia is 40 µg/L for Class 2B surface waters and is being revised concurrently with the development of this nitrate standard.

Based on the recommended EPA guidance (EPA, 1985), procedures for calculating full (Tier I) aquatic life criteria require the utilization of acceptable toxicity endpoints for eight specified taxonomic family-level categories. This method provides assurance of calculating a final acute value that is protective of aquatic communities. During the initial phases of developing this standard, information provided in the published literature was not enough to fulfill this requirement. Since then, additional toxicity tests were performed to fill this gap. These tests provided toxicity information for additional freshwater species, which served to fulfill the eight specified taxonomic categories.

Development of acute water quality criteria

Acute tests are typically of short duration (2 – 4 days), and survival (mortality) is the primary response observed and reported following acute exposures. Acute toxicity endpoints are described primarily through calculated values of point estimates of test concentrations causing lethality or morbidity of 50%

of the test population, referred to as the 50% lethal concentration (LC50) or 50% effective concentration (EC50).

Water quality criteria are calculated based on the Geometric Mean Acute Values (GMAV) for each generic-level taxon having acceptable toxicity information. For many of the nitrate toxicity data, a single species represents the genus. These GMAVs ranged from 103 mg nitrate-N/L for the aquatic insect *Hydropsyche* to 1902 mg nitrate-N/L for the lake whitefish (*Coregonus*) (Table 4; Figure 2). Invertebrates represent the majority of the species with acute toxicity endpoints below the median GMAV of 643 mg nitrate-N/L. Furthermore, invertebrates appeared to exhibit the greatest acute sensitivity to nitrate toxicity, as this group is represented in the four lowest ranked values in the calculation of the Final Acute Value (FAV) = 119.2 mg N:NO3/L (rounded to 120) as presented in Tables 2a-2c. The maximum standard (MS) = 59.6 (rounded to 60) mg N:NO3/L is calculated as half (120 ÷ 2) of the FAV for all Class 2 waters. Aquatic insects represent a group of invertebrates commonly reported in the literature, and who also rank in the four most sensitive taxa. Overall, invertebrate GMAVs varied in their toxicity endpoints by about an order of magnitude with the New Zealand mud snail (*Potamopygrus*) being the least sensitive invertebrate. Vertebrates showed to be the least sensitive group with an amphibian, *Hyla*, being the most sensitive among that group. Fish genera ranked in the top eight of 29 least sensitive taxa.

It is important to point out that three genera are not native to North America but were included in the full list of GMAVs taxa considered for use in developing the acute aquatic life criteria. The previously mentioned New Zealand mud snail is an exotic invasive in many parts of the world, including in North America, and is likely established within the aquatic community where present. In addition, the African Clawed Frog (*Xenopus*) and the Zebrafish (*Danio*) are well documented laboratory test species. Their use in this WQS development, however, is considered supplemental for this technical support document, and the magnitude of their reported endpoints support those from other organisms within the same taxonomic category.

Development of chronic water quality criteria

Methods used for development of chronic criteria follow the same procedures used to develop acute criteria when sufficient toxicity test endpoints are available. For nitrate, sufficient chronic toxicity test endpoints were available to fulfill the eight MDRs needed for calculating chronic water quality criteria. Chronic endpoints are effects of exposure to nitrate measured primarily as lethal endpoints of survival (or mortality), and sublethal endpoints of reproduction and growth of test organisms. These tests are performed over many days or weeks depending on the organism and specific protocols for minimum test duration and are typically referred to as full or partial life cycle tests. Further discussion of chronic endpoints is found in the MPCA guidance (MPCA, 2010).

Endpoints of chronic toxicity effects are often described through hypothesis testing of treatment responses compared to control responses. A No-observed-effect-concentration (NOEC) is the highest concentration with the response not statistically different from that observed in control organisms. A Lowest-observed-effect-concentration (LOEC) is the lowest concentration with a response statistically different from those observed in control organisms. Another important measure of effect uses regression to estimate effect concentrations of the 10th (EC10) and 20th (EC20) percentile test concentration that are observed for chronic endpoints.

Table 5 shows all data used to calculate genus mean chronic values (GMCV). Tables 3 and 4 show the GMCVs and calculation of the Final Chronic Values. GMCVs were reported for seven invertebrate genera and seven vertebrate genera. Invertebrate taxa represented three of four of the most sensitive genera. The remaining invertebrate taxa showed rankings distributed throughout the sensitivity distribution.

Fish and amphibians represented the vertebrate taxonomic categories and neither differed much regarding their sensitivity ranks. The exception to this is the chronic toxicity of nitrate to lake trout reported by McGurk et al (2006). Effects on fry weight, a critical chronic endpoint, were reported as a NOEC = 1.6 mg/L and a LOEC = 6.25 mg/L N:NO3 reported following a 146-day exposure. As provided in EPA guidance and in Minn. R. ch. 7050, more restrictive criteria may be applied when necessary to protect economically and ecologically important species given supporting toxicity information. In Minnesota, coldwater habitats, described in Minn. R. 7050.0420 and designated in Minn. R. 7050.0470 as Class 2A waters, have critical recreational and economic value. This designation provides a means to protect for the coldwater species assemblage, which includes lake trout. For this reason, chronic criteria were developed for both coldwater uses (Class 2A; Table 3 a,b,c) and all other Class 2 water uses (Class 2B and Class 2Bd; Table 4 a,b,c). Toxicity test information for the lake trout serves as a surrogate to the many other aquatic organisms present in coldwater systems. The calculated Final Chronic Value of 5.2 mg/L N:NO3 (adjusted to 5.0 mg/L N:NO3) will provide for that protection. First, the lake trout study's exposure (146 d) was considerably longer than all other chronic test endpoints. The intent of the EPA 1985 guidelines is to provide for a reasonable assurance that a criterion value avoids being too over-protective or under-protective. Given that understanding, the decision to use the LOEC as the chronic endpoint ensures that the observed response (weight) is directly associated with a measured concentration, is significantly different than the control response, and provides better assurance that the selected endpoint will not be overprotective.

Differences in the response of a test species to nitrate can be attributed to the organism age at test start, length of test and endpoint observed. In the case of the lake trout, acute tests were initiated with swim-up fry, whereas chronic tests used newly fertilized eggs at test start. The final observed endpoints for those two different toxicity tests occur at concentrations that are considerably different, but nonetheless relevant. Another example are the tests using the water column crustacean *Daphnia,* where the reported values for both acute exposures (2-d LC50 = 447 mg/L) and chronic (7-d MATC = 506 mg/L) are similar. While acute endpoints reported survival, and chronic endpoints reported offspring produced, the similarity of endpoint values suggests that *Daphnia* are somewhat resistant to nitrate effects. Another water column crustacean, *Ceriodaphnia*, exposed under similar test regimes and reported endpoints, were shown to be much more sensitive to chronic exposures.

In calculating the final chronic value for non-salmonid waters (Class 2B and Class 2Bd), the lake trout endpoint is removed from the genus ranks. This does two things. First, the total number of ranked organisms decreases and a new set of the four most sensitive taxa is established (Table 4b). The Final Chronic Value is recalculated as 8.26 (rounded to 8) mg/L N:NO_3.

Additional considerations of nitrate toxicity to aquatic organisms

A thorough examination of how nitrate exerts toxicity to aquatic organisms is beyond the scope of this document. However, two of the most likely causal actions are nitrate interference with cellular ion exchange, and the endogenous conversion of nitrate to nitrite. The latter action is strongly related to changes in the oxygen-carrying ability of hemoglobin, and may be an important factor in driving effects in fish and other aquatic organisms (Camargo et al. 2005). Examples of other reported effects of nitrate exposure include endocrine disruption in fathead minnows (Kellock et al. 2017) while Moore and Bringolf (2018) observed an impaired ability of a freshwater mussel to attach to their fish host and metamorphose. These reports conclude the need for the additional study of sublethal effects or chronic effects that have ecological relevance.

In addition to observed acute and chronic toxic effects on aquatic organisms, the relative potency of nitrate may vary with different water quality parameters. Potential toxicity effects due to the interaction of ions is well established in the study of water hardness ions, like calcium and magnesium, on the toxicity of certain metals (e.g., zinc, copper and nickel). The toxicity of nitrate has been hypothesized to also be influenced in a similar manner with hardness ions. Perhaps the most thorough study to date on this matter was published by Baker et al. (2017), which documented observed trends of decreasing nitrate toxicity with increased hardness concentration. Though these trends seems suggestive of influence on nitrate toxicity, presence of other water quality ions in the exposures precluded any assurance that hardness ions alone served to mitigate nitrate toxicity.

Why not a nitrate nutrient standard?

Nitrate is the form of nitrogen most available for use by plants. In freshwater systems, nitrogen can be a limiting nutrient for aquatic plant growth, and excess nitrogen, primarily in the nitrate form, may accumulate in these systems. In contrast, growth of saltwater plants typically is limited by available nitrogen in the ecosystem. As such, the transport of excess nitrogen, predominantly as nitrate from freshwater systems, has been implicated – along with phosphorus – in the formation of oxygen-depleted areas in many marine sites, including the Gulf of Mexico. These oxygen-depleted areas are largely the result of nutrient enrichment or eutrophication (excess algal growth and decay) due to nutrients discharged from the Mississippi River. Nitrogen, primarily in the form of nitrate, is the greatest contributor to eutrophication in marine systems.

In 2000, EPA published regional guidance for lakes and reservoirs to help states develop nutrient criteria (EPA, 2000). In Minnesota, WQS have been adopted to protect lakes and rivers from eutrophic conditions (see Minnesota Rules, Chapter 7050.0222). These nutrient standards are based on phosphorus concentration as the primary cause of eutrophication, and efforts to develop these standards considered the roles of both phosphorus and nitrogen. In developing the eutrophication standards, monitoring data was examined and compared to a number of responses measured in the biological community like fish assemblages and abundances. Though not entirely conclusive, no clear trend was established for the role of nitrogen in the response of these organisms or any direct contribution to eutrophication. The scientific literature has reported some information that describes effects of nitrate and nitrogen on plants ranging from single cellular (algae) to macrophytes. The focus of this research primarily considers the nutritive effects resulting when different ratios of nitrogen and phosphorus are considered within a range of aquatic (mostly lake) systems. These examinations have reported effects on the relative growth and competition of plants that may result in shifts to different plant communities. More recent information has linked excess nitrate in surface water to the production of harmful algal blooms (Wurtsbaugh, 2019). To our knowledge, direct toxic effects of nitrate on plants have not been reported.

Conclusion

Nitrate is both a naturally occurring substance and important nutrient in the life-cycle of plants in natural and cultivated settings. It can also be a common toxicant in Minnesota surface waters when present, and excessive nitrate released to surface waters is usually associated with human influence on the landscape. This document proposes draft numeric standards for nitrate to protect aquatic life in lakes and streams designated as Class 2 waters of the state. This use classification sets specific rules for protecting cold waters (Class 2A) uses and cool/warm water (Class 2B) uses. The draft WQS for nitrate were developed in efforts to protect these uses based on best available scientific information.

The draft acute value (maximum standard) calculated is 60 mg/L N:NO3 for a one-day duration concentration for all Class 2 waters, and the draft chronic values are 8 mg/L N:NO3 mg/L for Class 2B and 2Bd waters and 5 mg/L N:NO3 for Class 2A waters for concentrations based on a four-day duration (Table 1).

Table 1. Proposed nitrate criteria for the protection of aquatic life

	Acute (all Class 2 waters)	**Chronic (Class 2A)**	**Chronic (2Bd)**
Criteria value	60 mg/L*	5 mg/L^	8 mg/L^

*one day duration

^four day duration

Data

Table 2a. Ranks of genus acute sensitivity for calculating Class 2 value and maximum standard.

Genus	MDR	R	P	GMAV[*]
Coregonus	1	28	0.965517	1902.00
Notropis	2,3	26	0.896552	1354.00
Oncorhynchus	1	25	0.862069	1310.59
Micropterus	2,3	24	0.827586	1261.00
Cyprinella	2,3	23	0.793103	1241.48
Pimephales	2,3	22	0.758621	1172.79
Salvelinus	1	21	0.724138	1121.40
Potamopyrgus	7,8	20	0.689655	1042.00
Megalonaias	7,8	19	0.655172	937.00
Allocapnia	6,8	18	0.62069	836.00
Hybognathus	2,3	17	0.586207	760.00
Lithobates	2,3	16	0.551724	694.00
Pseudacris	2,3	15	0.517241	643.00
Acipenser	2,3	14	0.482759	625.97
Hyla	2,3	13	0.448276	601.00
Ceriodaphnia	4	12	0.413793	543.84
Unio	7,8	11	0.37931	504.00
Lampsilis	7,8	10	0.344828	487.24
Amphinemura	6,8	9	0.310345	456.00
Daphnia	4	8	0.275862	447.14
Sphaerium	7,8	7	0.241379	371.00
Anodonta	7,8	6	0.206897	369.00
Hyalella	5	5	0.172414	368.37
Chironomus	6,8	4	0.137931	189.00
Neocloeon	6,8	3	0.103448	179.00
Cheumatopsyche	6,8	2	0.068966	137.06
Hydropsyche	6,8	1	0.034483	102.98

[*] *mg/L N:NO3*

Table 2b. Four most sensitive genera for calculating Class 2 final acute value

Genus	Rank	GMAV	ln GMAV	(ln GMAV)^2	P = R/(N+1)	SQRT P
Chironomus	4	189.00	5.241747	27.47591	0.137931	0.371391
Neocloeon	3	179.00	5.187386	26.90897	0.103448	0.321634
Cheumatopsyche	2	137.06	4.920387	24.21021	0.068966	0.262613
Hydropsyche	1	102.98	4.634573	21.47927	0.034483	0.185695
	SUM		19.98409	100.0744	0.344828	1.141333

Table 2c. Calculation of Class 2A final acute value

S2 =	12.1751
S =	3.48928
L =	4.00042
A =	4.78064
FAV =	119.181 mg/L
MS =	59.5905 mg/L

Table 3a. Ranks of genus chronic sensitivity for calculating Class 2A final chronic value

Genus	GMCV	R	P
Daphnia	506.64	14	0.933333
Notropis	360.00	13	0.866667
Pimephales	214.13	12	0.8
Ceriodaphnia	65.59	11	0.733333
Potamopyrgus	57.80	10	0.666667
Hyla	47.00	9	0.6
Oncorhynchus	38.00	8	0.533333
Neocloeon	36.00	7	0.466667
Pseudacris	30.10	6	0.4
Rana	29.10	5	0.333333
Hyalella	18.92	4	0.266667
Lampsilis	17.45	3	0.2
Chironomus	9.56	2	0.133333
Salvelinus	6.25	1	0.066667

Table 3b. Four most sensitive genera for calculating Class 2A final chronic value

Genus	Rank	GMCV	ln GMCV	(ln GMCV)2	P = R/(N+1)	SQRT P
Hyalella	4	18.92	2.940	8.646	0.267	0.516
Lampsilis	3	17.45	2.860	8.177	0.200	0.447
Chironomus	2	9.56	2.258	5.097	0.133	0.365
Salvelinus	1	6.25	1.833	3.358	0.067	0.258
	SUM		9.890	25.278	0.667	1.587

Table 3c. Calculation of Class 2A final chronic value

S2 =	22.248
S =	4.717
L =	0.601
A =	1.656
FCV =	5.238 mg/L

Table 4a. Ranks of genus chronic sensitivity for calculating Class 2B final chronic value

Genus	GMCV	R	P
Daphnia	506.64	13	0.928571
Notropis	360.00	12	0.857143
Pimephales	214.13	11	0.785714
Ceriodaphnia	65.59	10	0.714286
Potamopyrgus	57.80	9	0.642857
Hyla	47.00	8	0.571429
Oncorhynchus	38.00	7	0.5
Neocloeon	36.00	6	0.428571
Pseudacris	30.10	5	0.357143
Rana	29.10	4	0.285714
Hyalella	18.92	3	0.214286
Lampsilis	17.45	2	0.142857
Chironomus	9.56	1	0.071429

Table 4b. Four most sensitive genera for calculating Class 2B final chronic value

Genus	Rank	GMCV	In GMCV	(In GMCV)2	P=R/(N+1)	SQRT P
Rana	4	29.100	3.371	11.362	0.286	0.535
Hyalella	3	18.923	2.940	8.646	0.214	0.463
Lampsilis	2	17.455	2.860	8.177	0.143	0.378
Chironomus	1	9.560	2.258	5.097	0.071	0.267
SUM			11.428	33.282	0.714	1.643

Table 4c. Calculation of Class 2B final chronic value

S2 =	15.872
S =	3.984
L =	1.221
A =	2.112
FCV =	8.264 mg/L

Figure 2. Distribution of Genus Mean Acute Values by percentile rank of sensitivity to nitrate

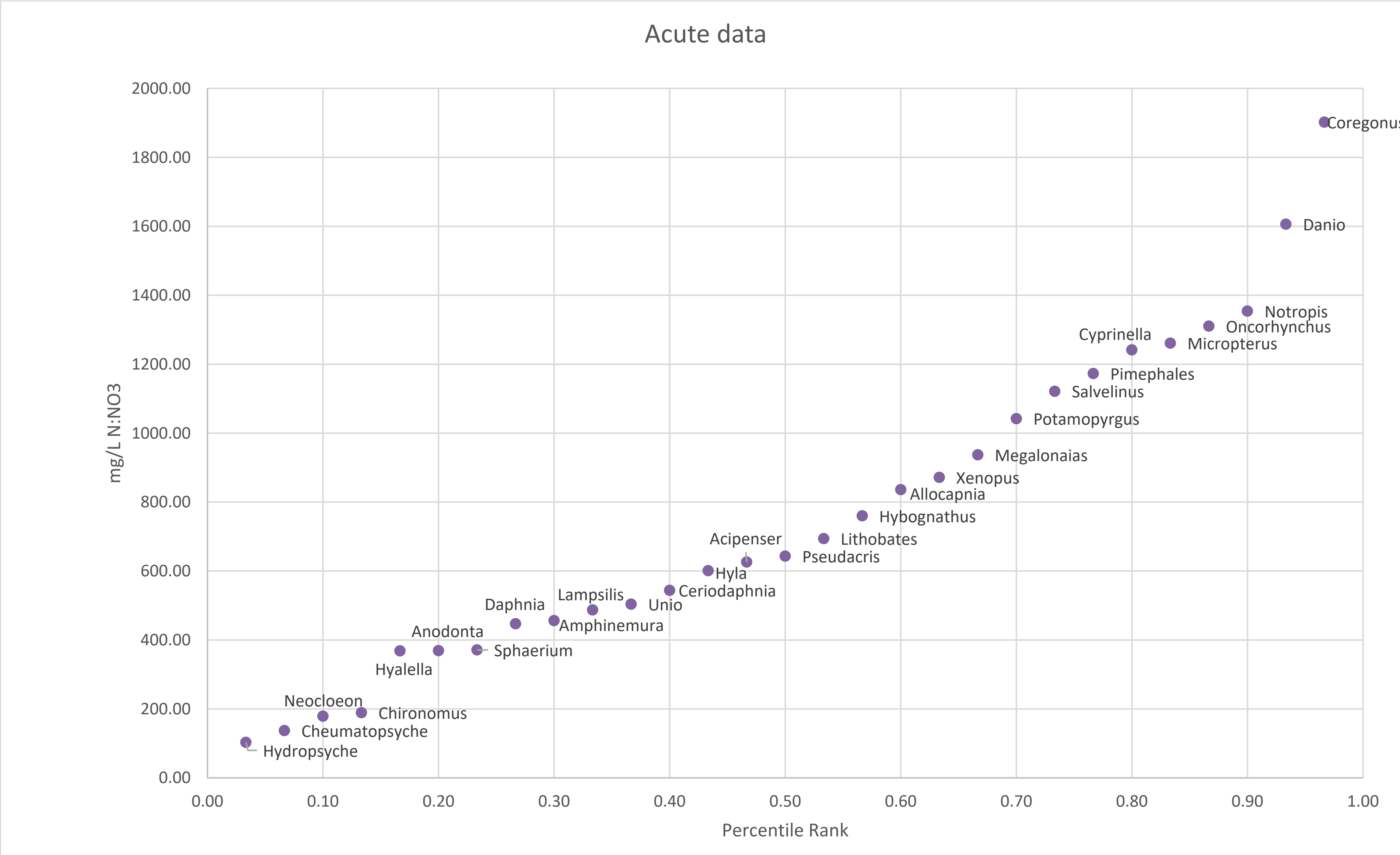


Table 5. All data used for acute criteria development.

Genus	MDR	Endpt Conc. (mg/L N:NO3)	GMAV	Effect measurement	Endpoint	Test duration (Days)	Author	Status of use for criteria development
Acipenser	2,3	1028	625.97	Mortality	LC50	4	Hamlin, 2006	OK
Acipenser	2,3	601		Mortality	LC50	4	Hamlin, 2006	OK
Acipenser	2,3	397		Mortality	LC50	4	Hamlin, 2006	OK
Allocapnia	6,8	836	836.00	Mortality	LC50	4	Soucek and Dickinson, 2012	OK
Amphinemura	6,8	456	456.00	Mortality	LC50	4	Soucek and Dickinson, 2012	OK
Anodonta	7,8	369	369.00	Mortality	LC50	4	Douda, 2010	OK; foot movement endpt
Ceriodaphnia	4	799	543.84	Mortality	LC50	2	Soucek and Dickinson, 2016	OK; most sensitive endpt
Ceriodaphnia	4	780		Mortality	LC50	2	Soucek and Dickinson, 2016	OK; most sensitive endpt
Ceriodaphnia	4	765		Mortality	LC50	2	Soucek and Dickinson, 2016	OK; most sensitive endpt
Ceriodaphnia	4	750		Mortality	LC50	2	Soucek and Dickinson, 2016	OK; most sensitive endpt
Ceriodaphnia	4	716		Mortality	LC50	2	Soucek and Dickinson, 2016	OK; most sensitive endpt
Ceriodaphnia	4	711		Mortality	LC50	2	Soucek and Dickinson, 2016	OK; most sensitive endpt
Ceriodaphnia	4	696		Mortality	LC50	2	Soucek and Dickinson, 2016	OK; most sensitive endpt
Ceriodaphnia	4	685		Mortality	LC50	2	Soucek and Dickinson, 2016	OK; most sensitive endpt
Ceriodaphnia	4	671		Mortality	LC50	2	Soucek and Dickinson, 2016	OK; most sensitive endpt
Ceriodaphnia	4	665		Mortality	LC50	2	Soucek and Dickinson, 2016	OK; most sensitive endpt
Ceriodaphnia	4	619		Mortality	LC50	2	Soucek and Dickinson, 2016	OK; most sensitive endpt
Ceriodaphnia	4	615		Mortality	LC50	2	Soucek and Dickinson, 2016	OK; most sensitive endpt
Ceriodaphnia	4	614		Mortality	LC50	2	Soucek and Dickinson, 2016	OK; most sensitive endpt
Ceriodaphnia	4	566		Mortality	LC50	2	Soucek and Dickinson, 2016	OK; most sensitive endpt
Ceriodaphnia	4	558		Mortality	LC50	2	Soucek and Dickinson, 2016	OK; most sensitive endpt
Ceriodaphnia	4	544		Mortality	LC50	2	Soucek and Dickinson, 2016	OK; most sensitive endpt
Ceriodaphnia	4	509		Mortality	LC50	2	Soucek and Dickinson, 2016	OK; most sensitive endpt
Ceriodaphnia	4	502		Mortality	LC50	2	Soucek and Dickinson, 2016	OK; most sensitive endpt
Ceriodaphnia	4	487		Mortality	LC50	2	Soucek and Dickinson, 2016	OK; most sensitive endpt
Ceriodaphnia	4	478		Mortality	LC50	2	Soucek and Dickinson, 2016	OK; most sensitive endpt

Genus	MDR	Endpt Conc. (mg/L N:NO3)	GMAV	Effect measurement	Endpoint	Test duration (Days)	Author	Status of use for criteria development
Ceriodaphnia	4	453		Mortality	LC50	2	Soucek and Dickinson, 2016	OK; most sensitive endpt
Ceriodaphnia	4	453		Mortality	LC50	2	Soucek and Dickinson, 2016	OK; most sensitive endpt
Ceriodaphnia	4	423		Mortality	LC50	2	Soucek and Dickinson, 2016	OK; most sensitive endpt
Ceriodaphnia	4	417		Mortality	LC50	2	Soucek and Dickinson, 2016	OK; most sensitive endpt
Ceriodaphnia	4	416		Mortality	LC50	2	Soucek and Dickinson, 2016	OK; most sensitive endpt
Ceriodaphnia	4	404		Mortality	LC50	2	Soucek and Dickinson, 2016	OK; most sensitive endpt
Ceriodaphnia	4	399		Mortality	LC50	2	Soucek and Dickinson, 2016	OK; most sensitive endpt
Ceriodaphnia	4	369		Mortality	LC50	2	Soucek and Dickinson, 2016	OK; most sensitive endpt
Ceriodaphnia	4	374		Mortality	LC50	2	Scott and Crunkilton, 2000	OK; most sensitive endpt
Ceriodaphnia	4	374		Mortality	LC50	2	Scott and Crunkilton, 2000	OK; most sensitive endpt
Cheumatopsyche	6,8	165.5	137.06	Mort/Morb	EC50	4	Camargo and Ward, 1992	OK; most sensitive endpt
Cheumatopsyche	6,8	113.5		Mort/Morb	EC50	4	Camargo and Ward, 1992	OK; most sensitive endpt
Chironomus	6,8	189	189.00	Mort/Morb	EC50	2	Wang et al., 2020	OK
Coregonus	1	1902	1902.00	Mortality	LC50	4	McGurk et al., 2006	OK; most sensitive endpt
Cyprinella	2,3	1744	1241.48	Mortality	LC50	4	Moore and Bringolf, 2020	OK; most sensitive endpt
Cyprinella	2,3	1717		Mortality	LC50	4	Moore and Bringolf, 2020	OK; most sensitive endpt
Cyprinella	2,3	639		Mortality	LC50	4	Moore and Bringolf, 2020	OK; most sensitive endpt
Danio	2,3	1606	1606.00	Mortality	LC50	4	Learmonth and Carvalho, 2015	Not used
Daphnia	4	611	447.14	Mortality	LC50	2	Scott and Crunkilton, 2000	OK
Daphnia	4	453		Mortality	LC50	2	Scott and Crunkilton, 2000	OK
Daphnia	4	323		Mortality	LC50	2	Scott and Crunkilton, 2000	OK
Hyalella	4	820	368.37	Mortality	LC50	4	Soucek et al., 2015	OK; most sensitive endpt
Hyalella	4	713		Mortality	LC50	4	Soucek et al., 2015	OK; most sensitive endpt
Hyalella	4	682		Mortality	LC50	4	Soucek et al., 2015	OK; most sensitive endpt
Hyalella	4	673		Mortality	LC50	4	Soucek et al., 2015	OK; most sensitive endpt
Hyalella	4	659		Mortality	LC50	4	Soucek et al., 2015	OK; most sensitive endpt
Hyalella	4	641		Mortality	LC50	4	Soucek et al., 2015	OK; most sensitive endpt

Genus	MDR	Endpt Conc. (mg/L N:NO3)	GMAV	Effect measurement	Endpoint	Test duration (Days)	Author	Status of use for criteria development
Hyalella	4	624		Mortality	LC50	4	Soucek et al., 2015	OK; most sensitive endpt
Hyalella	4	526		Mortality	LC50	4	Soucek et al., 2015	OK; most sensitive endpt
Hyalella	4	432		Mortality	LC50	4	Soucek et al., 2015	OK; most sensitive endpt
Hyalella	4	427		Mortality	LC50	4	Soucek et al., 2015	OK; most sensitive endpt
Hyalella	4	421		Mortality	LC50	4	Soucek et al., 2015	OK; most sensitive endpt
Hyalella	4	419		Mortality	LC50	4	Soucek et al., 2015	OK; most sensitive endpt
Hyalella	4	406		Mortality	LC50	4	Soucek et al., 2015	OK; most sensitive endpt
Hyalella	4	384		Mortality	LC50	4	Soucek et al., 2015	OK; most sensitive endpt
Hyalella	4	383		Mortality	LC50	4	Soucek et al., 2015	OK; most sensitive endpt
Hyalella	4	370		Mortality	LC50	4	Soucek et al., 2015	OK; most sensitive endpt
Hyalella	4	340		Mortality	LC50	4	Soucek et al., 2015	OK; most sensitive endpt
Hyalella	4	323		Mortality	LC50	4	Soucek et al., 2015	OK; most sensitive endpt
Hyalella	4	322		Mortality	LC50	4	Soucek et al., 2015	OK; most sensitive endpt
Hyalella	4	259		Mortality	LC50	4	Soucek et al., 2015	OK; most sensitive endpt
Hyalella	4	244		Mortality	LC50	4	Soucek et al., 2015	OK; most sensitive endpt
Hyalella	4	202		Mortality	LC50	4	Soucek et al., 2015	OK; most sensitive endpt
Hyalella	4	177		Mortality	LC50	4	Soucek et al., 2015	OK; most sensitive endpt
Hyalella	4	115		Mortality	LC50	4	Soucek et al., 2015	OK; most sensitive endpt
Hyalella	4	92		Mortality	LC50	4	Soucek et al., 2015	OK; most sensitive endpt
Hyalella	4	86		Mortality	LC50	4	Soucek et al., 2015	OK; most sensitive endpt
Hyalella	4	667		Mortality	LC50	4	Soucek et al., 2015	OK; most sensitive endpt
Hyalella	4	921		Mortality	LC50	4	Baker et al., 2017	OK; most sensitive endpt
Hyalella	4	484.9		Mortality	LC50	4	Baker et al., 2017	OK; most sensitive endpt
Hyalella	4	168.1		Mortality	LC50	4	Baker et al., 2017	OK; most sensitive endpt
Hybognathus	2,3	760	760.00	Mort/Morb	EC50	4	Buhl , 2002	OK; most sensitive endpt
Hydropsyche	6,8	109	102.98	Mort/Morb	EC50	4	Camargo and Ward, 1992	OK; most sensitive endpt
Hydropsyche	6,8	97.3		Mort/Morb	EC50	4	Camargo and Ward, 1992	OK; most sensitive endpt

Genus	MDR	Endpt Conc. (mg/L N:NO3)	GMAV	Effect measurement	Endpoint	Test duration (Days)	Author	Status of use for criteria development
Hyla	2,3	601	601.00	Mort/Morb	EC50	4	Wang et al., 2020	OK
Lampsilis	7,8	665	487.24	Mort/Morb	EC50	4	Wang et al., 2020	OK
Lampsilis	7,8	357		Mortality	LC50	4	Soucek and Dickinson, 2012	OK
Lithobates	2,3	694	694.00	Mort/Morb	EC50	4	Wang et al., 2020	OK
Megalonaias	7,8	937	937.00	Mortality	LC50	4	Soucek and Dickinson, 2012	OK
Micropterus	2,3	1261	1261.00	Mortality	LC50	4	Tomasso and Carmichael, 1986	OK
Neocloeon	6,8	179	179.00	Mortality	LC50	4	Soucek et al., 2015	OK
Notropis	2,3	1354	1354.00	Mortality	LC50	4	Adelman et al., 2009	OK
Oncorhynchus	1	1958	1310.59	Mortality	LC50	4	Baker et al., 2017	OK
Oncorhynchus	1	883		Mort/Morb	EC50	4	Wang et al., 2020	OK
Oncorhynchus	1	1658		Mortality	LC50	4	Buhl and Hamilton, 2000	OK
Oncorhynchus	1	1913		Mortality	LC50	4	Baker et al., 2017	OK
Oncorhynchus	1	1446		Mortality	LC50	4	Baker et al., 2017	OK
Oncorhynchus	1	808.5		Mortality	LC50	4	Baker et al., 2017	OK
Pimephales	2,3	1607	1172.79	Mortality	LC50	4	Scott and Crunkilton, 2000	OK
Pimephales	2,3	1406		Mortality	LC50	4	Scott and Crunkilton, 2000	OK
Pimephales	2,3	1010		Mortality	LC50	4	Scott and Crunkilton, 2000	OK
Pimephales	2,3	1537		Mortality	LC50	4	Moore and Bringolf, 2020	OK
Pimephales	2,3	1500		Mortality	LC50	4	Moore and Bringolf, 2020	OK
Pimephales	2,3	958		Mortality	LC50	4	Moore and Bringolf, 2020	OK
Pimephales	2,3	1278		Mortality	LC50	4	Buhl,K.J., 2002	OK
Pimephales	2,3	522		Mort/Morb	EC50	4	Buhl,K.J., 2002	OK
Potamopyrgus	7,8	1042	1042.00	Mortality	LC50	4	Alonso and Camargo, 2003	OK
Pseudacris	2,3	643	643.00	Mortality	LC50	4	Schuytema and Nebeker, 1999a	OK
Salvelinus	1	1121.4	1121.40	Mortality	LC50	4	McGurk et al., 2006	OK; most sensitive endpt
Sphaerium	7,8	371	371.00	Mortality	LC50	4	Soucek and Dickinson, 2012	OK
Unio	7,8	504	504.00	Mortality	LC50	4	Douda, 2010	OK; foot movement endpt

Genus	MDR	Endpt Conc. (mg/L N:NO3)	GMAV	Effect measurement	Endpoint	Test duration (Days)	Author	Status of use for criteria development
Xenopus	2,3	871.6	871.60	Mortality	LC50	4	Schuytema and Nebeker, 1999a	Not used

Table 6. All data used for chronic criteria development

Genus	Endpt Conc. (mg/L N:NO3)	GMCV (mg/L N:NO3)	Effect measurement	Endpoint	Test duration (Days)	Author	Status of use for criteria development
Ceriodaphnia	13.8		Reproduction	IC25	7	Baker et al., 2017	OK; geomean of EC20 and IC25
Ceriodaphnia	23.5		Reproduction	IC25	7	Baker et al., 2017	OK; geomean of EC20 and IC25
Ceriodaphnia	47.5		Reproduction	IC25	7	Baker et al., 2017	OK; geomean of EC20 and IC25
Ceriodaphnia	177	65.59	Reproduction	EC20	7	Soucek and Dickinson, 2016	OK; geomean of EC20 and IC25
Ceriodaphnia	91		Reproduction	EC20	7	Soucek and Dickinson, 2016	OK; geomean of EC20 and IC25
Ceriodaphnia	80		Reproduction	EC20	7	Soucek and Dickinson, 2016	OK; geomean of EC20 and IC25
Ceriodaphnia	263		Reproduction	EC20	7	Soucek and Dickinson, 2016	OK; geomean of EC20 and IC25
Chironomus	9.56	9.56	Biomass	EC20	10	Wang et al., 2020	OK; most sensitive endpt
Daphnia	717	506.64	Reproduction	LOEC	7	Scott and Crunkilton, 2000	OK
Daphnia	717		Reproduction	LOEC	7	Scott and Crunkilton, 2000	OK
Daphnia	358		Reproduction	NOEC	7	Scott and Crunkilton, 2000	OK
Daphnia	358		Reproduction	NOEC	7	Scott and Crunkilton, 2000	OK
Hyalella	11	18.92	Biomass	EC20	42	Soucek and Dickinson, 2016	Geomean of EC20 biomass; most sensitive endpt
Hyalella	22		Biomass	EC20	42	Soucek and Dickinson, 2016	Geomean of EC20 biomass; most sensitive endpt
Hyalella	28		Biomass	EC20	42	Soucek and Dickinson, 2016	Geomean of EC20 biomass; most sensitive endpt
Hyla	47	47.00	Metamorphosis	EC20	52	Wang et al., 2020	OK; most sensitive endpt
Lampsilis	17.39	17.45	Weight	EC20	28	Wang et al., 2020	Geomean of length and weight EC20
Lampsilis	17.52		Biomass	EC20	28	Wang et al., 2020	Geomean of length and weight EC20

Genus	Endpt Conc. (mg/L N:NO3)	GMCV (mg/L N:NO3)	Effect measurement	Endpoint	Test duration (Days)	Author	Status of use for criteria development
Neocloeon	36	36.00	Slowed/ Delayed Development	MATC	22.4	Soucek and Dickinson, 2016	OK; Reported endpoint same MATC for two observed effects (# d to PEN and % PEN WCF)
Notropis	486		Growth rate	LOEC	30	Adelman et al., 2009	OK; MATC
Notropis	268		Growth rate	NOEC	30	Adelman et al., 2009	OK; MATC
Notropis	360	360.00	Growth rate	MATC	30	Adelman et al., 2009	OK; Reported endpoint
Oncorhynchus	38		Biomass	EC20	42	Wang et al., 2020	OK; Endpts acceptable
Oncorhynchus	38	38.00	Weight	EC20	42	Wang et al., 2020	OK; Endpts acceptable
Oncorhynchus	38		Length	EC20	42	Wang et al., 2020	OK; Endpts acceptable
Pimephales	358.3	214.13	Biomass	IC25	7	Baker et al., 2017	Geomean of the four IC25 calcs
Pimephales	358.3		Biomass	IC25	7	Baker et al., 2017	Geomean of the four IC25 calcs
Pimephales	209		Biomass	IC25	7	Baker et al., 2017	Geomean of the four IC25 calcs
Pimephales	69.6		Biomass	IC25	7	Baker et al., 2017	Geomean of the four IC25 calcs
Potamopyrgus	21.4	57.80	Reproduction	LOEC	35	Alonso and Camargo, 2003	OK; MATC
Potamopyrgus	156.1		Reproduction	NOEC	35	Alonso and Camargo, 2003	OK; MATC
Pseudacris	30.1	30.1	Weight	LOEC	10	Schuytema and Nebeker,1999b	OK; most sensitive endpt
Pseudacris	30.1		Weight	NOEC	10	Schuytema and Nebeker, 1999b	OK; most sensitive endpt
Rana	29.1	29.10	Length	LOEL	16	Schuytema and Nebeker, 1999c	OK; most sensitive endpt; MATC of chronic effect (length)
Rana	29.1		Length	NOEL	16	Schuytema and Nebeker, 1999c	OK; most sensitive endpt; MATC of chronic effect (length)
Salvelinus	6.25	3.16	Weight	LOEC	120	McGurk et al., 2006	OK; most sensitive endpt
Salvelinus	1.6		Weight	NOEC	120	McGurk et al., 2006	OK; most sensitive endpt
Xenopus	56.7	37.50	Weight	LOEC	10	Schuytema and Nebeker, 1999a	Not used
Xenopus	24.8		Weight	NOEC	10	Schuytema and Nebeker, 1999a	Not used

References

Alonso, A., and J.A. Camargo. 2003. Short-Term Toxicity of Ammonia, Nitrite, and Nitrate to the Aquatic Snail *Potamopyrgus antipodarum* (Hydrobiidae, Mollusca). *Bull. Environ. Contam. Toxicol. 70*(5): 1006-1012.

Alonso, A., and J.A. Camargo. 2013. Nitrate Causes Deleterious Effects on the Behaviour and Reproduction of the Aquatic Snail *Potamopyrgus antipodarum* (Hydrobiidae, Mollusca). *Environ. Sci. Pollut. Res. Int. 20*(8): 5388-5396.

ASTM (2009) ASTM International standard guide for conducting acute toxicity tests with fishes, macroinvertebrates, and amphibians (E729-96 (2007). Annual Book of ASTM Standards Volume 11.06, West Conshohocken, PA.

Baker, J.A., G. Gilron, B.A. Chalmers, and J.R. Elphick. 2017. Evaluation of the Effect of Water Type on the Toxicity of Nitrate to Aquatic Organisms. *Chemosphere 168*:435-440.

Buhl, K.J. 2002. The Relative Toxicity of Waterborne Inorganic Contaminants to the Rio Grande Silvery Minnow (*Hybognathus amarus*) and Fathead Minnow (*Pimephales promelas*) in a Water Quality Simulating that in the Rio Grande, New Mexico. *Final Rep. to U.S. Fish and Wildl. Serv., Study No. 2F33-9620003.* U.S. Geol. Surv., Columbia Environ. Res. Ctr., Yankton Field Res. Stn., Yankton, SD:75 p.

Buhl, K.J., and S.J. Hamilton. 2000. Acute Toxicity of Fire-Control Chemicals, Nitrogenous Chemicals, and Surfactants to Rainbow Trout. *Trans. Am. Fish. Soc. 129* (2): 408-418.

Call, D.J., C.N. Polkinghorne, T.P. Markee, L.T. Brooke, D.L. Geiger, J.W. Gorsuch, and K.A. Robillard. 2006. Toxicity of Silver in Water and Sediment to the Freshwater Amphipod *Hyalella Azteca*. *Environ. Toxicol. Chem. 25* (7): 1802-1808.

Camargo, J. A. & Alonso, Á. (2006) Ecological and toxicological effects of inorganic nitrogen pollution in aquatic ecosystems: A global assessment. Environment International, 32, 831-849

Camargo, J.A., A. Alonso, and A. Salamanca. 2005. Nitrate Toxicity to Aquatic Animals: A Review with New Data for Freshwater Invertebrates. *Chemosphere 58*(9): 1255-1267.

Camargo, J.A., and J.V. Ward. 1992. Short-Term Toxicity of Sodium Nitrate (NaNO3) to Non-Target Freshwater Invertebrates. *Chemosphere 24*(1): 23-28.

Camargo, J.A., and J.V. Ward. 1995. Nitrate (NO3-N) Toxicity to Aquatic Life: A Proposal of Safe Concentrations for Two Species of Nearctic Freshwater Invertebrates. *Chemosphere 31*(5): 3211-3216.

Corrao, N. M., Darby, P. C. & Pomory, C. M. (2006) Nitrate impacts on the Florida apple snail, Pomacea paludosa. Hydrobiologia, 568(1), 135-143.

Douda, K. 2010. Effects of Nitrate Nitrogen Pollution on Central European Unionid Bivalves Revealed by Distributional Data and Acute Toxicity Testing. *Aquat. Conserv. 20*(2): 189-197.

Hamlin, H.J. 2006. Nitrate Toxicity in Siberian Sturgeon (*Acipenser baeri*). *Aquaculture* 253(1-4): 688-693.

Heiskary, S.A. and C.B. Wilson. 2008. Minnesota's approach to lake nutrient criteria development. *Lake Reserv. Manage.* 24:282-297.

Developing Nutrient Criteria, Third Edition. Minnesota Pollution Control Agency Report.

Krishnamurthy, S. V. & Smith, G. R. (2010) Growth, abnormalities, and mortality of tadpoles of American toad exposed to combinations of malathion and nitrate. Environ. Toxicol. Chem. 29 (12): 2777-2782.

Learmonth, C., and A.P. Carvalho. 2015. Acute and Chronic Toxicity of Nitrate to Early Life Stages of Zebrafish--Setting Nitrate Safety Levels for Zebrafish Rearing. *Zebrafish 12*(4): 305-311.

McGurk, M.D., F. Landry, A. Tang, and C.C. Hanks. 2006. Acute and Chronic Toxicity of Nitrate to Early Life Stages of Lake Trout (*Salvelinus namaycush*) and Lake Whitefish (*Coregonus clupeaformis*). *Environ. Toxicol. Chem. 25*(8): 2187-2196.

McShaffrey, D. (n.d.). *Environmental Biology- Ecosystems*. LON-capa environmental biology sequence - ecosystems. Retrieved February 25, 2022, from https://s2.lite.msu.edu/res/msu/botonl/b_online/library/marietta/ecosystem.html

Moore, A.P., and R.B. Bringolf. 2020. Comparative Toxicity of Nitrate to Common and Imperiled Freshwater Mussel Glochidia and Larval Fishes. *Arch. Environ. Contam. Toxicol. 78*: 536-544.

J. Omernik, S. Paulsen, G. Griffith and M. Weber. 2016. Regional patterns of total nitrogen concentrations in the National Rivers and Streams Assessment. Journal of Soil and Water Conservation 71 (3) 167-181. DOI: https://doi.org/10.2489/jswc.71.3.167.

MPCA (2010) Water Quality Standards Guidance and References to Support Development of Statewide Water Quality Standards. Minnesota Pollution Control Agency, Draft.

Pandey, R.B., G.L. Adams, and L.W. Warren. 2011. Survival and Precopulatory Guarding Behavior of *Hyalella azteca* (Amphipoda) Exposed to Nitrate in the Presence of Atrazine. *Environ. Toxicol. Chem. 30*(5): 1170-1177.

Romansic, J.M., K.A. Diez, E.M. Higashi, and A.R. Blaustein. 2006. Effects of Nitrate and the Pathogenic Water Mold *Saprolegnia* on Survival of Amphibian Larvae. *Dis. Aquat. Org. 68*(3): 235-243.

Schuytema, G.S., and A.V. Nebeker. 1999a. Comparative Effects of Ammonium and Nitrate Compounds on Pacific Treefrog and African Clawed Frog Embryos. *Arch. Environ. Contam. Toxicol. 36*(2): 200-206.

Schuytema, G.S., and A.V. Nebeker. 1999b. Comparative Toxicity of Ammonium and Nitrate Compounds to Pacific Treefrog and African Clawed Frog Tadpoles. *Environ. Toxicol. Chem. 18*(10): 2251-2257.

Schuytema, G.S., and A.V. Nebeker. 1999c. Effects of Ammonium Nitrate, Sodium Nitrate, and Urea on Red-Legged Frogs, Pacific Treefrogs, and African Clawed Frogs. *Bull. Environ. Contam. Toxicol. 63*(3): 357-364.

Scott, G., and R.L. Crunkilton. 2000. Acute and Chronic Toxicity of Nitrate to Fathead Minnows (*Pimephales promelas*), *Ceriodaphnia dubia*, and *Daphnia magna*. *Environ. Toxicol. Chem. 19*(12): 2918-2922.

Smith, G. R., K. G. Temple, H. A. Dingfelder, and D. A. Vaala. 2006. Effects of nitrate on the interactions of the tadpoles of two ranids (*Rana clamitans* and *R. catesbeiana*). Aquatic Ecology 40: 125–130.

Smith, G. R., K. G. Temple, D. A. Vaala, and H. A. Dingfelder. 2005. Effects of Nitrate on the Tadpoles of Two Ranids (*Rana catesbeiana* and *R. clamitans*). Archives of Environmental Contamination and Toxicology, 49(4): 559-562.

Soucek, D.J., and A. Dickinson. 2012. Acute Toxicity of Nitrate and Nitrite to Sensitive Freshwater Insects, Mollusks, and a Crustacean. *Arch. Environ. Contam. Toxicol. 62*(2): 233-242.

Soucek, D.J., and A. Dickinson. 2015. Full-Life Chronic Toxicity of Sodium Salts to the Mayfly *Neocloeon triangulifer* in Tests with Laboratory Cultured Food. *Environ. Toxicol. Chem. 34*(9): 2126-2137.

Soucek, D.J., and A. Dickinson. 2016. Influence of Chloride on the Chronic Toxicity of Sodium Nitrate to *Ceriodaphnia dubia* and *Hyalella Azteca*. *Ecotoxicology 25*(7): 1406-1416.

Soucek, D.J., D.R. Mount, A. Dickinson, J.R. Hockett, and A.R. Mcewen. 2015. Contrasting Effects of Chloride on Growth, Reproduction, and Toxicant Sensitivity in Two Genetically Distinct Strains of *Hyalella Azteca*. *Environ. Toxicol. Chem. 34*(10): 2354-2362.

Tilak, K. S. V., K. Lakshmi, S. Jhansi (2006) Effects of ammonia, nitrate and nitrite on toxicity and hematological changes in the carps. J. Ecotoxicol. Environ. Monit., 16(1): 9-12.

Tomasso, J.R., and G.J. Carmichael. 1986. Acute Toxicity of Ammonia, Nitrite, and Nitrate to the Guadalupe Bass, *Micropterus treculi*. *Bull. Environ. Contam. Toxicol. 36*(6): 866-870.

EPA. 1985. Guidelines for deriving numerical national water quality criteria for the protection of aquatic organisms and their uses. PB85- 227049. National Technical Information Service, Springfield, VA. (ed C. E. Stephan, D.I. Mount, D.J. Hansen, J.H. Gentile, G.A. Chapman, W.A. Brungs).

EPA. 2000. Nutrient Criteria Technical Guidance Manual Lakes and Reservoirs. EPA-822-B00-001. United States Environmental Protection Agency, Office of Water, Office of Science and Technology, Washington, DC 20460. www.epa.gov

EPA. 2010. Final Report on Acute and Chronic Toxicity of Nitrate, Nitrite, Boron, Manganese, Fluoride, Chloride and Sulfate to Several Aquatic Animal Species. EPA 905-R-10-002. U.S. Environmental Protection Agency, Region 5, Chicago, Illinois.

Wang, N., R.A. Dorman, C.D. Ivey, D.J. Soucek, A. Dickinson, B.K. Kunz, J.A. Steevens, E.J. Hammer, and C.R. Bauer. 2020. Acute and Chronic Toxicity of Sodium Nitrate and Sodium Sulfate to Several Freshwater Organisms in Water-Only Exposures. *Environ. Toxicol. Chem. 39*(5): 1071-1085.

Wurtsbaugh, W. A., H. W. Paerl, and W. K. Dodds. 2019. Nutrients, eutrophication and harmful algal blooms along the freshwater to marine continuum. Wiley Interdisciplinary Reviews: Water, 6(5), e1373.

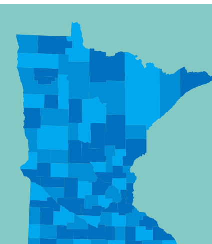
Ammonia

July 2022

Aquatic Life Water Quality Standards for Ammonia: Draft Technical Support Document

Amendments to Class 2 water quality standards in Minn. R. chs. 7050 and 7052

MINNESOTA POLLUTION CONTROL AGENCY



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Document number: wq-rule4-25b

Table of contents

Acronyms, abbreviations, and units of measurement

Acronym	Meaning
CCC	Criterion continuous concentration
CMC	Criterion maximum concentration
CS	Chronic standard
DNR	Minnesota Department of Natural Resources
EPA	U.S. Environmental Protection Agency
FAV	Final acute value
FCV	Final chronic value
GMAV	Genus mean acute value
GMCV	Genus mean chronic value
Minn. R.	Minnesota Rules
MPCA	Minnesota Pollution Control Agency
MS	Maximum standard
SMAV	Species mean acute value
SMCV	Species mean chronic value
TAN	Total ammonia nitrogen
WQS	Water quality standards
mg/L	Milligrams per liter
µg/L	Micrograms per liter

Definitions

Beneficial uses: Surface water uses by people, aquatic communities, and wildlife that are recognized in Minnesota's water quality standards at Minn. R. 7050.0140, including:

Class 1: Domestic consumption

Class 2: Aquatic life and recreation

Class 3: Industrial consumption

Class 4: Agriculture and wildlife

Class 5: Aesthetics and navigation

Class 6: Other uses

Class 7: Limited Resource Value Water (LRVW)

Multiple beneficial use classes are designated for each surface water body, or segment thereof, as described in Minn. R. 7050.0400 to Minn. R. 7050.0470.

Chronic standard (CS): An estimate of the highest toxicant concentration in ambient water to which aquatic life can be exposed indefinitely without chronic toxicity (mortality, reduced growth, reproductive impairment, harmful changes in behavior, or other adverse effects). The CS is an element of Minnesota's water quality standards and is analogous to the EPA-defined CCC.

Criterion maximum concentration (CMC): An estimate provided by EPA of the highest toxicant concentration in ambient water to which an aquatic community can be briefly exposed without unacceptable adverse effects on growth, reproduction, or survival. Equivalent to the FAV divided by two, the CMC is also referred to as the "acute criterion".

Criterion continuous concentration (CCC): An estimate provided by EPA of the highest toxicant concentration in ambient water to which an aquatic community can be exposed indefinitely without unacceptable adverse effects on growth, reproduction, or survival. Equivalent to the FCV divided by two, the CCC is also referred to as the "chronic criterion".

Final acute value (FAV): The toxicant concentration corresponding to the 5^{th} percentile of the acute toxicity value distribution for the genera on which acute toxicity tests have been conducted (i.e., 5^{th} percentile of the GMAV distribution).

Final chronic value (FCV): The toxicant concentration corresponding to the 5^{th} percentile of the chronic toxicity value distribution for the genera on which chronic toxicity tests have been conducted (i.e., 5^{th} percentile of the GMCV distribution).

Genus mean acute value (GMAV): The geometric mean of all species mean acute values (SMAVs) available within a genus.

Genus mean chronic value (GMCV): The geometric mean of all species mean chronic values (SMCVs) available within a genus.

Maximum standard (MS): An estimate of the highest toxicant concentration in ambient water to which aquatic life can be exposed briefly with zero to slight mortality. Also referred to as the "acute standard", the MS is an element of Minnesota's water quality standards and is analogous to the EPA-defined CMC. It equals the FAV divided by two.

Species mean acute value (SMAV): The geometric mean of all available and acceptable measures of acute toxicity effects for a species.

Species mean chronic value (SMCV): The geometric mean of all available and acceptable measures of chronic toxicity effects for a species.

Total ammonia nitrogen (TAN): The sum of nitrogen present in the forms of un-ionized ammonia (NH_3) and ionized ammonium (NH_4^+), expressed as a concentration (e.g., mg/L TAN).

National recommended water quality criteria (or 304(a) Criteria): National recommendations established by EPA, as required under Section 304(a) of the Clean Water Act, regarding the quality of water sufficient to ensure adequate protection of designated uses. The criteria generally assume the form of numeric concentrations or qualitative measures of pollutants.

Water quality standards (WQS): The fundamental regulatory and policy foundation established to preserve and restore the quality of all waters of the state, consisting of three elements:

1. Designated beneficial use classes.
2. Narrative and numeric descriptions[1] of pollutant levels that should not be exceeded.
3. Antidegradation policies to maintain existing uses, protect high quality waters, and preserve waters of outstanding value.

[1] *Note that EPA and most states refer to these descriptions as "criteria", while in Minnesota they are generally referred to as "standards".*

Purpose

The suite of water quality standards (WQS) for the State of Minnesota is designed to protect multiple beneficial uses of aquatic resources, including domestic and industrial consumption, recreational activity, aesthetic character, navigability, and maintenance of a healthy community of aquatic life. Development of WQS entails the classification of waters based on potential beneficial uses, derivation of numeric or narrative conditions to protect those uses, and establishment of antidegradation policies to maintain existing uses as well as to protect high-quality waters and preserve waters of outstanding value (Minn. R. ch. 7050). Each standard requires specification of the beneficial use to be protected as well as provision of scientific support for the stated protective conditions.

This technical support document describes the formulation of numeric WQS for ammonia in Class 2 waters for the purpose of protecting the propagation and maintenance of aquatic life. To ensure adequate protection of aquatic life from both acute and chronic ammonia toxicity, the MPCA proposes to update its existing WQS by adopting the national recommended ambient water quality criteria for ammonia provided by the U.S. Environmental Protection Agency (EPA, 2013). The adopted criteria would serve as the new numeric thresholds for judgments of water quality impairment due to ammonia, and they would guide the MPCA's determination of ammonia discharge limits from regulated facilities. Proposed updates to Minnesota WQS include the addition of new acute standards and revision of the current 4-day chronic standard, supplemented by a new 30-day chronic standard.

Background

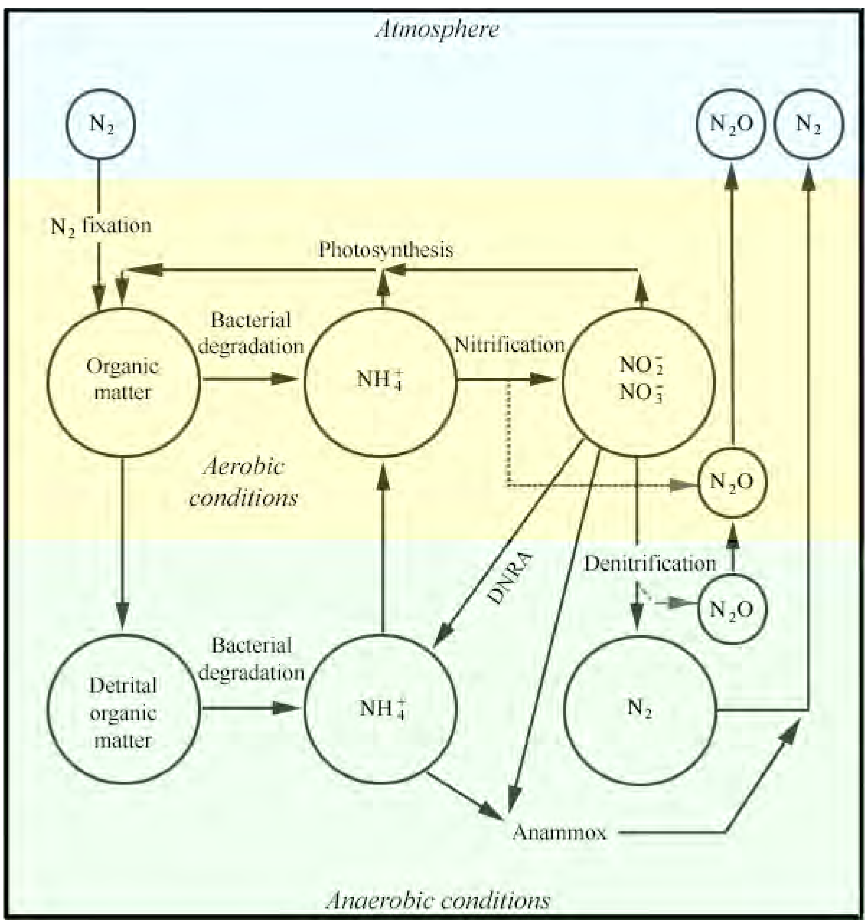
Ammonia in the aquatic environment exists in un-ionized (NH_3) and ionized (ammonium, NH_4^+) forms, the balance of which is strongly influenced by local pH and temperature (Emerson et al., 1975). Measurements of ammonia in water samples are typically reported as total ammonia nitrogen (TAN), defined as the sum of nitrogen present in both chemical forms. The toxicity of ammonia to aquatic life is primarily attributed to the un-ionized form (Chipman, 1934; Thurston et al., 1981); lethality to aquatic organisms and/or impairment of their biologic functions depends not only on the prevalence of un-ionized ammonia in the environment but also the organism's degree of sensitivity to it, which may additionally vary along a gradient of pH and temperature conditions (EPA, 1985a; EPA, 2013).

Urban stormwater conveyances and wastewater treatment facility discharges are important anthropogenic sources of ammonia to aquatic environments, as are overland flow and subsurface drainage from agricultural lands on which artificial fertilizers and/or manure are applied. Certain types of industrial discharges may also contain significant quantities of ammonia, such as those generated by food processers (including sugar beet factories), canneries, meat packers, tanneries, dairies, rendering plants, oil refineries, chemical processers, metal finishers, and pharmaceutical producers (MPCA, 1981; EPA, 2013). Natural sources of ammonia include decomposing organic matter, animal excretions, and atmospheric deposition (at levels that are anthropogenically enhanced; Lehmann et al., 2007; Behera et al., 2013).

Metabolism of nitrogen-containing compounds by aquatic organisms results in the internal production of ammonia waste that must be excreted from the body, generally accomplished via passive diffusion from internal organs into the surrounding water (Smith, 1929; Randall & Wright, 1987). Outward diffusion of ammonia relies upon a positive concentration gradient between internal tissues (higher concentration) and the water (lower concentration). High ambient concentrations of ammonia caused by pollution discharge may lessen or even reverse the diffusive gradient, resulting in the accumulation of ammonia in tissues and blood. The toxic effects of un-ionized ammonia accumulation in aquatic organisms can include damage to gill tissues, reduction in the oxygen-carrying capacity of blood, oxidative stress, depletion of adenosine triphosphate (ATP) energy reserves in the brain, disruption of osmoregulation and circulation, and impairment of liver and kidney function (EPA, 2013; EPA, 2022). Fish can additionally experience loss of equilibrium, hyperexcitability, slowed growth and morphological development, and reduced hatching success (EPA, 1985a). Excessive ammonia levels can cause convulsions, coma, and death. In freshwater mussels, toxic effects include a variety of negative physiological responses – impaired secretion of anchoring threads, reduction in valve opening for respiration and feeding, metabolic alterations due to depletion of energy stores – that inhibit growth, reproduction, and survivorship (EPA, 2013). Ammonia concentrations in anoxic sediment porewaters – especially within highly-organic, nutrient-rich sediments – frequently exceed concentrations in overlying surface water and therefore can impose additional stress on mussels and other benthic aquatic organisms (Frazier et al., 1996; Kinsman-Costello et al., 2015).

Because nitrogen readily cycles between multiple forms in nature, following various microbial transformation pathways (Figure 1), ammonia in the aquatic environment may not have originally entered as such. It may be produced via bacterial degradation of organic matter, released from dead microbial tissue, or converted from nitrate or nitrite under anaerobic conditions in a process called dissimilatory nitrate reduction to ammonium (DNRA). Ammonia in its ionic form (ammonium) is consumed via incorporation into plant and microbial biomass, anaerobic oxidation (anammox) to nitrogen or nitrogen dioxide gases, or conversion to nitrate (nitrification) under aerobic conditions. The connectedness of ammonia, nitrate, and other forms of nitrogen warrants consideration of holistic approaches to reduce pollutant nitrogen entering the aquatic environment. The State of Minnesota has a long-standing nutrient reduction strategy that focuses on lessening nitrogen and phosphorus loads in state waters as well as those downstream (MPCA, 2014). Despite this effort, nitrogen levels are increasing in both surface water and groundwater throughout the state (MPCA, 2013).

Figure 1. Biological transformations of nitrogen in aerobic and anaerobic environments, based on Wollast (1981) and the modifications of Schlesinger and Bernhardt (2013).



Minnesota is a water-rich state containing more than 4,500 square miles of lake area and over 92,000 miles of streams and rivers. It is home to a considerable diversity of aquatic life that includes approximately 50 species of mussels – 28 of which are listed as extirpated, endangered, threatened, or of special concern (Minnesota Department of Natural

Resources (DNR), 2022b and 2022c) – and over 150 species of fish (Hatch, 2015) – 34 of which are similarly listed (DNR, 2022c). Aquatic snails, although broadly distributed and prevalent in general, include 9 rare species (DNR, 2022c). Recognized by various conservation organizations as the most imperiled group of animals in North America, freshwater mussels declined in both abundance and diversity over the past century due to dam construction, stream channel modification, sedimentation, chemical pollutants, overharvesting, and invasive fauna (DNR, 2022b). Their biological importance as ecosystem engineers (DNR, 2022a; Gutiérrez et al., 2003; Vaughn, 2017), precarious conservation status, and sensitivity to ammonia pollution provide strong rationales for adopting water quality protections that account for updated science on the acute and chronic toxicity of ammonia to aquatic invertebrates.

Aquatic life criteria for ammonia

Development of EPA recommendations

National recommended water quality criteria are developed by EPA in accordance with Section 304(a)(1) of the Clean Water Act and with the objective to protect the vast majority (approximately 95%) of animal species in an aquatic community from unacceptable adverse effects on growth, reproduction, or survival. Established procedures for derivation of national criteria (EPA, 1985b) are predicated on the assumption that laboratory-based determinations of toxicity in cultured and collected aquatic organisms apply in outdoor settings with similar toxicant concentrations and key environmental conditions (e.g., pH and temperature). EPA conducts a thorough review of available toxicological information in the scientific literature, screens findings of toxicant effect thresholds according to specific data quality requirements, and assembles a dataset spanning a variety of taxonomic and functional groups that collectively represent the North American assemblage of aquatic organisms. From this dataset, EPA then calculates a criterion maximum concentration (CMC) for short-term (acute) exposures and a criterion continuous concentration (CCC) for long-term (chronic) exposures. The CMC and CCC are analogous to Minnesota's maximum standard (MS) and chronic standard (CS), respectively, which are used under Minnesota Rules chapter 7050 as numeric expressions of state-level WQS. Derivations of numeric criteria by EPA and MPCA are based solely upon toxicological data and best professional scientific judgments regarding toxicological effects.

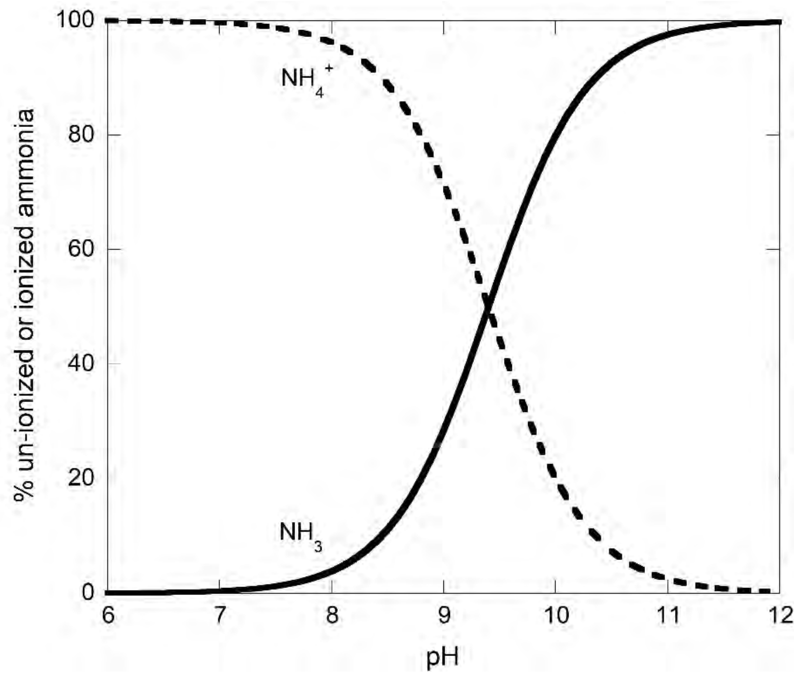
Current Class 2 ammonia standards for Minnesota, last updated in 1981, are based on an assessment of acute and chronic toxicity data for a limited number of resident fish species (MPCA, 1981). Separate chronic standards (4-day average concentration values) apply to Subclasses 2A and 2B, which are protected for the propagation and maintenance of coldwater aquatic biota (2A) and cool or warmwater aquatic biota (2B). The numeric value assigned to Subclass 2B also applies to Subclass 2Bd, which is additionally protected for use as drinking water, as well as to Subclass 2D (wetlands). These standards do not take into account the often-greater sensitivity of freshwater mussels (Augspurger et al., 2003), gill-bearing snails (Besser et al., 2009), and other aquatic fauna to ammonia, as determined in toxicological studies published over subsequent decades. The dataset compiled by EPA for its determination of national ammonia criteria includes important additions and updates for these groups of organisms (EPA, 2013).

The most recent national recommended ambient ammonia criteria for the protection of aquatic life are derived from a dataset composed of acute toxicity test results from 100 freshwater aquatic species across 69 genera and chronic toxicity test results from 21 freshwater aquatic species across 16 genera (EPA, 2013). Multiple families of coldwater and warmwater fish are represented in the acute toxicity data, as are planktonic and benthic crustaceans, mollusks (including sensitive gill-breathing snails and freshwater mussels in Family Unionidae that had not previously been tested), insects, and amphibians.

Biological collections information contained in the Minnesota Biodiversity Atlas (Bell Museum, 2022), explored in conjunction with readily accessible species range descriptions, indicate that at least 55 of the 100 species represented in the acute toxicity tests (and at least 54 of the 69 genera) reside in Minnesota. Many of the nonresident species provide useful surrogate representation of untested yet functionally- or taxonomically-related resident species. Freshwater phytoplankton and vascular plants are not represented in either the acute or chronic toxicity studies, but prior analysis of available data for these groups indicated that aquatic vegetation is far less sensitive to ammonia than aquatic animals (EPA, 1985a). EPA therefore assumes that any ammonia criteria derived for the protection of aquatic animals will also be protective of aquatic vegetation.

Toxicity tests used in the development of water quality criteria were performed with measured concentrations of ammonia (recorded as mg/L TAN, or converted to TAN if originally expressed in terms of un-ionized ammonia) in a controlled laboratory setting. For all test organisms, ammonia effect concentration values were then adjusted – statistically normalized – to a common pH of 7, following pH-TAN toxicity relationships established in an earlier version of the national recommended aquatic life criteria for ammonia (EPA, 1999), which EPA determined "still hold" and can be reasonably applied to newly-included organisms. The pH-dependence of ammonia toxicity, and therefore of ammonia criteria, may reflect the shifting chemical equilibrium between un-ionized ammonia and ionized ammonium. At higher pH values, the proportion of un-ionized ammonia increases (Figure 2), as does observed ammonia toxicity. For invertebrate test organisms, ammonia effect concentrations were further normalized to a temperature of 20°C, following temperature-TAN toxicity relationships outlined in the earlier national criteria document (EPA, 1999). Whereas vertebrate (fish) sensitivity to TAN does not meaningfully change with temperature, invertebrate sensitivity increases at higher temperatures.

Figure 2. The pH-dependent chemical speciation of ammonia at a temperature of 20°C, calculated from equilibrium relationships expressed in Emerson et al. (1975).



After any appropriate adjustments for pH and temperature, the reported ammonia effect concentrations resulting from toxicity tests on aquatic organisms were sorted by species to calculate species mean acute values (SMAVs) and species mean chronic values (SMCVs). These species-level values were then organized by genus to calculate genus mean acute values (GMAVs) and genus mean chronic values (GMCVs). Each calculation was performed using the geometric mean of all underlying data. Genus-level values, rank ordered to form a sensitivity distribution, were then used to determine, by regression analysis, a final acute value (FAV) and final chronic value (FCV), each equivalent to the 5th percentile of its corresponding distribution (EPA, 1985; EPA, 2013).

Acute criteria

At an example pH of 7 and temperature of 20°C, EPA recommends an acute criterion (CMC) of 17 mg/L TAN – a one-hour average concentration not to be exceeded more than once every 3 years on average. The range of acute criteria under varying pH and temperature conditions is defined by the following equation:

Equation 1

$$\mathrm{CMC} = MIN\left(\left(\frac{0.275}{1+10^{7.204-\mathrm{pH}}}\right) + \left(\frac{39.0}{1+10^{\mathrm{pH}-7.204}}\right), \left(0.7249 \times \left(\frac{0.0114}{1+10^{7.204-\mathrm{pH}}} + \frac{1.6181}{1+10^{\mathrm{pH}-7.204}}\right) \times \left(23.12 \times 10^{0.036 \times (20-\mathrm{T})}\right)\right)\right)$$

where: CMC = criterion maximum concentration in mg/L TAN
T = temperature in degrees Celsius

The equation incorporates a pH-TAN acute toxicity relationship determined by pooled regression analysis of data across multiples species as well as a temperature-based adjustment for aquatic invertebrates (EPA, 1999; EPA, 2013). The CMC returned by the above equation equals the minimum value produced by two mathematical expressions, separated by a comma. The first expression, which does not contain a temperature variable, is specific to rainbow trout (*Oncorhynchus mykiss*), which is regarded as a recreationally- and commercially-important fish species. Although not native to Minnesota, rainbow trout have been introduced to many coldwater habitats in the state and continue to be stocked by the Minnesota DNR. Additionally, the existing Class 2A chronic water quality standard for Minnesota is based on toxicity data for the species (MPCA, 1981). The second mathematical expression, which includes both temperature and pH variables, considers the full set of tested organisms and yields a value approximately equivalent to the 5th percentile of the GMAV sensitivity distribution.

Because the lowest GMAVs in the sensitivity distribution for acute ammonia toxicity are for aquatic invertebrates (specifically, freshwater Unionid mussels), the CMC is both pH- and temperature-dependent. However, because the sensitivity of these invertebrates to ammonia declines with decreasing temperature (EPA, 1999), temperature-invariant vertebrates (fish) emerge as the most sensitive organisms below a particular temperature threshold and therefore determine the calculated CMC under low-temperature conditions. Where *Oncorhynchus* species are present, this temperature threshold occurs at 15.7°C and Equation 1 applies. Where *Oncorhynchus* species are absent, the CMC equation is modified to:

Equation 2

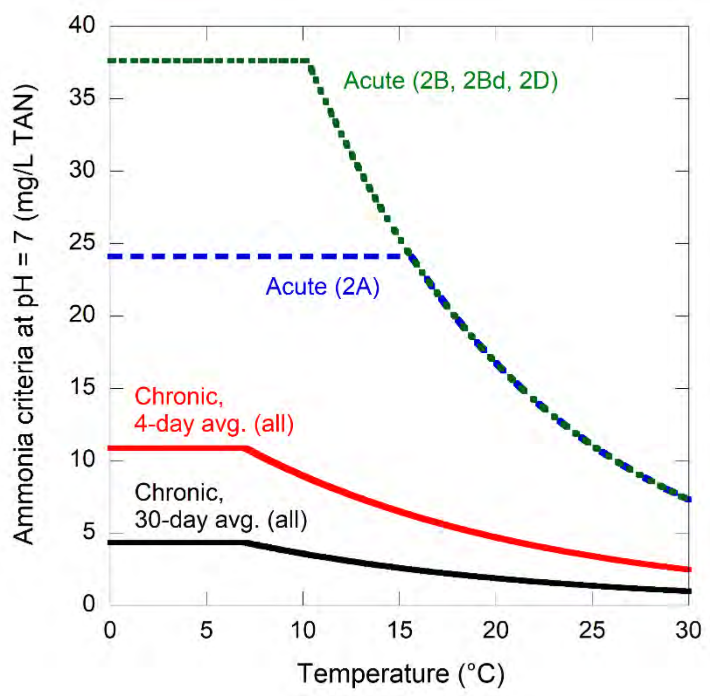
$$\mathrm{CMC} = 0.7249 \times \left(\frac{0.0114}{1+10^{7.204-\mathrm{pH}}} + \frac{1.6181}{1+10^{\mathrm{pH}-7.204}}\right) \times MIN\left(51.93, 23.12 \times 10^{0.036 \times (20-\mathrm{T})}\right)$$

where: CMC = criterion maximum concentration in mg/L TAN
T = temperature in degrees Celsius

Equation 2 retains the same pH and temperature adjustments, excludes the separate expression for the commercially- and recreationally-important rainbow trout, and incorporates a new temperature sensitivity threshold based on the fish genus *Prosopium*. In the absence of *Oncorhynchus* species, the mountain whitefish (*Prosopium williamsoni*) becomes the most sensitive species at 10.2°C and below. This species does not reside in Minnesota, but it is regarded as an "appropriately sensitive surrogate species" for other fish in Class Actinopterygii (EPA, 2013).

Taken together, Equations 1 and 2 create a bifurcated acute criterion dependent on pH, temperature, and the presence or absence of fish in genus *Oncorhynchus* (see dashed lines in Figure 3). The CMC increases with decreasing temperature over a portion of the temperature range, as depicted in the curvature of the dashed lines, because aquatic invertebrates exhibit greater sensitivity to ammonia at higher temperatures (i.e., the invertebrates can tolerate higher concentrations of ammonia at lower temperatures). The sensitivity of vertebrate taxa (*Oncorhynchus* or other fish) to ammonia, in contrast, does not change appreciably with temperature. Consequently, at sufficiently low temperatures, vertebrate fish species become the organisms most sensitive to ammonia (i.e., the temperature-dependent sensitivity of invertebrates declines below the temperature-invariant sensitivity of vertebrates). If *Oncorhynchus* species are present, the CMC remains constant below a temperature of 15.7°C. If *Oncorhynchus* species are absent, the temperature threshold at which CMC values form a plateau changes to 10.2°C. Because *Oncorhynchus* species are coldwater fish, the MPCA proposes to apply the "*Oncorhynchus* present" acute criterion to Subclass 2A waters as the maximum standard, implemented as a one-day average in accordance with Minnesota Rules chapter 7050. The acute criterion developed for the "*Oncorhynchus* absent" scenario would then be applied to all other Class 2 waters (Subclasses 2B, 2Bd, and 2D) as the maximum standard, also implemented as a one-day average. Numeric values for the proposed standards, as defined by the above equations, are summarized for reference across a selected range of pH and temperature conditions in Tables 1 and 2.

Figure 3. Recommended ambient water quality criteria for the protection of aquatic life (EPA, 2013) and their translation to Class 2 waters in Minnesota. Numeric values are extrapolated across a temperature gradient at pH = 7.



Chronic criteria

At an example pH of 7 and temperature of 20°C, EPA recommends a chronic criterion (CCC) of 1.9 mg/L TAN as a 30-day rolling average, not to be exceeded more than once every 3 years on average. In addition, EPA stipulates that that the chronic criterion cannot exceed 2.5 times this value (4.8 mg/L TAN) as a 4-day average within the 30-day period. The range of chronic criteria across varying pH and temperature conditions is described by the following equations:

Equation 3

$$\mathrm{CCC}_{30} = 0.8876 \times \left(\frac{0.0278}{1 + 10^{7.688-\mathrm{pH}}} + \frac{1.1994}{1 + 10^{\mathrm{pH}-7.688}}\right) \times \left(2.126 \times 10^{0.028 \times (20-MAX(\mathrm{T},7))}\right)$$

where: CCC_{30} = chronic standard (30-day rolling average) in mg/L TAN
T = temperature in degrees Celsius

Equation 4

$$\mathrm{CCC}_{4} = \mathrm{CCC}_{30} \times 2.5$$

where: CCC_{30} = chronic standard (30-day rolling average) in mg/L TAN
CCC_4 = chronic standard (highest 4-day average) in mg/L TAN

Equation 3 incorporates a pH-TAN chronic toxicity relationship and a temperature-based adjustment for aquatic invertebrates (EPA, 1999; EPA, 2013). Because the lowest GMCVs in the sensitivity distribution for chronic toxicity are again for freshwater Unionid mussels, calculated CCC values are both pH- and temperature-dependent – except below a temperature threshold of 7.0°C, when the early life stages of temperature-invariant *Lepomis* fish (namely bluegill, *Lepomis macrochirus*) become most sensitive. The chronic criteria, expressed as both 30-day and 4-day average values (Figure 3), are not bifurcated based on the presence of a commercially- or recreationally-important taxon and do not distinguish between coldwater and warmwater species assemblages. The MPCA therefore proposes to apply the CCC_{30} and CCC_4 as chronic standards (CS) across all Class 2 waters (see Tables 3 and 4 for values across a selected range of pH and temperature conditions).

Minnesota's existing chronic standards for ammonia are 16 µg/L and 40 µg/L, expressed as un-ionized NH_3 and implemented as 4-day averages, for Subclass 2A and Subclass 2B/2Bd/2D, respectively. The proposed new standards therefore include several changes: 1) numeric values are expressed in terms of TAN rather than un-ionized NH_3; 2) the same values are applied across all of Class 2 and no longer differ by subclass; and 3) the time-averaged basis for standards calculations includes a 30-day period as well as a 4-day period. New 4-day average values may be either more stringent or less stringent than existing values, depending on the subclass of water and the local pH (Table 5 provides a simple comparison of values at an example pH of 7 and temperature of 20°C).

Summary

The MPCA proposes to adopt the 2013 EPA national recommended water quality criteria for ammonia as its Class 2 ammonia water quality standards for the protection of aquatic life. Such adoption will bring Minnesota's standards into alignment with current scientific understanding on the sensitivity of freshwater mussels, snails, coldwater fish, and other organisms to ammonia in the aquatic environment. Adoption of EPA national criteria entails revising the existing 4-day chronic standard, adding a new 30-day chronic standard, and adding new acute standards – each with their own set of numeric values that vary across temperature and pH conditions. The temperature- and pH-dependent nature of the numeric standards reflects the shifting balance of un-ionized ammonia (more toxic) and ionized ammonium (less toxic), as well as known changes in the sensitivities of some aquatic species to ammonia, along these environmental gradients.

The proposed acute standard for Class 2 waters at an example pH of 7 and temperature of 20°C is 17 mg/L TAN. Because the recommended USEPA acute criterion bifurcates below a temperature of 15.7°C based on the presence or absence of coldwater trout and salmon in the genus *Oncorhynchus*, the MPCA will apply the "with *Oncorhynchus*" set of numeric values to Class 2A waters, which are regarded as favorable habitat for coldwater aquatic species, and the "without Oncorhynchus" set of numeric values to all other Class 2 waters (2B, 2Bd, 2D). The new acute water quality standard for Class 2A is defined by the set of numeric values in Table 1 and can be derived from Equation 1. The new acute water quality standard for Classes 2B, 2Bd, and 2D is defined by the set of numeric values in Table 2 and can be derived from Equation 2. At an example pH of 7 and temperature of 20°C, the proposed chronic standards for Class 2 waters are 1.9 mg/L TAN (30-day rolling average) and 4.8 mg/L TAN (highest 4-day average within a 30-day averaging period), applied uniformly across all subclasses. Chronic values at other temperature and pH conditions can be located in Tables 3 and 4 or calculated according to Equations 3 and 4.

Tables

Table 1. Temperature (°C) and pH-dependent values of the EPA acute* water quality criterion for ammonia (*Oncorhynchus* species present), in mg/L TAN

pH	0-14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
6.5	33	33	32	29	27	25	23	21	19	18	16	15	14	13	12	11	9.9
6.6	31	31	30	28	26	24	22	20	18	17	16	14	13	12	11	10	9.5
6.7	30	30	29	27	24	22	21	19	18	16	15	14	13	12	11	9.8	9.0
6.8	28	28	27	25	23	21	20	18	17	15	14	13	12	11	10	9.2	8.5
6.9	26	26	25	23	21	20	18	17	15	14	13	12	11	10	9.4	8.6	7.9
7.0	24	24	23	21	20	18	17	15	14	13	12	11	10	9.4	8.6	7.9	7.3
7.1	22	22	21	20	18	17	15	14	13	12	11	10	9.3	8.5	7.9	7.2	6.7
7.2	20	20	19	18	16	15	14	13	12	11	9.8	9.1	8.3	7.7	7.1	6.5	6.0
7.3	18	18	17	16	14	13	12	11	10	9.5	8.7	8.0	7.4	6.8	6.3	5.8	5.3
7.4	15	15	15	14	13	12	11	9.8	9.0	8.3	7.7	7.0	6.5	6.0	5.5	5.1	4.7
7.5	13	13	13	12	11	10	9.2	8.5	7.8	7.2	6.6	6.1	5.6	5.2	4.8	4.4	4.0
7.6	11	11	11	10	9.3	8.6	7.9	7.3	6.7	6.2	5.7	5.2	4.8	4.4	4.1	3.8	3.5
7.7	9.6	9.6	9.3	8.6	7.9	7.3	6.7	6.2	5.7	5.2	4.8	4.4	4.1	3.8	3.5	3.2	2.9
7.8	8.1	8.1	7.9	7.2	6.7	6.1	5.6	5.2	4.8	4.4	4.0	3.7	3.4	3.2	2.9	2.7	2.5
7.9	6.8	6.8	6.6	6.0	5.6	5.1	4.7	4.3	4.0	3.7	3.4	3.1	2.9	2.6	2.4	2.2	2.1
8.0	5.6	5.6	5.4	5.0	4.6	4.2	3.9	3.6	3.3	3.0	2.8	2.6	2.4	2.2	2.0	1.9	1.7
8.1	4.6	4.6	4.5	4.1	3.8	3.5	3.2	3.0	2.7	2.5	2.3	2.1	2.0	1.8	1.7	1.5	1.4
8.2	3.8	3.8	3.7	3.4	3.1	2.9	2.7	2.4	2.3	2.1	1.9	1.8	1.6	1.5	1.4	1.3	1.2
8.3	3.1	3.1	3.1	2.8	2.6	2.4	2.2	2.0	1.9	1.7	1.6	1.4	1.3	1.2	1.1	1.0	0.96
8.4	2.6	2.6	2.5	2.3	2.1	2.0	1.8	1.7	1.5	1.4	1.3	1.2	1.1	1.0	0.93	0.86	0.79
8.5	2.1	2.1	2.1	1.9	1.8	1.6	1.5	1.4	1.3	1.2	1.1	0.98	0.90	0.83	0.77	0.71	0.65
8.6	1.8	1.8	1.7	1.6	1.5	1.3	1.2	1.1	1.0	0.96	0.88	0.81	0.75	0.69	0.63	0.58	0.54
8.7	1.5	1.5	1.4	1.3	1.2	1.1	1.0	0.94	0.87	0.80	0.73	0.68	0.62	0.57	0.53	0.49	0.45
8.8	1.2	1.2	1.2	1.1	1.0	0.93	0.86	0.79	0.73	0.67	0.62	0.57	0.52	0.48	0.44	0.41	0.37
8.9	1.0	1.0	1.0	0.93	0.85	0.79	0.72	0.67	0.61	0.56	0.52	0.48	0.44	0.40	0.37	0.34	0.32
9.0	0.88	0.88	0.86	0.79	0.73	0.67	0.62	0.57	0.52	0.48	0.44	0.41	0.37	0.34	0.32	0.29	0.27

*CMC values (EPA, 2013), to be applied to Class 2A waters in Minnesota as the maximum standard (MS)

Table 2. Temperature and pH-dependent values of the EPA acute* water quality criterion for ammonia (*Oncorhynchus* species absent), in mg/L TAN

pH	0-10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
6.5	51	48	44	41	37	34	32	29	27	25	23	21	19	18	16	15	14	13	12	11	9.9
6.6	49	46	42	39	36	33	30	28	26	24	22	20	18	17	16	14	13	12	11	10	9.5
6.7	46	44	40	37	34	31	29	27	24	22	21	19	18	16	15	14	13	12	11	9.8	9.0
6.8	44	41	38	35	32	30	27	25	23	21	20	18	17	15	14	13	12	11	10	9.2	8.5
6.9	41	38	35	32	30	28	25	23	21	20	18	17	15	14	13	12	11	10	9.4	8.6	7.9
7.0	38	35	33	30	28	25	23	21	20	18	17	15	14	13	12	11	10	9.4	8.6	7.9	7.3
7.1	34	32	30	27	25	23	21	20	18	17	15	14	13	12	11	10	9.3	8.5	7.9	7.2	6.7
7.2	31	29	27	25	23	21	19	18	16	15	14	13	12	11	9.8	9.1	8.3	7.7	7.1	6.5	6.0
7.3	27	26	24	22	20	18	17	16	14	13	12	11	10	9.5	8.7	8.0	7.4	6.8	6.3	5.8	5.3
7.4	24	22	21	19	18	16	15	14	13	12	11	9.8	9.0	8.3	7.7	7.0	6.5	6.0	5.5	5.1	4.7
7.5	21	19	18	17	15	14	13	12	11	10	9.2	8.5	7.8	7.2	6.6	6.1	5.6	5.2	4.8	4.4	4.0
7.6	18	17	15	14	13	12	11	10	9.3	8.6	7.9	7.3	6.7	6.2	5.7	5.2	4.8	4.4	4.1	3.8	3.5
7.7	15	14	13	12	11	10	9.3	8.6	7.9	7.3	6.7	6.2	5.7	5.2	4.8	4.4	4.1	3.8	3.5	3.2	2.9
7.8	13	12	11	10	9.3	8.5	7.9	7.2	6.7	6.1	5.6	5.2	4.8	4.4	4.0	3.7	3.4	3.2	2.9	2.7	2.5
7.9	11	9.9	9.1	8.4	7.7	7.1	6.6	6.0	5.6	5.1	4.7	4.3	4.0	3.7	3.4	3.1	2.9	2.6	2.4	2.2	2.1
8.0	8.8	8.2	7.6	7.0	6.4	5.9	5.4	5.0	4.6	4.2	3.9	3.6	3.3	3.0	2.8	2.6	2.4	2.2	2.0	1.9	1.7
8.1	7.2	6.8	6.3	5.8	5.3	4.9	4.5	4.1	3.8	3.5	3.2	3.0	2.7	2.5	2.3	2.1	2.0	1.8	1.7	1.5	1.4
8.2	6.0	5.6	5.2	4.8	4.4	4.0	3.7	3.4	3.1	2.9	2.7	2.4	2.3	2.1	1.9	1.8	1.6	1.5	1.4	1.3	1.2
8.3	4.9	4.6	4.2	3.9	3.6	3.3	3.1	2.8	2.6	2.4	2.2	2.0	1.9	1.7	1.6	1.4	1.3	1.2	1.1	1.0	0.96
8.4	4.1	3.8	3.5	3.2	3.0	2.7	2.5	2.3	2.1	2.0	1.8	1.7	1.5	1.4	1.3	1.2	1.1	1.0	0.93	0.86	0.79
8.5	3.3	3.1	2.9	2.7	2.4	2.3	2.1	1.9	1.8	1.6	1.5	1.4	1.3	1.2	1.1	0.98	0.90	0.83	0.77	0.71	0.65
8.6	2.8	2.6	2.4	2.2	2.0	1.9	1.7	1.6	1.5	1.3	1.2	1.1	1.0	0.96	0.88	0.81	0.75	0.69	0.63	0.58	0.54
8.7	2.3	2.2	2.0	1.8	1.7	1.5	1.4	1.3	1.2	1.1	1.0	0.94	0.87	0.80	0.73	0.68	0.62	0.57	0.53	0.49	0.45
8.8	1.9	1.8	1.7	1.5	1.4	1.3	1.2	1.1	1.0	0.93	0.86	0.79	0.73	0.67	0.62	0.57	0.52	0.48	0.44	0.41	0.37
8.9	1.6	1.5	1.4	1.3	1.2	1.1	1.0	0.93	0.85	0.79	0.72	0.67	0.61	0.56	0.52	0.48	0.44	0.40	0.37	0.34	0.32
9.0	1.4	1.3	1.2	1.1	1.0	0.93	0.86	0.79	0.73	0.67	0.62	0.57	0.52	0.48	0.44	0.41	0.37	0.34	0.32	0.29	0.27

*CMC values (EPA, 2013), to be applied to Class 2B, 2Bd, and 2D waters in Minnesota as the maximum standard (MS)

Table 3. Temperature (°C) and pH-dependent values of the EPA chronic* (30-day average) water quality criterion for ammonia, in mg/L TAN

pH	0-7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
6.5	4.9	4.6	4.3	4.1	3.8	3.6	3.3	3.1	2.9	2.8	2.6	2.4	2.3	2.1	2.0	1.9	1.8	1.6	1.5	1.4	1.4	1.3	1.2	1.1
6.6	4.9	4.6	4.3	4.0	3.8	3.5	3.3	3.1	2.9	2.7	2.5	2.4	2.2	2.1	2.0	1.8	1.7	1.6	1.5	1.4	1.3	1.3	1.2	1.1
6.7	4.8	4.5	4.2	3.9	3.7	3.5	3.2	3.0	2.8	2.7	2.5	2.3	2.2	2.1	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.2	1.1
6.8	4.7	4.4	4.1	3.8	3.6	3.4	3.2	3.0	2.8	2.6	2.4	2.3	2.1	2.0	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.1	1.1
6.9	4.5	4.2	4.0	3.7	3.5	3.3	3.1	2.9	2.7	2.5	2.4	2.2	2.1	2.0	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.2	1.1	1.0
7.0	4.4	4.1	3.8	3.6	3.4	3.2	3.0	2.8	2.6	2.4	2.3	2.1	2.0	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.1	1.1	0.99
7.1	4.2	3.9	3.7	3.5	3.2	3.0	2.8	2.7	2.5	2.3	2.2	2.1	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.2	1.1	1.0	0.95
7.2	4.0	3.7	3.5	3.3	3.1	2.9	2.7	2.5	2.4	2.2	2.1	2.0	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.2	1.1	1.0	0.96	0.90
7.3	3.8	3.5	3.3	3.1	2.9	2.7	2.5	2.4	2.2	2.1	2.0	1.8	1.7	1.6	1.5	1.4	1.3	1.3	1.2	1.1	1.0	0.97	0.91	0.85
7.4	3.5	3.3	3.1	2.9	2.7	2.5	2.4	2.2	2.1	2.0	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.2	1.1	1.0	0.96	0.90	0.85	0.79
7.5	3.2	3.0	2.8	2.7	2.5	2.3	2.2	2.1	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.2	1.1	1.0	0.95	0.89	0.83	0.78	0.73
7.6	2.9	2.8	2.6	2.4	2.3	2.1	2.0	1.9	1.8	1.6	1.5	1.4	1.4	1.3	1.2	1.1	1.0	0.98	0.92	0.86	0.81	0.76	0.71	0.67
7.7	2.6	2.5	2.3	2.2	2.0	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.1	1.1	1.0	0.94	0.88	0.83	0.78	0.73	0.68	0.64	0.60
7.8	2.4	2.2	2.1	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.2	1.1	1.0	0.95	0.89	0.84	0.79	0.74	0.69	0.65	0.61	0.57	0.53
7.9	2.1	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.2	1.1	1.0	0.95	0.89	0.84	0.79	0.74	0.69	0.65	0.61	0.57	0.53	0.50	0.47
8.0	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.1	1.1	1.0	0.94	0.89	0.83	0.78	0.73	0.68	0.64	0.60	0.56	0.53	0.50	0.46	0.44	0.41
8.1	1.6	1.5	1.4	1.3	1.2	1.1	1.1	0.99	0.93	0.87	0.81	0.76	0.72	0.67	0.63	0.59	0.55	0.52	0.49	0.46	0.43	0.40	0.38	0.35
8.2	1.3	1.2	1.2	1.1	1.0	0.96	0.90	0.84	0.79	0.74	0.70	0.65	0.61	0.57	0.54	0.50	0.47	0.44	0.42	0.39	0.37	0.34	0.32	0.30
8.3	1.1	1.1	0.99	0.93	0.87	0.82	0.77	0.72	0.67	0.63	0.59	0.55	0.52	0.49	0.46	0.43	0.40	0.38	0.35	0.33	0.31	0.29	0.27	0.26
8.4	0.95	0.89	0.84	0.79	0.74	0.69	0.65	0.61	0.57	0.53	0.50	0.47	0.44	0.41	0.39	0.36	0.34	0.32	0.30	0.28	0.26	0.25	0.23	0.22
8.5	0.81	0.75	0.71	0.66	0.62	0.58	0.55	0.51	0.48	0.45	0.42	0.40	0.37	0.35	0.33	0.31	0.29	0.27	0.25	0.24	0.22	0.21	0.19	0.18
8.6	0.68	0.64	0.60	0.56	0.53	0.49	0.46	0.43	0.41	0.38	0.36	0.33	0.31	0.29	0.28	0.26	0.24	0.23	0.21	0.20	0.19	0.18	0.16	0.15
8.7	0.58	0.54	0.51	0.47	0.44	0.42	0.39	0.37	0.34	0.32	0.30	0.28	0.27	0.25	0.23	0.22	0.21	0.19	0.18	0.17	0.16	0.15	0.14	0.13
8.8	0.49	0.46	0.43	0.40	0.38	0.35	0.33	0.31	0.29	0.27	0.26	0.24	0.23	0.21	0.20	0.19	0.17	0.16	0.15	0.14	0.13	0.13	0.12	0.11
8.9	0.42	0.39	0.37	0.34	0.32	0.30	0.28	0.27	0.25	0.23	0.22	0.21	0.19	0.18	0.17	0.16	0.15	0.14	0.13	0.12	0.11	0.11	0.10	0.10
9.0	0.36	0.34	0.32	0.30	0.28	0.26	0.24	0.23	0.21	0.20	0.19	0.18	0.17	0.16	0.15	0.14	0.13	0.12	0.11	0.11	0.10	0.09	0.09	0.08

*CCC values (EPA, 2013), to be applied to all Class 2 waters in Minnesota as a 30-day chronic standard (CS)

Table 4. Temperature (°C) and pH-dependent values of the EPA chronic* (4-day average) water quality criterion for ammonia in mg/L TAN

pH	0-7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30
6.5	12	12	11	10	9.5	8.9	8.4	7.8	7.4	6.9	6.5	6.1	5.7	5.3	5.0	4.7	4.4	4.1	3.9	3.6	3.4	3.2	3.0	2.8
6.6	12	11	11	10	9.4	8.8	8.2	7.7	7.2	6.8	6.4	6.0	5.6	5.2	4.9	4.6	4.3	4.1	3.8	3.6	3.3	3.1	2.9	2.8
6.7	12	11	10	9.8	9.2	8.6	8.1	7.6	7.1	6.7	6.2	5.9	5.5	5.2	4.8	4.5	4.2	4.0	3.7	3.5	3.3	3.1	2.9	2.7
6.8	12	11	10	9.6	9.0	8.4	7.9	7.4	6.9	6.5	6.1	5.7	5.4	5.0	4.7	4.4	4.1	3.9	3.6	3.4	3.2	3.0	2.8	2.6
6.9	11	11	9.9	9.3	8.7	8.2	7.7	7.2	6.8	6.3	5.9	5.6	5.2	4.9	4.6	4.3	4.0	3.8	3.5	3.3	3.1	2.9	2.7	2.6
7.0	11	10	9.6	9.0	8.4	7.9	7.4	7.0	6.5	6.1	5.7	5.4	5.0	4.7	4.4	4.2	3.9	3.7	3.4	3.2	3.0	2.8	2.6	2.5
7.1	10	9.8	9.2	8.6	8.1	7.6	7.1	6.7	6.3	5.9	5.5	5.2	4.8	4.5	4.2	4.0	3.7	3.5	3.3	3.1	2.9	2.7	2.5	2.4
7.2	10	9.3	8.8	8.2	7.7	7.2	6.8	6.3	5.9	5.6	5.2	4.9	4.6	4.3	4.0	3.8	3.6	3.3	3.1	2.9	2.7	2.6	2.4	2.3
7.3	9.4	8.8	8.2	7.7	7.3	6.8	6.4	6.0	5.6	5.3	4.9	4.6	4.3	4.1	3.8	3.6	3.3	3.1	2.9	2.8	2.6	2.4	2.3	2.1
7.4	8.7	8.2	7.7	7.2	6.8	6.3	5.9	5.6	5.2	4.9	4.6	4.3	4.0	3.8	3.5	3.3	3.1	2.9	2.7	2.6	2.4	2.3	2.1	2.0
7.5	8.1	7.6	7.1	6.6	6.2	5.8	5.5	5.1	4.8	4.5	4.2	4.0	3.7	3.5	3.3	3.1	2.9	2.7	2.5	2.4	2.2	2.1	2.0	1.8
7.6	7.3	6.9	6.5	6.1	5.7	5.3	5.0	4.7	4.4	4.1	3.9	3.6	3.4	3.2	3.0	2.8	2.6	2.5	2.3	2.2	2.0	1.9	1.8	1.7
7.7	6.6	6.2	5.8	5.5	5.1	4.8	4.5	4.2	3.9	3.7	3.5	3.3	3.1	2.9	2.7	2.5	2.4	2.2	2.1	1.9	1.8	1.7	1.6	1.5
7.8	5.9	5.5	5.2	4.8	4.5	4.3	4.0	3.7	3.5	3.3	3.1	2.9	2.7	2.5	2.4	2.2	2.1	2.0	1.8	1.7	1.6	1.5	1.4	1.3
7.9	5.2	4.8	4.5	4.3	4.0	3.7	3.5	3.3	3.1	2.9	2.7	2.5	2.4	2.2	2.1	2.0	1.8	1.7	1.6	1.5	1.4	1.3	1.3	1.2
8.0	4.5	4.2	4.0	3.7	3.5	3.3	3.1	2.9	2.7	2.5	2.4	2.2	2.1	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.2	1.1	1.0
8.1	3.9	3.6	3.4	3.2	3.0	2.8	2.6	2.5	2.3	2.2	2.0	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.1	1.1	1.0	0.94	0.88
8.2	3.3	3.1	2.9	2.7	2.6	2.4	2.3	2.1	2.0	1.9	1.7	1.6	1.5	1.4	1.3	1.3	1.2	1.1	1.0	0.97	0.91	0.86	0.80	0.75
8.3	2.8	2.6	2.5	2.3	2.2	2.0	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.1	1.1	1.0	0.94	0.88	0.83	0.78	0.73	0.68	0.64
8.4	2.4	2.2	2.1	2.0	1.8	1.7	1.6	1.5	1.4	1.3	1.3	1.2	1.1	1.0	0.97	0.91	0.85	0.80	0.75	0.70	0.66	0.62	0.58	0.54
8.5	2.0	1.9	1.8	1.7	1.6	1.5	1.4	1.3	1.2	1.1	1.1	0.99	0.93	0.87	0.82	0.77	0.72	0.67	0.63	0.59	0.55	0.52	0.49	0.46
8.6	1.7	1.6	1.5	1.4	1.3	1.2	1.2	1.1	1.0	0.95	0.89	0.84	0.78	0.74	0.69	0.65	0.61	0.57	0.53	0.50	0.47	0.44	0.41	0.39
8.7	1.4	1.3	1.3	1.2	1.1	1.0	0.98	0.92	0.86	0.81	0.75	0.71	0.66	0.62	0.58	0.55	0.51	0.48	0.45	0.42	0.40	0.37	0.35	0.33
8.8	1.2	1.1	1.1	1.0	0.94	0.88	0.83	0.78	0.73	0.68	0.64	0.60	0.56	0.53	0.50	0.46	0.44	0.41	0.38	0.36	0.34	0.32	0.30	0.28
8.9	1.0	0.98	0.92	0.86	0.81	0.76	0.71	0.66	0.62	0.58	0.55	0.51	0.48	0.45	0.42	0.40	0.37	0.35	0.33	0.31	0.29	0.27	0.25	0.24
9.0	0.90	0.84	0.79	0.74	0.69	0.65	0.61	0.57	0.54	0.50	0.47	0.44	0.41	0.39	0.36	0.34	0.32	0.30	0.28	0.26	0.25	0.23	0.22	0.20

*To be applied to all Class 2 waters in Minnesota as a 4-day chronic standard (CS). Each value equals 2.5 times the 30-day chronic value

Table 5. Comparison of existing water quality standards (MPCA) and recommended national criteria (EPA), as mg/L TAN (pH=7, T=20°C)*

Standard or criterion	Class 2A existing[§]	Class 2A recommended	Class 2B, 2Bd, 2D existing[§]	Class 2B, 2Bd, 2D recommended
FAV	--	33.5	--	33.5
MS	--	16.8	--	16.8
CS (4-day average)	4.1	4.8	10.1	4.8
CS (30-day average)	--	1.9	--	1.9

*FAV and MS values may differ across classes at lower temperatures

[§] Existing values converted from µg/L un-ionized NH_3

References

Augspurger, T., Keller, A.E., Black, M.C., Cope, W.G. and Dwyer, F.J. 2003. Water quality guidance for protection of freshwater mussels (Unionidae) from ammonia exposure. *Environmental Toxicology and Chemistry: An International Journal*, 22(11): 2569-2575.

Behera, S.N., Sharma, M., Aneja, V.P. and Balasubramanian, R. 2013. Ammonia in the atmosphere: a review on emission sources, atmospheric chemistry and deposition on terrestrial bodies. *Environmental Science and Pollution Research, 20*(11): 8092-8131.

Bell Museum, University of Minnesota. 2022. Minnesota Biodiversity Atlas. Online, accessed February 2022. Available at: https://bellatlas.umn.edu/collections/map/index.php.

Besser, J.M., Hardesty, D.L., Greer, I.E., and Ingersoll, C.G. 2009. Sensitivity of freshwater snails to aquatic contaminants: Survival and growth of endangered snail species and surrogates in 28-day exposures to copper, ammonia and pentachlorophenol. U.S. Geological Survey, Columbia Environmental Research Center, Columbia, MO, Administrative Report CERC-8335-FY07-20-10.

Chipman, W.A., Jr. 1934. The role of pH in determining the toxicity of ammonium compounds. Ph.D. Thesis, University of Missouri, Columbia, MO: 153 p.

Emerson, K., Russo, R.C., Lund, R.E. and Thurston, R.V. 1975. Aqueous ammonia equilibrium calculations: effect of pH and temperature. *Journal of the Fisheries Board of Canada*, 32(12): 2379-2383.

Gutiérrez, J.L., Jones, C.G., Strayer, D.L. and Iribarne, O.O. 2003. Mollusks as ecosystem engineers: the role of shell production in aquatic habitats. *Oikos*, 101(1): 79-90.

Hatch, J.T. 2015. Minnesota fishes: just how many species are there anyway? *American Currents*, 40(2): 10-21.

Lehmann, C., Bowersox, V.C., Larson, R.S. and Larson, S.M. 2007. Monitoring long-term trends in sulfate and ammonium in US precipitation: Results from the National Atmospheric Deposition Program/National Trends Network. *Water, Air, & Soil Pollution: Focus,* 7: 59-66.

Minnesota Department of Natural Resources (DNR). 2022a. Importance of mussels. Web page, accessed February 2022. Available at: https://www.dnr.state.mn.us/mussels/importance.html.

Minnesota Department of Natural Resources (DNR). 2022b. Minnesota statewide mussel survey. Web page, accessed February 2022. Available at: https://www.dnr.state.mn.us/nhnrp/mussel_survey/index.html.

Minnesota Department of Natural Resources (DNR). 2022c. Rare species guide. Web page, accessed February 2022. Available at: https://www.dnr.state.mn.us/rsg/index.html.

Minnesota Pollution Control Agency (MPCA). 1981. In the Matter of the Proposed Amendments to MPCA Rules WPC 14, 15, 24 and 25 and the Proposed Repeal of WPC 2, 3, 5, 6, 7, 8, 9, 10, 11, 12, 13, 16, 17, 18, 19, 20, 21, 23, 26, 29, 31 and 32. Statement of Need and Reasonableness. MPCA publication PCA-004-80-AK.

Minnesota Pollution Control Agency (MPCA). 2014. The Minnesota nutrient reduction strategy. MPCA publication wq-s1-80. Available at: https://www.pca.state.mn.us/sites/default/files/wq-s1-80.pdf.

Minnesota Pollution Control Agency (MPCA). 2013. Nitrogen in Minnesota surface waters: Conditions, trends, sources, and reductions. MPCA publication wq-s6-26a. Available at: https://www.pca.state.mn.us/sites/default/files/wq-s6-26a.pdf.

Randall, D.J. and Wright, P.A. 1987. Ammonia distribution and excretion in fish. *Fish Physiology and Biochemistry* 3(3): 107-120.

Schlesinger, W. H. and Bernhardt, E.S. 2013. The global cycles of nitrogen and phosphorus. *Biogeochemistry: an analysis of global change* (3rd Edition), Academic Press, Boston, pp. 445-467.

Smith, H.W. 1929. The excretion of ammonia and urea by the gills of fish. *Journal of Biological Chemistry* 81(3): 727–742.

Thurston, R.V., R.C. Russo, and Vinogradov, G.A. 1981. Ammonia toxicity to fishes: effect of pH on the toxicity of the un-ionized ammonia species. *Environmental Science & Technology* 15(7): 837-840.

U.S. Environmental Protection Agency (EPA). 1985a. Ambient aquatic life water quality criteria for ammonia – 1984. Office of Water Regulations and Standards Division, Washington D.C., EPA 440/5-85-001. Available at: https://www.epa.gov/sites/default/files/2019-02/documents/ambient-wqc-ammonia-1984.pdf.

U.S. Environmental Protection Agency (EPA). 1985b. Guidelines for deriving numerical national water quality criteria for the protection of aquatic organisms and their uses. Office of Research and Development, Environmental Research Laboratories, Duluth MN; Narragansett, RI, Corvallis, OR; PB85-227049. Available at: https://www.epa.gov/wqc/guidelines-deriving-numerical-national-water-quality-criteria-protection-aquatic-organisms-and.

U.S. Environmental Protection Agency (EPA). 1999. 1999 Update of ambient water quality criteria for ammonia. Office of Water, Washington D.C., EPA-822-R-99-014.

U.S. Environmental Protection Agency (EPA). 2013. Aquatic life ambient water quality criteria for ammonia – freshwater. Office of Water, Washington D.C., EPA-822-R-13-001. Available at: https://www.epa.gov/wqc/aquatic-life-criteria-ammonia.

U.S. Environmental Protection Agency (EPA). 2022. CADDIS Volume 2: Ammonia. Web page, accessed June 2022. Available at: https://www.epa.gov/caddis-vol2/ammonia.

Vaughn, C.C., 2018. Ecosystem services provided by freshwater mussels. *Hydrobiologia*, 810(1): 15-27.

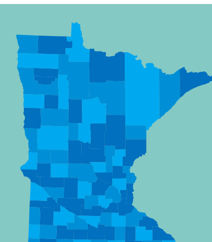
Wollast, R. 1981. Interactions between major biogeochemical cycles in marine ecosystems. *Some perspectives of the major biogeochemical cycles (SCOPE 17)*, pp.125-142.

Groundwater quality

July 2019

The Condition of Minnesota's Groundwater Quality, 2013-2017

MINNESOTA POLLUTION CONTROL AGENCY



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Executive summary

This report describes the condition and trends in the quality Minnesota's ambient groundwater. State agency data collected from 2013-2017 were used to describe the condition of the state's groundwater resources, focusing on the sand and gravel aquifers which occur throughout the state and the bedrock aquifers in southeastern Minnesota. Trends were evaluated using data from 2005-2017.

This assessment of groundwater quality conditions includes familiar pollutants that adversely affect the drinkability of water, such as nitrate, chloride, arsenic, volatile organic chemicals (VOCs), and pesticides. It also includes more recently recognized pollutants including contaminants of emerging concern (CECs) such as medications, insect repellents, and flame retardants and fluorinated compounds known as per- and polyfluorinated alkyl substances (PFAS). Land use strongly affects the occurrence and distribution of most of these pollutants since some of these substances are predominantly used in urban areas while others are used more in agricultural settings. A few of the pollutants discussed in this report are naturally occurring in the groundwater, namely trace elements like arsenic and manganese, and only are detected at high levels when wells are installed in particular parts of the state or at a particular depth in an aquifer.

Chloride, VOCs, and CECs primarily affected the groundwater quality in urban areas. High chloride concentrations were an issue near the water table in the Twin Cities Metropolitan Area (TCMA), where most of the wells that had concentrations over the state class 1 domestic consumption use standard of 250 mg/L (Minn. Rules ch. 7050, 7060) were located. In addition, chloride concentrations in the buried sand and gravel and Prairie du Chien-Jordan aquifers generally were greater in the counties within or near the TCMA compared to those outstate. The few detections of VOCs in the ambient groundwater also occurred in urban areas. New wells installed for the Minnesota Pollution Control Agency's (MPCA) monitoring network showed that commercial/industrial land use affected chloride concentrations in the shallow groundwater the most; the median concentrations in these areas were over 30 mg/L greater than those in residential areas. The high chloride concentrations near the water table also appeared to be migrating downward into the aquifers used for drinking water supplies. The trend analysis conducted for this investigation showed the majority of wells with increasing chloride concentrations were installed in bedrock aquifers in the TCMA and southeastern Minnesota; some of these wells were as deep as 340 feet. Chloroform, the most-frequently detected VOC, appeared to occur where water supplies undergo chlorine disinfection. The detections of VOCs associated with solvents, such as trichloroethylene, typically occurred near the water table in commercial/industrial areas where they may be used to degrease metals and in other applications. The most commonly detected CECs were the antibiotic sulfamethoxazole, the flame retardant tris (1,3-dichloro-2-propyl) phosphate, the x-ray contrast agent iopamadol, and the non-anionic surfactant mixture branch p-nonylphenols. These chemicals all are known to be widely used, resistant to degradation, and persist in the environment.

Perfluorobutanoic acid (PFBA) was the most commonly detected PFAS in the ambient groundwater. Most of the PFAS monitoring in the ambient groundwater from 2013-2017, however, was for the perfluoroalkyl carboxylates and sulfonates, many of which are no longer in use, and the replacement products for these chemicals were not monitored. The data collected also indicated that PFAS detections in the groundwater were related to urban land use. PFBA was detected in almost 70% of the sampled ambient network wells in 2013. The highest measured concentration was 1,680 ng/L, which was well below the 7,000 ng/L human health limit set by the Minnesota Department of Health (MDH) for drinking water. Perfluorooctanoic sulfate (PFOS) was detected in about 12% of the sampled wells in 2013, and concentrations in seven wells had concentrations exceeding the 15 ng/L health based value set by the MDH in 2019. The limited follow-up sampling of 12 wells in 2017 showed that PFAS detections and concentrations did not remain the same in many of the resampled wells. This result was not unexpected since most of the wells contained very young groundwater, and there have been changes in the types of PFAS used in products. In the wells sampled outside of Washington County, which has known industrial contamination, perfluorohexanoic sulfate, perfluorooctanoic acid, and PFOS concentrations decreased by more than one-half compared to what was measured in 2013.

Nitrate primarily was an issue in the agricultural parts of the state. In these areas, 49% of the tested monitoring wells installed near the water table exceeded the state class 1 domestic consumption use standard of 10 mg/L. The Minnesota Department of Agriculture's (MDA's) Township Testing Program identified where domestic water supplies in agricultural areas were most impacted by high nitrate concentrations, which was defined as at least 10% of the tested wells having concentrations of 10 mg/L or greater. The majority of these townships were located in southeastern Minnesota, often in places where the shallow aquifer was naturally vulnerable to contamination from the land surface. Monitoring data collected by the MDA and MPCA shows that nitrate concentrations near the water table in urban areas generally were much lower than those in agricultural areas, with median concentrations ranging from 1.1 to 1.8 mg/L in urban areas and 10 mg/L in agricultural areas.

Herbicides were the most common type of pesticide detected as part of ambient monitoring by the MDA in 2017. No pesticide concentrations exceeded any applicable human health guidance set by the MDH. Degradation products of acetochlor, alachlor, atrazine, and metolachlor were among the most-frequently detected chemicals in the shallow groundwater. All of these pesticides are in "common detection" status by the MDA, which triggers activities such as the development of best management practices. Three neonicotinoid insecticides, clothiadin, imidacloprid, and thiamethoxam, were among the most-commonly detected pesticides in the shallow groundwater. These chemicals were detected in eight to 16% of the groundwater samples.

Introduction

Sufficient amounts of clean groundwater are vital to the State of Minnesota. Groundwater supplies drinking water to about 75% of all Minnesotans and nearly 90% of the water used to irrigate the state's crops. Groundwater flowing into Minnesota's streams, lakes, and wetlands is also important to maintain their water levels, pollution assimilative capacity, and/or temperature.

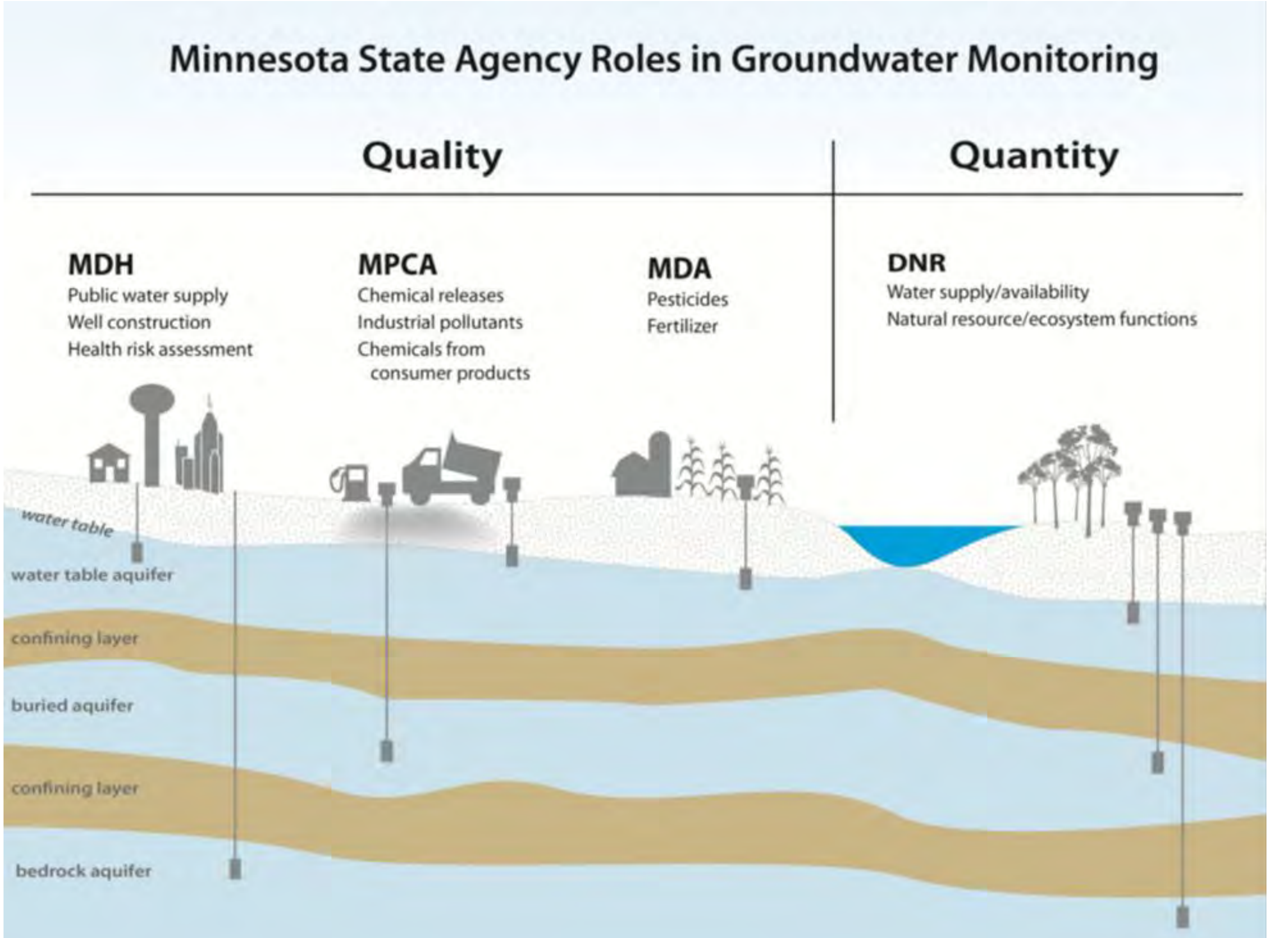
To meet Minnesotans' needs, groundwater must be clean. The Minnesota Pollution Control Agency (MPCA) considers all groundwater as potential drinking water sources, and the agency's policy is to maintain it in its natural condition as nearly as possible (Minn. R. ch. 7060). Polluted groundwater often is unsuitable for drinking and usually is very expensive to clean up. In addition, it costs more to install water-supply wells in areas with contaminated groundwater because they often need to be drilled deeper to tap uncontaminated aquifers. In some areas, deep underlying aquifers are not available so treatment devices must be installed to clean the contaminated groundwater before use, which incurs additional expenses.

Minnesota state law splits the groundwater monitoring and protection responsibilities among several state agencies that have unique expertise. Each of the agencies involved handles a specific facet of groundwater monitoring and protection. It takes the concerted effort of all these agencies, along with local and federal partners, to build the comprehensive picture of the status of the state's groundwater resources.

The state statutory roles and responsibilities in protecting the quality of Minnesota's groundwater is shown in Figure 1. The MPCA and MDA conduct statewide ambient groundwater quality monitoring for non-agricultural chemicals and agricultural chemicals, respectively. These two agencies share many monitoring resources, including the computer database that stores the collected data, technical staff that manage this information, and occasionally field staff that collect the state's groundwater samples. The MDH conducts monitoring to evaluate and address the human health risk of contaminants in groundwater that is used for drinking. In addition to these agencies, the Minnesota Department of Natural Resources (DNR) monitors groundwater quality in selected counties throughout the state as part of its County Geologic Atlas Program, and the Metropolitan Council conducts regional water supply planning using the information collected by the MPCA, MDA, MDH, and DNR.

In the last five years, much more was learned about the quality of Minnesota's groundwater due to enhanced monitoring that was made possible by the Clean Water Legacy Amendment. This funding allowed the MPCA to install shallow monitoring wells in key areas where existing wells were not available, such as residential areas that use subsurface sewage treatment systems (SSTS) for wastewater disposal, and commercial/industrial areas. It also allowed the MPCA to expand the list of chemicals it routinely analyzed in water samples to include contaminants of emerging concern (CECs), such as prescription and non-prescription medicines, and poly- and perfluoroalkyl substances (PFAS). By committing to annual monitoring, particularly in bedrock aquifers, MPCA increased the number of monitored sites with data sufficient to calculate groundwater quality changes over time. This same source of funding also allowed the MDA to better understand the groundwater quality in the aquifers that underlie the agricultural lands of the state. During this same timeframe, the MDA expanded its groundwater monitoring to include domestic wells in selected townships across the state that are naturally vulnerable to contamination due to regional geology.

Figure 1. State agency roles in groundwater monitoring (Graphic courtesy of the Minnesota Department of Natural Resources).



Purpose and Scope

This report describes the recent quality of Minnesota's ambient groundwater and determines, to the extent possible, whether it changed over time. The term "ambient groundwater" refers to the parts of this water resource that are affected by the general, routine use of chemicals and are not affected by localized pollutant spills or leaks. Monitoring data from 2013-2017 were used to determine the condition of the state's groundwater, and information from the last 12 years (2005-2017) was used to quantify whether any changes in groundwater quality occurred. Similar to the last MPCA assessment of the state's groundwater quality (Kroening and Ferrey 2013), this report also focuses on the quality of aquifers that are often tapped for municipal and domestic water supplies and are vulnerable to human-caused contamination.

The data analyzed in this report primarily were from ambient monitoring networks operated by Minnesota state agencies or previously published reports. The main sources of groundwater quality information used were the MPCA's Ambient Groundwater Monitoring Network; the MDA's Ambient Groundwater Monitoring Network, Central Sands Private Well Network, and Township Testing Program; the Southeast Volunteer Nitrate Monitoring Network; and the DNR's County Geologic Atlas Program.

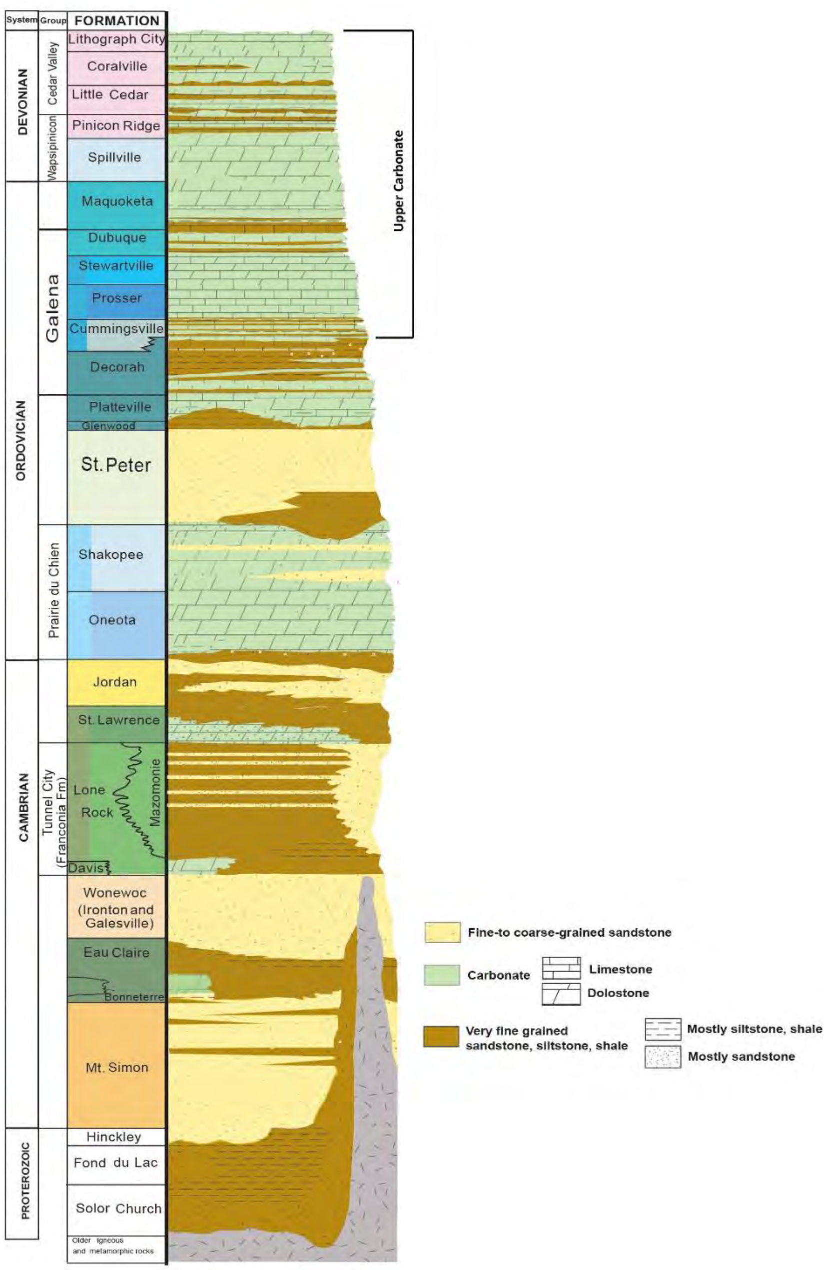
This assessment includes traditional pollutants known to adversely affect the potability of groundwater, such as nitrate, chloride, trace elements like arsenic, and volatile organic compounds (VOCs). In addition, it also includes some more recently recognized pollutants, including CECs and PFAS.

Minnesota's Groundwater Resources

The state's oldest aquifers are composed of crystalline bedrock and are important sources of groundwater in northern and southwestern Minnesota. These aquifers generally were formed from sands and silts that weathered and eroded from ancient volcanic rocks. Over time, these weathered materials were cemented together and transformed into crystalline rocks by the heat from now long-extinct volcanoes. The rocks that form these aquifers are the oldest in the state, at least 600 million to several billion years old. Crystalline bedrock aquifers underlie the entire state, but in most areas, these are deeply buried by other productive aquifers, so they usually are not an important source of water. Important crystalline bedrock aquifers in northeastern Minnesota include the North Shore Volcanic, Proterozoic metasedimentary, and Biwabik iron formation. The Sioux quartzite aquifer is important for some water supplies in Southwestern Minnesota.

Bedrock aquifers composed of sandstone and carbonate rock are important sources of water supply in southeastern Minnesota. These aquifers were formed when seas covered Minnesota about 500 million years ago. These aquifers include (in order from youngest to oldest) the Upper Carbonate, Red River-Winnipeg, St. Peter, Prairie du Chien, Jordan, Tunnel City/Wonewoc, and the Mount Simon-Hinckley. All of these aquifers, except the Red River-Winnipeg, form a vertical sequence of aquifers in southeastern Minnesota, including the Twin Cities Metropolitan Area (TCMA) (Figure 2). The Red River-Winnipeg aquifer only is present in northwestern Minnesota and typically is not used for water supply because it contains naturally salty water.

Figure 2. Stratigraphic column of the bedrock aquifers in the southeastern Minnesota (Figure modified from Runkel et al. 2013)



The Upper Carbonate is the uppermost and youngest in this sequence of bedrock aquifers. The U.S. Geological Survey (USGS) defines the Upper Carbonate Aquifer system as all of the aquifer groups from the Cedar Valley to the Galena (Olcott 1992). This aquifer system is located in extreme southeastern Minnesota and extends only about 80 miles north into Minnesota from the Iowa border. The Upper Carbonate, as its name suggests, primarily is composed of limestone and dolomite, and most of the water from this aquifer is obtained from solution channels, joints, and fissures.

The St. Peter aquifer underlies the Upper Carbonate and extends as far north as the TCMA. This aquifer consists of a white, crumbly, fine- to medium-grained sandstone. Most of the flow through it is intergranular or between the sand grains themselves. The St. Peter typically is not used for public water supplies in the TCMA because it does not occur continuously in this area and the underlying bedrock aquifers are much more productive.

The Prairie du Chien-Jordan is the third in this sequence of bedrock aquifers and is a major source of water supplies. This aquifer is present throughout southeastern Minnesota and extends to the TCMA. Some wells in this aquifer yield as much as 2,700 gallons per minutes (Adolphson, Ruhl, and Wolf 1981). The Prairie du Chien-Jordan aquifer consists of two different units. The first is the Prairie du Chien Group, which is a sandy dolomite. The second is the Jordan sandstone. Since the Prairie du Chien and Jordan aquifers many times have a hydraulic connection, these often are considered together as a single aquifer in many groundwater investigations, usually called the Prairie du Chien-Jordan. However, the lower part of the Prairie du Chien Group can serve locally as a confining unit for the Jordan sandstone.

The Tunnel City/Wonewoc is the fourth in the series of bedrock aquifers in southeastern Minnesota. Like the others, this aquifer is present throughout southeastern Minnesota and extends slightly beyond the TCMA. This aquifer consists of very fine to coarse sandstone that is interbedded with shale, dolomitic sandstone, and dolomitic siltstone. The upper and lower parts of the Tunnel City/Wonewoc aquifer are separated by a confining unit. Flow in the upper part of the aquifer primarily is through bedding plane features, and flow in the lower part of the aquifer is primarily intergranular. Despite having these two parts, the aquifer traditionally is considered as one unit in groundwater investigations.

The Mount Simon-Hinckley is the fifth and lowermost in this aquifer series. This aquifer has the widest extent of all of the state’s limestone and sandstone aquifers and extends almost as far north as the City of Duluth. This aquifer overlies the crystalline basement rocks and consists of two sandstone formations, the Mount Simon and Hinckley. Both of these sandstones have similar hydraulic characteristics (Schoenberg 1984) and usually are grouped together in groundwater investigations. The Mount Simon-Hinckley is overlain by other Paleozoic-age bedrock aquifers south of the TCMA. However, north of the TCMA, these other aquifers are not present and the Mount Simon-Hinckley is the uppermost bedrock aquifer.

In southeastern Minnesota, the rocks that form the Upper Carbonate and Prairie du Chien-Jordan aquifers form flat plateaus and mesas that are important recharge points. The Upper Carbonate Plateau is the highest of the two and is separated from the Prairie du Chien Plateau, which lies to the east, by escarpments and valleys. These two plateaus are important points for recharge water to enter these aquifers because they are typically covered by less than 50 feet of unconsolidated deposits (described further in the next paragraph). In addition, when confining units are present, they often are breached by vertical fractures which allow water (and any associated pollution) to flow through it.

In most parts of the state, unconsolidated clay, silt, sand, or gravel deposits overlie all of the bedrock aquifers. These sediments have not yet been cemented together to form rock, and they generally were deposited about two million to 12,000 years ago when Minnesota had a very cold climate and glaciers periodically advanced through the state. These sediments form aquifers (called sand and gravel aquifers in this report) in places where the glacial meltwater left sandy and/or gravelly deposits.

The sand and gravel aquifers are the youngest in the state and important sources of groundwater throughout Minnesota. These aquifers are concentrated in the central part of the state, where they may either be near the land surface or buried within clays.

The composition of the state’s sand and gravel aquifers varies depending upon the source area of the sediments comprising them, which geologists term provenance. These aquifers were formed from materials that originated from source areas northwest and northeast of Minnesota, that had very distinctive bedrock (Meyer and Knaeble 1996). The glaciers that traversed into Minnesota from source areas northwest of the state left loamy to clayey till deposits, some containing carbonate rock and shale. In contrast, glaciers entering the state from the northeast traversed igneous and metamorphic rocks and left sandy till that had a more siliceous composition and few carbonate pebbles.

Minnesota's Monitoring Strategy

Groundwater quality monitoring by the Minnesota state agencies primarily is a coordinated effort among the MDA, MPCA, and MDH. The Minnesota Groundwater Protection Act (Minn. Stat. Ch. 103H) splits the ambient groundwater quality monitoring responsibilities between the MDA and MPCA. The MDA is charged with assessing agricultural chemicals including pesticides and fertilizers, and the MPCA has the complementary charge to assess all other non-agricultural contaminants. The MDH's monitoring responsibilities focus on drinking water, as MDH is the state's Safe Drinking Water Act authority. The MDH works with the state's public water system suppliers to test their water for up to 118 different contaminants. The agency also compiles the bacteria, nitrate, and arsenic data required from all newly installed water-supply wells before they are placed in service (Minn. R. ch. 4725.5650).

A large part of the MPCA and MDA's monitoring is not on the ambient environment but instead focuses on sites where pollutants are known to be present from chemical spills and inadvertent releases. Over the years, the MPCA has monitored over 21,000 polluted sites as part of its cleanup activities. These include old landfills, tank releases, gasoline spills, and Superfund sites. The MDA monitors all fertilizer and pesticide spills in the state. Since the contamination associated with most of these spill sites is very localized, the assessments of groundwater quality in this report will be based on the information collected as part of the MPCA and MDA's ambient groundwater monitoring since this best characterizes general groundwater quality conditions across the state.

The MPCA and MDA each maintain their own ambient groundwater-monitoring network that, combined, provides good spatial coverage of groundwater quality conditions across the state. The MPCA's ambient groundwater monitoring primarily targets aquifers in urbanized parts of the state, and most of the MDA's monitoring is done in agricultural areas. The MDA also monitors private, domestic wells to assess the impact of agricultural chemicals reaching Minnesota's drinking water. Detailed descriptions of the MPCA's and MDA's ambient monitoring networks are given in the following sections of this report.

MPCA's Ambient Groundwater Monitoring Network

The MPCA's Ambient Groundwater Monitoring Network was designed to meet its requirements under the Minnesota Groundwater Protection Act to monitor for non-agricultural pollution in the groundwater. The network assesses the presence of non-agricultural chemicals from routine, normal practices and identifies any changes in groundwater quality. It does not assess groundwater quality conditions in the immediate vicinity of known chemical spills or releases because these locations already are monitored as part of the agency's cleanup and solid waste activities. The network mainly is comprised of shallow monitoring wells which intersect the water table but also includes some deep wells. The shallow wells, which have a median depth of 22 feet, comprise an "early warning system" and allows the agency to understand what chemicals can readily be transported to the groundwater as well as discern the effect land use has on groundwater quality and quickly identify any emerging trends. The deep wells, which primarily are domestic wells installed in the Prairie du Chien-Jordan aquifer, provide information on the quality of the water that is consumed by Minnesotans, plus it lets the agency know how quickly any contamination from the surface is percolating downward.

The shallow early warning system was designed to assess current groundwater quality conditions and trends in key urban settings. The wells in the "early warning system" were placed according to a strict protocol. For a well to be placed in this subnetwork, 75% of the land within a 500-meter circular buffer surrounding each well site was required to be in the targeted land use setting. Wells were not placed near potential chemical release sites, such as gasoline stations or dry cleaners.

Most of the wells that comprise the “early warning system” were installed near the water table in areas where the land use is either predominantly residential or commercial/industrial. The residential settings assessed by the network were further subdivided based on whether the neighborhood was served by a centralized sewage treatment system where municipal wastes are treated and typically disposed in a stream or river, or a SSTS, where wastewater is disposed to the soil for final treatment. To see how the information collected in these urban settings compares to background levels, the network also sampled aquifers in forested, undeveloped areas. Finally, to quickly see what non-agricultural chemicals were present and determine whether groundwater conditions improved, got worse, or stayed the same, all of the wells sampled by the MPCA were installed in aquifers that were vulnerable to contamination. These aquifers often were close to the land surface and were covered by permeable materials, such as sand or gravel, that allow water and any associated contamination to readily flow through it.

Since the publication of the last Groundwater Condition Report in 2013 (Kroening and Ferrey 2013), the MPCA upgraded its Ambient Groundwater Monitoring Network, adding approximately 150 new wells. These new wells filled gaps that existed in the network. This included replacing wells sampled in commercial areas that were installed to inform the agency’s groundwater remediation work with others that better represented ambient conditions and improving the network’s coverage in residential areas that rely on SSTS for wastewater disposal and treatment. This network was initially designed using existing wells to minimize the start-up costs associated with groundwater monitoring, but this approach resulted in some monitoring gaps. For example, most of the early warning system wells that represented commercial/industrial settings did not really represent ambient conditions because they were originally installed to inform the agency’s pollution clean-up efforts, mainly petroleum spills. The reliance on these wells for monitoring, even the ones upgradient of the known chemical release, resulted in a greater number of volatile organic compound (VOC) detections as well as a bias towards the VOCs associated with gasoline (Kroening and Ferrey 2013). There also were few shallow wells available in residential areas that relied on SSTS for wastewater treatment and disposal. In 2011, only 14 wells in this land use setting were available for sampling. To address these and other monitoring gaps, the MPCA installed about 150 wells across the state specifically for its network, primarily from 2010-2015. This greatly improved the representation of urban land use in the MPCA’s “early warning system” by adding 34 additional monitoring wells in commercial/industrial areas and 37 new wells in residential areas that use SSTS.

Age dating of select wells sampled by the MPCA’s network confirmed that the water in them was very young which indicates they are very vulnerable to contamination from the land surface. The age of the young part of the groundwater in 51 of the MPCA’s network wells was determined using the tritium-helium method (Cook and Herczeg 2000). Scientists often refer to the tritium-helium method as measuring the “young fraction of the groundwater” because in some situations, the water in the well is a mixture of young and old groundwaters, and this method only determines the age of the young component. The young fraction of the groundwater was less than five years old in 86% of the tested wells.

MDA’s Ambient Groundwater Monitoring Network

The MDA monitors aquifers that are likely impacted by agricultural chemicals. The MDA’s ambient monitoring network is similar to the MPCA’s in that it primarily targets shallow sand and gravel aquifers; except MDA monitors these that underlie the agricultural parts of the state. The network’s monitoring design is based on the state’s ten pesticide-monitoring regions (PMRs), which represent different agricultural practices and/or hydrogeologic conditions. The network currently consists of about 170 monitoring sites. Most of these are monitoring wells that typically are located near the edge of farm fields; however, the network does include thirteen springs and twelve domestic water-supply wells. About 80 of the network's monitoring sites are located in PMR 4 in Central Minnesota, and the remaining sites are divided among most of the state's other PMRs. The wells sampled in PMR 10, which includes the TCMA, are primarily twenty wells from the MPCA's Ambient Groundwater Monitoring Network. Although MDA's groundwater monitoring network was designed to assess the presence and distribution of pesticides in the groundwater, the staff also collects and analyzes water samples for nitrate to add to the body of information that relates to the potential environmental impact to groundwater associated with agricultural activities.

Water samples generally are collected at least annually from all network-monitoring sites. The sampling frequency varies among the sites. Some are sampled as frequently as four times each year. All water samples are analyzed at the MDA Laboratory in St. Paul for nitrate and a suite of 150 pesticides and degradates.

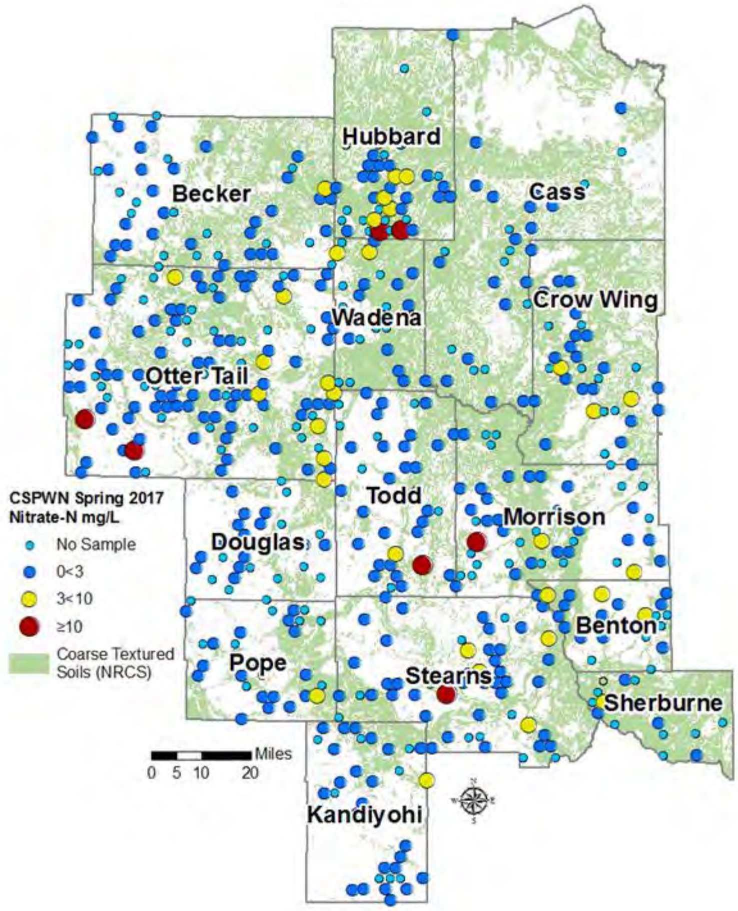
The MDA expanded its assessments of nitrate concentrations in private drinking water wells in vulnerable aquifers throughout the state. These activities included operating the Central Sands Private Well Monitoring Network (CSPWM), Southeast Volunteer Nitrate Monitoring Network (SEVMN), and the Township Testing Program. Goals for all of these activities were to determine whether nitrate concentrations in the groundwater varied with depth and if it affected the aquifers accessed by private domestic wells, which 4 million Minnesotans use (Minnesota Department of Agriculture 2015). The MDA worked closely with other agencies to develop each of these regional private well nitrate networks. Homeowner volunteers are the cornerstone of each of them. For all of the networks, the homeowners collected their own water sample and sent it by mail to be tested by a laboratory at no cost. This method was developed from years of collaboration with other state and local agencies through pilot projects testing different methods of collection and sample delivery.

The MDA continued to operate the CSPWN, which was started in 2011. For this network, about 500 citizen volunteers in 14 counties in Central Minnesota (Figure 3) were recruited to participate in annual sampling of their private domestic drinking water wells. In 2017, 367 private drinking water wells were sampled for nitrate.

The agency also began coordinating the SEVMN in 2014 (Figure 4). This private well network initially was started in 2008 as part of a project funded by the EPA 319 and the MPCA Clean Water Partnership Programs. In 2017, 341 homeowners from the network collected samples.

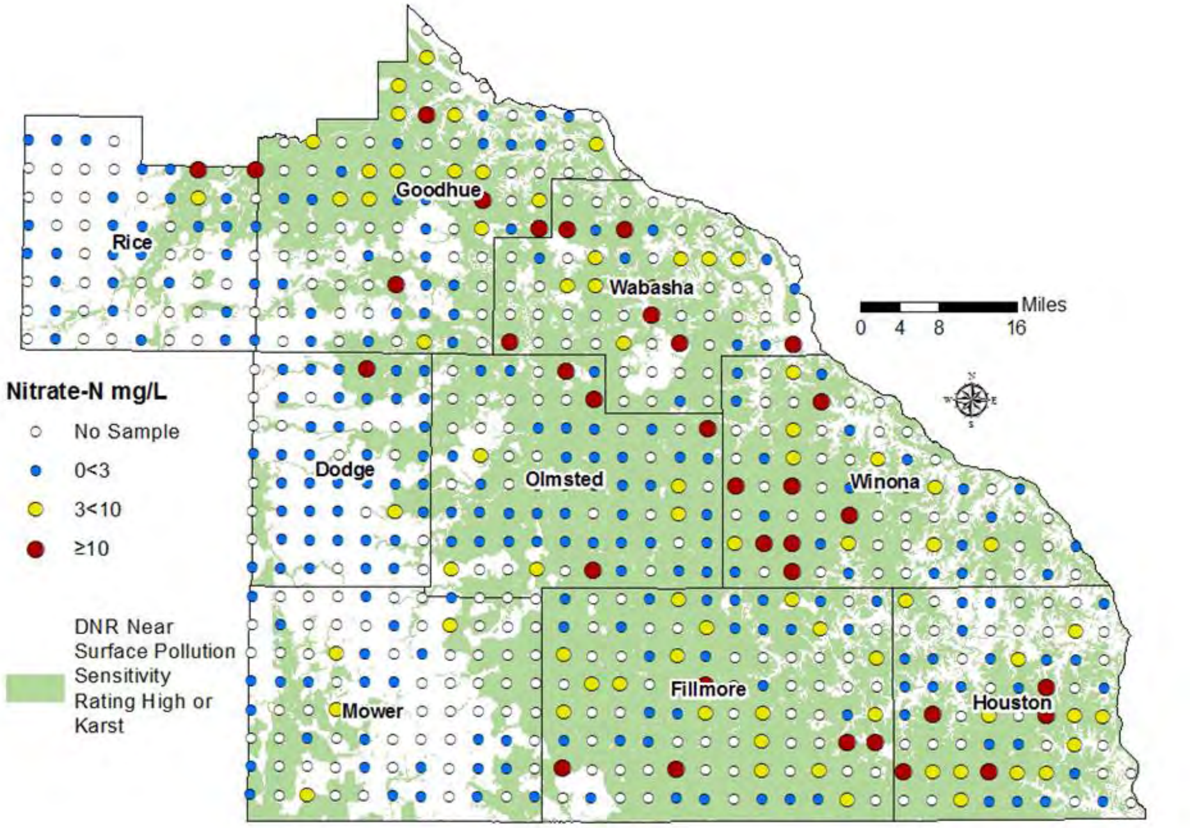
In 2013, the MDA started the Township Testing Program as required by its revised nitrogen fertilizer management plan (Minnesota Department of Agriculture 2015). This program, conducted in partnership with counties and soil and water conservation districts, will run through 2020 and is similar to the other private well networks in that it targets privately owned drinking water wells for sampling but focuses on a finer, township scale compared to the regional networks. The townships selected for sampling in this network were based on the vulnerability of the groundwater to contamination from the land surface, the proportion of land in row crops, and other information that indicated the groundwater may be contaminated with nitrate. It is anticipated that nitrate testing will be offered to over 70,000 domestic wells as part of this effort. The initial water sampling in this program was performed by the property owner, who collected and mailed a water sample to a certified laboratory. If nitrate was detected in the sample, a trained professional collected a second follow-up sample and conducted a site assessment. As of March 2018, nitrate testing was conducted in 242 townships in 24 counties across the state. From 2013-2017, 25,652 wells were tested by this program.

Figure 3. Nitrate concentrations in wells tested as part of the MDA's Central Sands Private Well Monitoring Network in 2017 [Figure courtesy of the Minnesota Department of Agriculture].



To provide information about the occurrence and distribution of pesticides in private drinking water wells, the MDA started its Private Well Pesticide Sampling Project (PWPS) in 2014. This seven-year effort targeted wells that had nitrate detected in them as part of the agency's Township Testing Program. As part of the PWPS Project, well owners also were given an opportunity to have a low-level pesticide sample collected from their well. From 2014-2017, this project sampled about 4,100 private wells, and it is expected that about 3,800 more wells will be sampled by the time this project ends in 2020 (Minnesota Department of Agriculture 2018).

Figure 4. Nitrate concentrations in wells tested as part of the MDA's Southeast Volunteer Nitrate Monitoring Network in 2017 [Figure courtesy of the Minnesota Department of Agriculture].



Groundwater Quality

Both human-caused and natural sources of pollution contaminate the groundwater. Most human-caused pollution results from substances that are deliberately applied or accidently spilled on the land surface, such as fertilizers and pesticides distributed on agricultural fields or garden plots, deicing chemicals applied to pavement or petroleum chemicals that unintentionally leaked from their storage tank. Naturally occurring pollutants often are elements present in the sediments and rocks that form the state's aquifers such as arsenic or manganese. In some instances, the geochemical conditions of the aquifer dictate whether these natural contaminants will be released into the groundwater, like the water's pH or amount of oxygen dissolved in it.

Geology strongly affects how far and fast any pollution will spread in the groundwater, especially for very soluble contaminants such as nitrate and chloride. The physical properties of the soils, unconsolidated sediments, and bedrock determine the speed at which water and any associated pollution move. Coarse-grained sediments, such as sands and gravels, have a high hydraulic conductivity, and water and any associated pollution will very quickly move through them. Surficial aquifers with these types of sediments are classified as "highly sensitive" to groundwater contamination in Minnesota (Adams 2016). In contrast, it may take many decades to hundreds of years for water and any associated pollution to move through sediments with low permeability, such as clays. Several characteristics affect how quickly water and its associated contamination reaches the state's bedrock aquifers. The first of these is the thickness and types of unconsolidated materials covering the bedrock. Water will take a long time to travel through these materials, especially in the parts of the state where they are several hundred feet thick and contain fine-grained material. Secondly, the type of bedrock itself affects the speed at which water flows. Some rocks, such as poorly cemented sandstones, have a high vertical permeability and water easily moves through it. Others, like shale, are very impermeable and readily retard the movement of water and any associated contamination; however, the presence of fractures or sinkholes in these rocks allows movement of water and any associated contaminants.

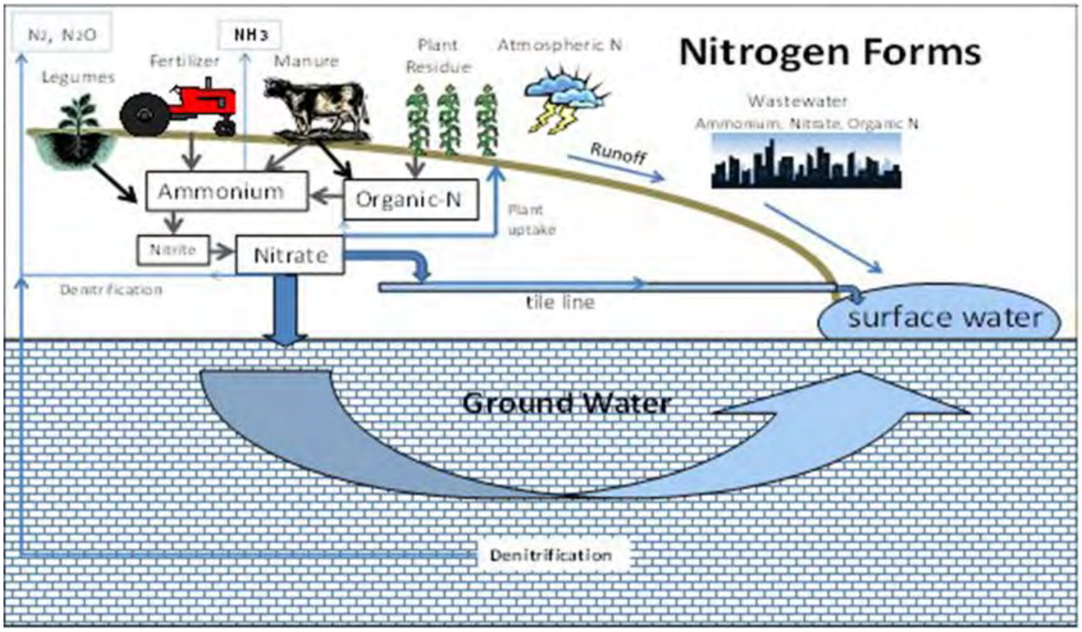
Nitrate

Nitrate is a common human-caused source of pollution to the groundwater. The most recent national assessment of nitrate (Dubrovsky et al. 2010) found that concentrations usually were much greater in the groundwater underlying urban and agricultural lands compared to those, which occur naturally. Very high concentrations tended to be measured in the groundwater in agricultural areas. Nationally, more than 20% of the shallow wells (less than 100 feet deep) sampled in agricultural areas throughout the nation had concentrations greater than 10 mg/L as nitrogen.

Nitrogen-containing compounds are needed for all life to survive, but too much, especially in the form of nitrate, harms human and aquatic health. Nitrogen is an integral part of all proteins, which are the basic building blocks of all plants and animals. In addition, it forms the enzymes involved in life-sustaining reactions and the chemicals involved in plant photosynthesis. Too much nitrate in water, on the other hand, harms human health, especially young babies. High nitrate concentrations in drinking water may cause methemoglobinemia, a blood disorder that typically affects infants and susceptible adults. In this potentially fatal disorder, the blood is unable to carry oxygen to the rest of the body, which results in the skin turning a bluish color. To protect human health, the U. S. Environmental Protection Agency (EPA) established a Maximum Contaminant Level (MCL) of 10 mg/L for nitrate. This is a legally enforceable standard that applies to public drinking water systems and is the highest concentration allowed. The MCL also was adopted as a state class 1 domestic consumption use standard and applies to all groundwater (Minn. R. ch. 7050, 7060). In surface waters, too much nitrate may stimulate the excessive growth of algae, and in some cases, this algal growth is so severe that it interferes with activities like swimming and boating. Foul odors also can occur when this algae decays, and the decomposition process can deplete all of the oxygen from the water resulting in fish kills.

When assessing the groundwater, it is important to consider all of the forms of nitrogen that may be present because these can changed into nitrate by a variety of natural processes. These include assimilation, mineralization, nitrification, denitrification, and volatilization. The combination of all of these is called the Nitrogen Cycle (Figure 5).

Figure 5. Nitrogen cycle, showing primary sources, forms, and routes to surface and groundwater [Minnesota Pollution Control Agency (2013)].



The form nitrogen takes also dictates how quickly it will be transported to the groundwater. The very soluble forms, such as nitrate, may be directly transported to the soils and groundwater with rainfall. Other forms of nitrogen are not very soluble and do not readily move to the groundwater. For example, ammonium (NH_4^+) is a positively charged compound and readily sorbs onto most soils, organic matter, and aquifer materials and does not move quickly in the groundwater.

Sources to the Environment

High nitrate concentrations in groundwater usually are the result of human-caused pollution, such as fertilizers, animal and human waste, and contaminated rainfall. Nitrogen fertilizers commonly are applied to the state's agricultural crops and urban landscapes to enhance crop yields and maintain optimal turfgrass, garden, and landscape plant growth. It is estimated that 1,359 million pounds of nitrogen fertilizer are applied to the state's crops each year and about 12 million pounds are applied to urban lawns (Mulla et al. 2013). Most of these are in the form of ammonia, ammonium nitrate, and ammonium sulfate. Animal and human wastes are another nitrogen source that can reach both surface and groundwater if not properly managed. Mulla et al. (2013) estimated that 446 million pounds of livestock manure are spread on the state's agricultural lands each year. Another important source of nitrogen to Minnesota's landscape is atmospheric deposition. This contributes almost as much nitrogen to Minnesota as livestock manure, contributing about 427 tons of nitrogen to the state each year. Human activities contribute most of this nitrogen to the atmosphere. The EPA (2011) estimates that fossil fuel combustion and ammonia volatilization from livestock manure and commercial fertilizers are the largest sources of nitrogen to the atmosphere in the United States.

Undisturbed landscapes typically contribute small amounts of nitrogen to the environment. Only a few natural, undisturbed settings are known to contain high nitrate concentrations, and none of these occur in Minnesota. Data collected across the Nation by the USGS indicates the background nitrate concentration in the groundwater is low, about 1 mg/L (Dubrovsky et al. 2010). The MPCA's last statewide groundwater quality assessment indicates that the shallow groundwater underlying forested settings in Minnesota is even lower than this, with a median concentration of 0.05 mg/L (Kroening and Ferrey 2013).

Nitrate in the Groundwater

Monitoring conducted in Minnesota from 2013-2017 showed the highest nitrate concentrations usually occur near the water table in agricultural areas (Figure 6, Table 1). High concentrations near the water table generally are not a human health issue because this groundwater typically is not a drinking water supply. However, these may migrate downward to the deep aquifers used for potable water supplies or be transported to surface waters as groundwater inflow. Monitoring data compiled from the “early warning” component of the MPCA’s monitoring network and the MDA’s ambient network were used to assess the effect of land use on nitrate concentrations. In the agricultural parts of the state, the median nitrate concentration reported from 2013-2017 was at the state class 1 domestic consumption use standard of 10 mg/L, and 49% of the wells had concentrations that exceeded the state class 1 standard. Concentrations were much lower in the groundwater underlying urban areas, with median concentrations ranging from about 1-2 mg/L, and in forested areas the median concentration was just slightly above the analytical method reporting limit. These results were similar to the results from the last MPCA Groundwater Condition Report (Kroening and Ferrey 2013) and other groundwater quality assessments conducted in Minnesota (Anderson 1993, Fong 2000, Trojan et al. 2003) In contrast to the results from the agricultural parts of the state, few shallow wells in the urban settings had concentrations that exceeded 10 mg/L. Six of the 144 sampled shallow wells in the urban settings had nitrate concentrations which exceeded 10 mg/L.

Table 1. Summary statistics of nitrate nitrogen concentrations in the groundwater with land use, 2013-2017 [statistics based upon the most recent sampling event during this period at each well].

Land Use	Number of Wells Sampled	Median Well Depth	Median Concentration	Range in Concentrations
Agricultural	113	20.0 feet	10.0 mg/L	<0.2 – 71.5 mg/L
Sewered Residential	50	18.8 feet	1.8 mg/L	<0.05 – 24.0 mg/L
Residential SSTS	51	25.0 feet	1.1 mg/L	<0.05 – 20.0 mg/L
Commercial/Industrial	44	19.0 feet	1.2 mg/L	<0.05 – 12.0 mg/L
Undeveloped	50	18.0 feet	0.1 mg/L	<0.05 – 2.9 mg/L

Figure 6. Nitrate concentrations in the surficial sand and gravel aquifers, 2013-2017 [concentrations are expressed as nitrogen].

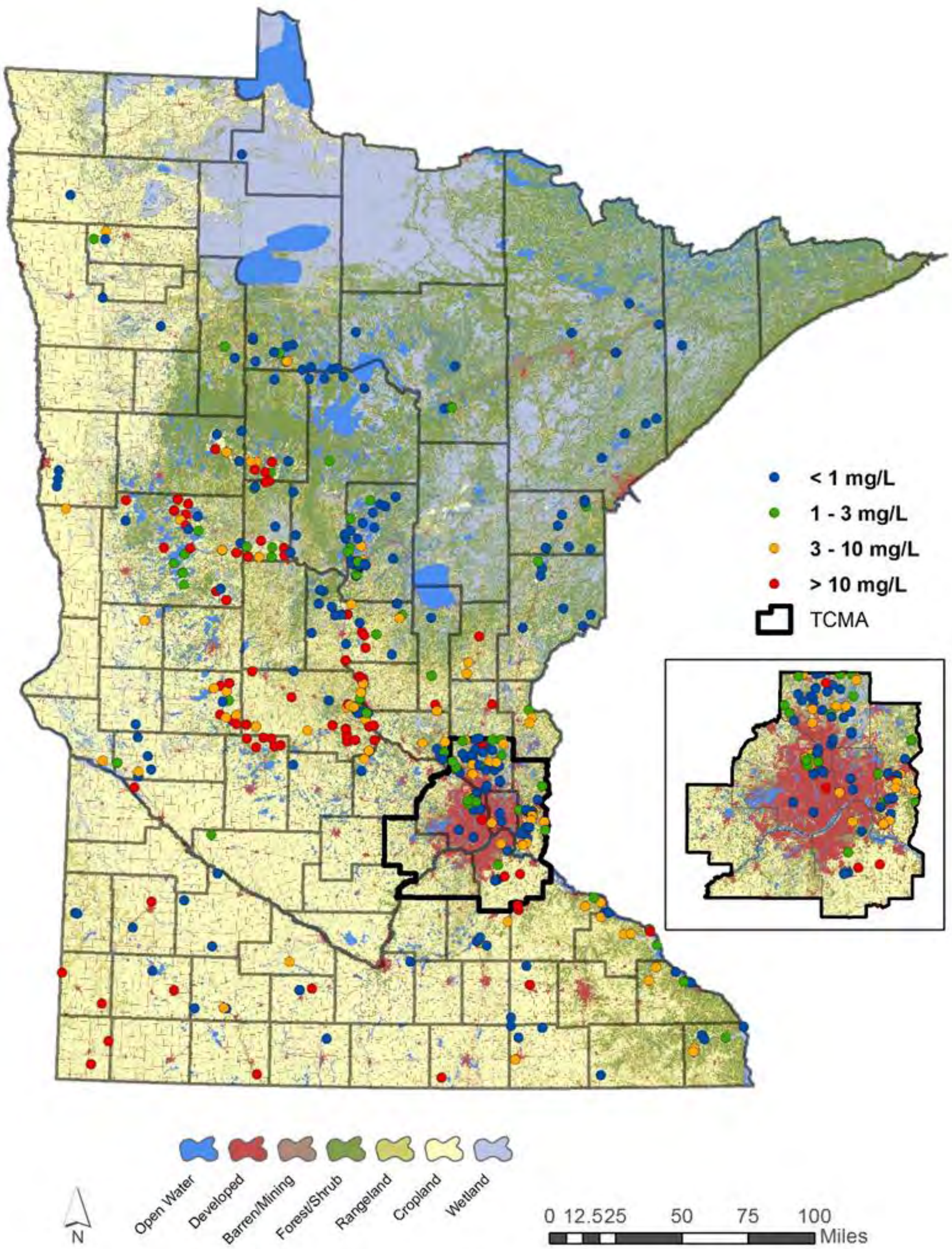


Table 2. Summary statistics (based on the most recent sampling event from the well) for nitrate nitrogen concentrations in Minnesota's groundwater, 2013-2017, by aquifer.

Aquifer	Number of Wells	Median Depth of Wells	Median Concentration	Minimum Concentration	Maximum Concentration
Surficial sand and gravel	446	22 feet	1.7 mg/L	<0.003 mg/L	71.5 mg/L
Buried sand and gravel	810	102 feet	0.01 mg/L	<0.0030 mg/L	26.4 mg/L
Cretaceous	44	187 feet	0.01 mg/L	0.002 mg/L	0.4 mg/L
Galena	47	136 feet	0.05 mg/L	<0.05 mg/L	13.0 mg/L
St. Peter	43	253 feet	0.05 mg/L	0.02 mg/L	15.2 mg/L
Prairie du Chien	161	240 feet	2.0 mg/L	<0.01 mg/L	26.0 mg/L
Jordan	124	340 feet	0.66 mg/L	<0.003 mg/L	32.0 mg/L
Tunnel City	118	318 feet	0.021 mg/L	<0.003 mg/L	12.0 mg/L
Wonewoc	69	268 feet	0.026 mg/L	<0.003 mg/L	4.7 mg/L

High nitrate concentrations occasionally were reported in the parts of the sand and gravel aquifers that are tapped for water supplies. MPCA and DNR staff measured concentrations exceeding the state class 1 standard of 10 mg/L in 18 water-supply wells in these aquifers from 2013-2017. Most of these wells were located outside of the 7-county TCMA and ranged from 40 to 111 feet deep.

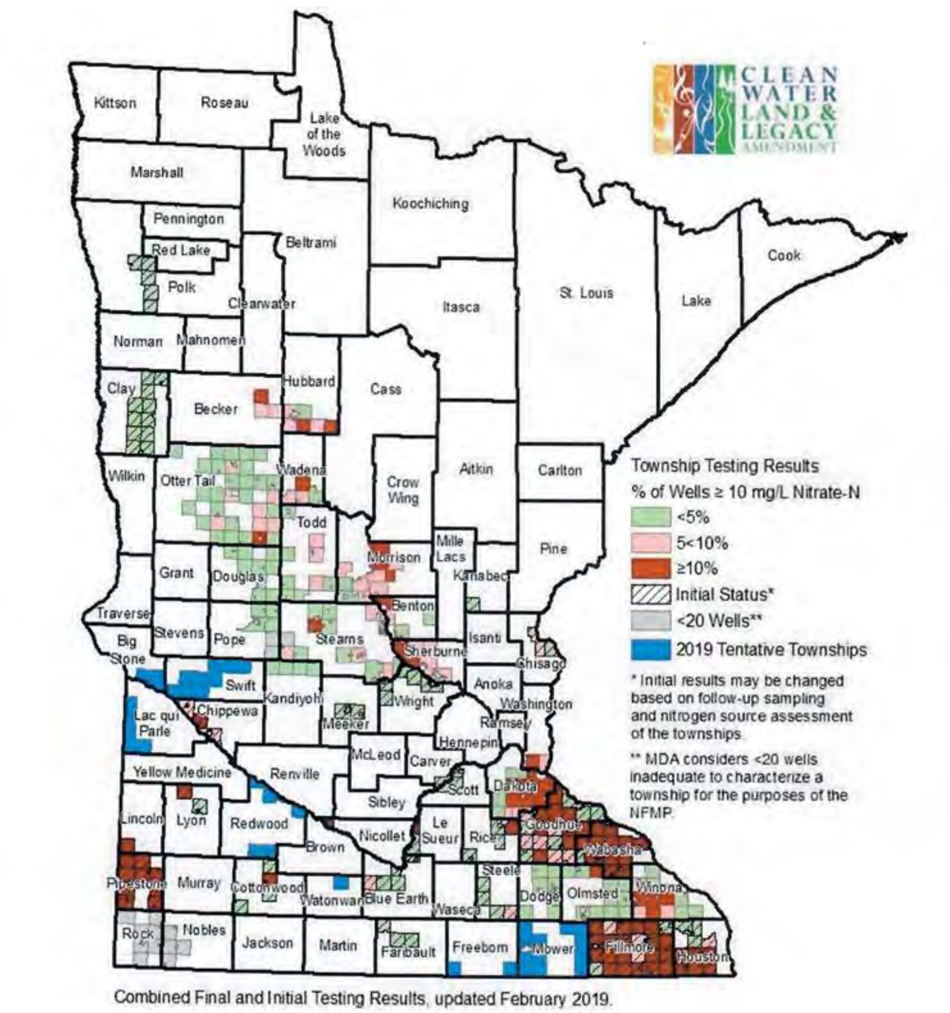
Concentrations in the buried sand and gravel and bedrock aquifers typically were much lower compared to those in the surficial sand and gravel (Table 2). The high median nitrate concentration reported in the Prairie du Chien aquifer likely reflects that the data compiled from 2013-2017 represent the parts of this aquifer that are very vulnerable to contamination from the land surface. Twenty wells installed in the Prairie du Chien had concentrations exceeding the state class 1 standard of 10 mg/L. Three of these 20 wells were located in the southeastern TCMA, and the remainder were located in southeastern Minnesota. The wells in southeastern Minnesota that exceeded the nitrate state class 1 standard were located on the Prairie du Chien Plateau, where large amounts of recharge water and any associated contamination, like nitrate, enter it.

The available monitoring data suggested that nitrate concentrations generally decreased with depth in the surficial sand and gravel aquifers. For this report, data were compiled from 375 shallow monitoring wells and 71 water-supply wells installed in these aquifers. The monitoring wells had a median depth of 21 feet, and the water-supply wells, which mainly supplied water to individual residences, had a median depth of 64 feet. Nitrate concentrations were typically higher in the shallow wells than in the deeper ones. The median concentration in the shallow monitoring wells was 2.0 mg/L compared to 0.7 mg/L in the deeper water-supply wells. The results from MDA's monitoring near the water table and the CSPWN also suggested that concentrations decreased with depth. In 2017, 2.2% of the tested wells in the CSPWM had concentrations equal to or exceeding 10 mg/L compared to 49% of the water table wells. There are a couple of reasons that may explain the low concentrations in the deep wells. First, the nitrate in the shallow parts of these aquifers may not yet have migrated down into the deep parts of the sand and gravel aquifers. Second, nitrate also may have been removed naturally in the deeper parts of the aquifer by denitrification.

Some wells in the bedrock aquifers tapped for water supplies in southeastern Minnesota also were impacted by high nitrate concentrations. MPCA and DNR staff measured nitrate concentrations exceeding state class 1 standard of 10 mg/L in 43 wells accessing these aquifers. These wells were deeper compared to the sand and gravel aquifer wells with high concentrations and had a median depth of 151 feet. The MDA also found that concentrations were equal to or greater than 10 mg/L in 10% of the samples collected for the SEVMN in 2017, which primarily targets bedrock aquifer wells (Minnesota Department of Agriculture 2017).

Expanded testing by the MDA showed the townships with the largest percentages of drinking water supply wells with nitrate concentrations exceeding 10 mg/L tend to be located in southeastern Minnesota (Figure 7). Since the beginning of the Township Testing Program in 2017, 10% of the 25,652 wells tested contained nitrate concentrations greater than or equal to 10 mg/L. The MDA produced result maps from this program at both the county and statewide scale and classified the townships most-impacted by nitrate as having at least 10% of the tested wells with concentrations equal to or exceeding the state class 1 standard of 10 mg/L. The majority of townships most impacted by nitrate contamination (shown in red in Figure 7) were located in southeastern Minnesota.

Figure 7. Percentage of wells exceeding 10 mg/L in townships tested in Minnesota [Figure courtesy of the Minnesota Department of Agriculture].

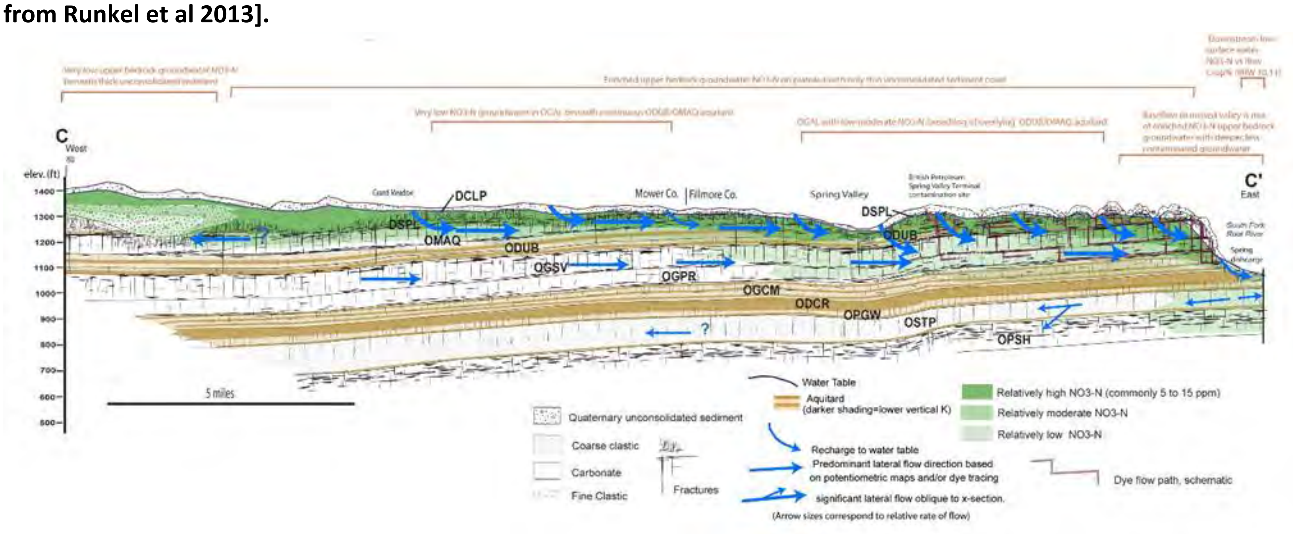


Over 40% of the tested wells in a few townships exceeded the state class 1 standard. The limited initial sampling data from Nobles and Rock Counties in southwestern Minnesota showed that 41 to 93% of the tested wells in each township contained nitrate concentrations that exceeded the state class 1 standard. Four other townships in the state had 40% or more of the tested wells exceeding the state class 1 standard. These included Marshan Township in eastern Dakota County, Agram Township in central Morrison County, and Fremont and Utica Townships in western Winona County. In each of these four townships, 43 to 55% of the tested wells had nitrate concentrations of
10 mg/L or greater.

Geology had a large influence on whether high nitrate concentrations were transported to the state's bedrock aquifers. The geologic controls on nitrate transport to the bedrock aquifers in southeastern Minnesota was recently assessed by the MGS (Runkel et al. 2013) as part of an investigation conducted for the MPCA to assist with watershed planning efforts. For this study, the MGS researchers compiled existing nitrate data along with geologic maps and other databases in order to evaluate how the concentrations varied with respect to this region's hydrogeology. This work, along with a few other studies (Falteisek et al. 1996, Falteisek 1997, Minnesota Department of Natural 2002, Minnesota Department of Natural Resources 2003, 2001), found that recharge water along with any associated contamination like nitrate quickly enters the bedrock aquifers on the Upper Carbonate and Prairie du Chien Plateaus.

The influence of the thickness of the unconsolidated materials covering the bedrock aquifers on nitrate transport to the groundwater can be seen in a cross section in Mower County that was published by Runkel et al. (2013) (Figure 8). In the western part of the cross section, the bedrock aquifers are covered by about 100 feet or more of unconsolidated deposits (identified as quaternary unconsolidated sediment or coarse clastic). These thick deposits sufficiently retard the flow of water and any associated contamination, resulting in low nitrate concentrations in the underlying bedrock aquifers. In contrast, the uppermost bedrock aquifer is covered by a thin layer (less than 50 feet) of unconsolidated deposits in the eastern part of the cross section. These thin deposits readily allow water and associated nitrate to flow through them, and as a result, concentrations in the uppermost bedrock aquifers commonly range between 5-15 mg/L.

Figure 8. Cross section showing nitrate transport in the bedrock aquifers in Mower and Fillmore Counties [Figure from Runkel et al 2013].



The investigation by Runkel et al. (2013) also showed that nitrate concentrations in the bedrock aquifers in southeastern Minnesota are strongly influenced by the aquitards that separate them, such as the Dubuque, Decorah, or Glenwood shales. These aquitards generally limit the vertical transport of water and any associated nitrate contamination, resulting in low nitrate concentrations in the deep, underlying aquifers, which generally is related to the age of the groundwater. This also can be seen in the cross section shown in Figure 8. In the middle part of the cross section, the recharge water and nitrate contamination in the uppermost bedrock aquifer flows laterally along the underlying thick aquitard that lacks vertical fractures (identified as ODUB and OGCM). In the eastern part of the cross section, the upper aquitard is thin and breached by vertical fractures in many places, and this allows the nitrate contamination to be transported to another underlying bedrock aquifer. These vertical fractures are especially common where the uppermost bedrock is within about 50 feet of the land surface. Eventually, the groundwater and its associated nitrate contamination reaches the incised river valleys in southeastern Minnesota, and is discharged as baseflow to these streams.

Temporal Trends

Trends in nitrate concentrations from 2005-2017 generally showed no consistency statewide, at the watershed scale, or within any particular land use setting. Trends could be examined at all of these levels due to the wealth of available nitrate data. Over 100 wells and springs sampled by the MPCA and MDA's ambient monitoring networks had sufficient data to determine whether nitrate concentrations changed from 2005-2017. These sites were fairly evenly split between the MPCA's and MDA's ambient monitoring networks. Fifty of the wells used for trend analysis were part of the MPCA's Ambient Groundwater Monitoring Network, and the remaining sixty-four wells and three springs were from the MDA's monitoring network.

The majority of the tested sites had no significant temporal trend in nitrate concentrations. All of the wells and springs were tested individually for temporal trends in nitrate using the nonparametric Mann-Kendall test, which accounted for both censored and tied data. Seventy-four of the sites had no statistically significant change in concentrations from 2005-2017. A much smaller number of sites had significant increases or decreases in nitrate concentrations. Nineteen sites had statistically significant upward trends in nitrate from 2005-2017, and twenty-four sites had statistically significant decreases. The sites with significant upward or downward trends were scattered throughout the state and generally did not appear to be located within any particular region or land use setting.

Further statistical testing confirmed the informal finding that there was no statewide trend in nitrate concentrations in the state's shallow groundwater. A variation of the Mann-Kendall trend test called the Regional Kendall test (Helsel and Frans 2006) was used for this analysis and confirmed that there was no consistent trend at the statewide scale in nitrate concentrations in the shallow groundwater (slope=0, tau=-0.0409, p-value=0.0156). Even though the result from this statistical test was statistically significant, the Theil-Sen's slope of zero and low Kendall's tau value indicated that the nitrate concentrations in the groundwater have not changed.

No trends in nitrate concentrations generally were found in the groundwater in each of the state's major watersheds or the TCMA from 2005-2017 (Appendix A). For this analysis, only major watersheds that had at least five wells with sufficient data to compute temporal trends were considered. There was a statistically significant upward trend in nitrate concentrations in the Lower Mississippi River Basin. In this watershed, five of the nine sites had statistically significant increasing trends. Three of these sites were springs, and the other two were domestic water-supply wells.

In this report, the major watersheds used for the trend analysis generally were considered to be the subregions defined by the USGS's Hydrologic Unit Maps (Seaber, Kapinos, and G.L. 1987). In the instance where a major watershed overlapped the TCMA, the watershed boundary was truncated so it did not include the TCMA. There were at least five wells with sufficient data for trend analysis in the TCMA and 4 of the 12 major watersheds. There were no or insufficient data to calculate temporal trends in these watersheds: 1) Big Sioux and Rock River Basins, 2) Des Moines River Basin, 3) Little Sioux River Basin, 4) Rainy River Basin, 4) St. Croix River Basin, 5) Western Lake Superior Basin, 6) Upper Iowa River Basin, 7) Wapsipnicon River Basin, and 8) Western Lake Superior Basin.

There also were no statistically significant trends in nitrate concentrations from 2005-2017 when the analysis was performed by land use setting (Appendix A). Similar to the trend testing by watershed, this testing only included land use settings that had at least five wells with sufficient data to compute temporal trends. For the urban settings, there only were sufficient nitrate data collected from the wells located in sewered residential areas to compute trends.

MDA's analysis of the private well networks also showed nitrate concentrations have not changed recently. Kaiser, Schaefer, and VanRysWyk (2017) analyzed the SEVMN and CSPWN data for trends. No temporal trends were found in the SEVMN data from 2008-2015 or the CSPWN data from 2011-2015.

Chloride

Chloride transported to the groundwater is considered a "permanent" pollutant because it is not broken down by typical environmental processes. Once in the groundwater, any chloride will remain there until it is transported either downward to deep aquifers (which typically are used for drinking water) or to streams, lakes, and wetlands as groundwater inflow.

Excessive chloride in groundwater restricts its use for drinking and may degrade aquatic habitat if it is transported to surface waters. High chloride concentrations adversely affects drinking water not due to human toxicity but because it imparts a salty taste that consumers find objectionable. High concentrations also change the chemistry of the water and can result in lead and copper being leached from plumbing and fixtures (Edwards, Jacobs, and Dodrill 1999, Nguyen et al. 2010, Nguyen, Stone, and Edwards 2011). To minimize taste problems with public drinking water supplies, the EPA set a Secondary Maximum Contaminant Level (SMCL) for chloride of 250 mg/L. SMCLs are not enforced by the EPA; they are a guideline to assist public drinking water suppliers in managing their systems for aesthetic considerations. However, the SMCL was adopted as Class 1 domestic consumption use standard in Minnesota and applies to all groundwater (Minn. R. ch. 7050, 7060). Additionally, high chloride concentrations are toxic to aquatic life. Streams and lakes with high chloride concentrations may have decreased biological integrity or even may be limited to just salt-tolerant species. To protect these plants and animals from water with high chloride concentrations, the State of Minnesota set a chronic water quality standard of 230 mg/L and an acute water quality standard of 850 mg/L (Minn. R. ch. 7050).

Additional monitoring conducted over the last several years filled some of the gaps in our knowledge of human-caused chloride contamination in Minnesota's groundwater. This included chloride data collected from the: 1) MPCA's newly-installed ambient network monitoring wells, 2) MDA's ambient monitoring network, 3) the SEVMN, and 4) DNR's County Geologic Atlas projects.

The MPCA's monitoring network enhancements allowed the agency to better assess how land use affects chloride concentrations in the groundwater. The assessment of chloride concentrations in the last MPCA Groundwater Condition Report (Kroening and Ferrey 2013) was based on limited data from commercial/industrial areas and residential areas using SSTS for wastewater disposal and treatment. For the 2013 assessment, chloride data were available only from nine shallow wells representing ambient conditions commercial/industrial areas and thirteen wells in residential areas that rely on SSTS for wastewater treatment.

The most complete picture to date of chloride concentrations in the shallow groundwater underlying the state's agricultural areas was provided by the sampling of the MDA's ambient monitoring network in 2014. For this collaborative monitoring effort, the MDA drew groundwater samples from their network of over 100 wells in agricultural areas, and MPCA analyzed the samples for chloride, bromide, and sulfate. Prior to this sample collection, the only available chloride data in the agricultural parts of the state were collected about 20-25 years ago by the MPCA and USGS (Cowdery 1998, Fong 2000, Trojan et al. 2003). These studies were not conducted statewide but focused on the shallow groundwater underlying agricultural areas in western Minnesota, the Anoka Sand Plain in central Minnesota, and agricultural land near the City of St. Cloud.

Chloride information from the SEVMN and the DNR's County Geologic Atlas Program expanded coverage in the bedrock aquifers in southeastern Minnesota and the buried sand and gravel aquifers. The main goal of the SEVMN is to track nitrate concentrations in drinking water from private wells; however, chloride samples were collected from 416 network wells during 2013-14. Data from the buried sand and gravel aquifers included the information 365 wells, primarily private drinking water wells, in Anoka, Renville, Sherburne, and Wright Counties.

The trend analyses in this report also represented a broader distribution of wells compared to the last analysis (Kroening and Ferrey 2013). The last temporal trend analysis of chloride in groundwater primarily focused on wells located in the northern TCMA, Washington County, and near the cities of Bemidji and St. Cloud because at this time these were the only ones available that had long-term information. Since this time, enough data has been collected from the MPCA's Ambient Groundwater Monitoring Network to compute trends in other locations, including near the cities of Austin, Rochester, and Wabasha. The updated trend analysis in this report also included more wells installed in the state's bedrock aquifers. Fifteen of the 35 wells used for chloride trend analysis were installed in bedrock aquifers, primarily the Prairie du Chien-Jordan.

The wells used in this temporal trend analysis also were installed at a variety of depths. The sand and gravel aquifer wells ranged from 9 to 73 feet deep. These primarily were monitoring wells screened at the water table, and the majority of these wells were located in the TCMA and near the City of St. Cloud. The bedrock aquifer wells analyzed for trends were 52 to 340 feet deep. These primarily were domestic water-supply wells installed in the Prairie du Chien-Jordan aquifer in the TCMA; however, five wells tapping the Galena aquifer and one well tapping the St. Peter aquifer in southeastern Minnesota were included in the analysis.

Sources and Fate of Chloride in Groundwater

Chloride is present naturally to some degree in Minnesota's groundwater. Many of the minerals that comprise the state's bedrock and sand and gravel aquifers contain a little chloride, and rock weathering releases some of this into the groundwater. Sedimentary rocks, especially those containing the mineral halite (commonly known as rock salt), usually contain more chloride compared to igneous rocks. In aquifers with very old water, chloride also may be naturally present if these still contain connate water, which is the water that was initially trapped in the rock when it was formed in a marine environment. In Minnesota, the aquifers composed of sedimentary rocks, like the Prairie du Chien-Jordan, likely contained high chloride concentrations when they were formed. Some aquifers also may naturally contain chloride if it is transported from saline to fresh aquifers through contacts between the aquifers, faults, or fractures.

Scientists at the University of Minnesota estimate that the largest sources of chloride to Minnesota's environment are de-icing chemical application, agriculture, and household water softening (Overbo and Heger 2018). The use of salt for pavement de-icing is the largest anthropogenic source, contributing over 400,000 tons each year. Agricultural activities also contribute about this same amount of chloride to Minnesota's environment. Overbo and Heger (2018) estimate that almost 200,000 metric tons of chloride are applied each year in Minnesota to fertilize crops and over 150,000 metric tons of chloride were excreted by livestock. Household water softening is estimated to contribute almost 150,000 tons of chloride each year to Minnesota's environment.

Monitoring conducted in Minnesota and other northern climates found that these anthropogenic sources of chloride have migrated down into the groundwater. The last statewide MPCA assessment of chloride in the groundwater (Kroening and Ferrey 2013), which focused on aquifers that are vulnerable to contamination in urban areas, found human-caused chloride contamination in a substantial number of the tested wells, especially those installed near the water table in the TCMA. Similar contamination of the groundwater has been found in studies conducted in other states in the northern U.S. and Canada (Cassanelli and Robbins 2013, Howard and Taylor 1998, Kelly 2008, Williams, Williams, and Cao 2000) and in a national-scale assessment of the glacial aquifer system (Mullvaney, Lorenz, and Arntson 2009). Other studies have characterized chloride concentrations in the groundwater in agricultural areas. Pionke and Urban (1985) measured the chloride concentrations in groundwater in Pennsylvania, and Fong (2000) assessed the shallow groundwater beneath agricultural land in the Anoka Sand Plain in Minnesota. Both of these studies found that agricultural land use resulted in increased chloride concentrations in the shallow groundwater. The average measured concentrations reported in the groundwater underlying agricultural areas were around 15 mg/L, which was considerably lower compared to those reported in urban areas. The low concentrations likely resulted from fertilizers and manure being typically distributed among much larger areas compared to de-icing chemicals.

Distribution and Sources in the Groundwater

The highest chloride concentrations in the groundwater typically occurred near the water table in sand and gravel aquifers, especially within the TCMA (Figure 9). Similar to nitrate, high chloride concentrations near the water table typically are not a drinking water concern, but they do signal contaminated water may slowly be seeping downward to the aquifers tapped for drinking water or, alternatively, could adversely affect aquatic life if they are transported to surface waters. Concentrations varied widely throughout the surficial sand and gravel aquifers, ranging from less than the reporting limit of 0.5 to 815 mg/L (Table 3). The lowest concentrations typically were measured in northern Minnesota, and the highest were in the TCMA.

The state class 1 domestic consumption use standard of 250 mg/L was exceeded mainly in shallow monitoring wells located in the TCMA and other urban areas in the state. Twenty-four of the sampled wells contained water with chloride concentrations that exceeded the state class 1 standard in the most recent samples collected from the wells from 2013-2017 (Figures 9-10, table 3). All but two of these were monitoring wells, and they typically were very shallow, with a median depth of 26 feet. The deepest well with a chloride concentration exceeding the state class 1 standard had a depth of 72 feet. Two-thirds of the wells that exceeded the state class 1 standard were located in the 11-county TCMA, and the remaining wells typically were located in other urban areas, such as Cloquet or Moose Lake.

Fewer wells in the TCMA exceeded the state class 1 standard compared to the last MPCA Groundwater Condition Report (Kroening and Ferrey 2013), but this should not be inferred as declining concentrations. The prior assessment included chloride data collected from wells that were originally installed to inform the agency's remediation efforts, primarily investigations of petroleum spills at gas stations. The sampling of these wells was discontinued by the agency's Ambient Groundwater Monitoring Network in 2008 after a review of the data indicated that these wells biased the statewide assessment of VOCs in the groundwater. A reanalysis of the chloride data compiled for the MPCA's 2013 statewide assessment of groundwater quality (Kroening and Ferrey 2013) showed that the median concentration in the remediation wells (330 mg/L) was over ten times greater compared to those in wells installed outside of contaminated areas (22 mg/L). The shallow groundwater near the petroleum spill sites probably contained high chloride concentrations because places such as gas stations likely received large applications of de-icing chemicals during the winter months.

Table 3. Summary statistics (based on the most recent sampling event from the well) for chloride concentrations in Minnesota's groundwater, 2013-2017, by aquifer.

Aquifer	Number of Wells	Median Depth of Wells	Median Concentration	Minimum Concentration	Maximum Concentration
Surficial sand and gravel	373	21 feet	17.7 mg/L	<0.5 mg/L	815 mg/L
Buried sand and gravel	306	108 feet	3.5 mg/L	<0.5 mg/L	184 mg/L
Galena	47	136 feet	13.2 mg/L	<0.5 mg/L	89.3 mg/L
St. Peter	40	270 feet	1.5 mg/L	<0.5 mg/L	30.1 mg/L
Prairie du Chien	129	285 feet	6.8 mg/L	<0.5 mg/L	443 mg/L
Jordan	66	350 feet	2.4 mg/L	<0.5 mg/L	145 mg/L
Tunnel City	50	207 feet	1.4 mg/L	0.367 mg/L	112 mg/L

Figure 9. Chloride concentrations in the surficial sand and gravel aquifers, 2013-2017.

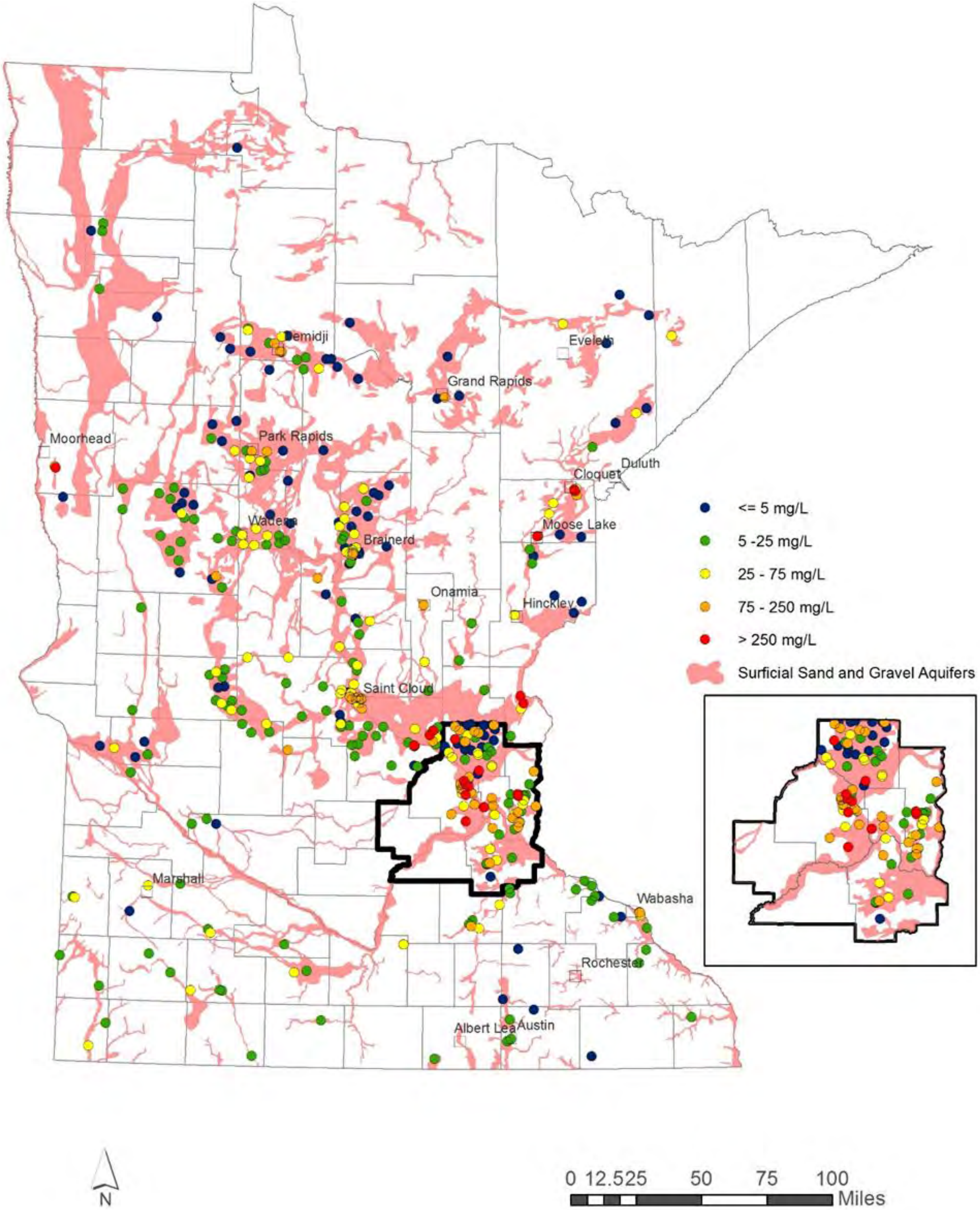
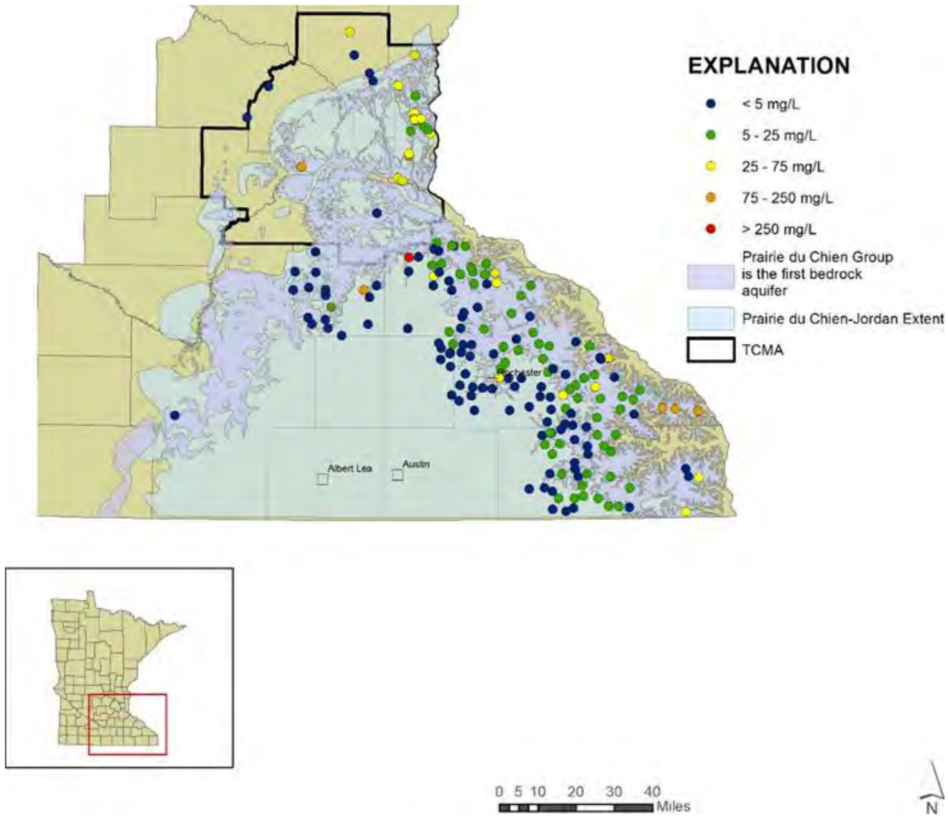


Figure 10. Chloride concentrations in the Prairie du Chien-Jordan Aquifer, 2013-2017



Two of the sampled domestic wells had chloride concentrations exceeding the state class 1 standard. One of these wells tapped the Prairie du Chien aquifer in Goodhue County (Figure 10). This well was installed in 1955, almost two decades before the state well code was enacted in 1974, and was 60 feet deep. The other domestic well that contained water with a chloride concentration exceeding the SMCL was 72-feet deep and installed in the Buffalo Aquifer in Clay County (Figure 9); this is an area which is known to contain recently recharged groundwater and human-caused chloride contamination (Berg 2018).

Land Use Influences

The MPCA's monitoring network improvements found that commercial/industrial land use affects chloride in groundwater more than what was previously known. The expanded monitoring in this setting showed the median chloride concentration in the shallow groundwater underlying the state's commercial/industrial areas was 81.9 mg/L (Table 4). This is about 25 mg/L higher than the median value reported in 2013 (Kroening and Ferrey 2013). In addition, the data from the expanded monitoring showed that concentrations were almost twice as high in the shallow groundwater underneath commercial/industrial areas compared to residential. The wells in commercial/industrial areas with the highest chloride concentrations generally were located near heavily travelled roadways, such as interstate freeways or U.S. highways, or were near parking lots.

Table 4. Summary statistics of chloride concentrations in the groundwater with land use, 2013-2017 [statistics based upon the most recent sampling event during this period at each well].

Land Use	Number of Wells Sampled	Median Well Depth	Median Concentration	Range in Concentrations
Commercial/Industrial	43	19 feet	81.9	1.4 – 790 mg/L
Sewered Residential	50	9 feet	44.6 mg/L	<0.5 – 463 mg/L
Residential SSTS	51	25 feet	16.1 mg/L	<0.5 – 429 mg/L
Agricultural	113	20 feet	14.1 mg/L	<0.5 – 308 mg/L
Undeveloped	50	13 feet	1.1 mg/L	<0.5 – 97 mg/L

Distinguishing chloride sources in groundwater

Chloride to bromide (Cl/Br) ratios are used by many researchers to distinguish among the various sources of human-caused and natural contamination in the groundwater. Cl/Br ratios are a useful tool to discriminate between sources because chloride is about 40-8000 times more abundant than bromide. As a result, small differences in bromide concentrations in the various chloride sources yield vastly different Cl/Br ratios. Pristine groundwater has Cl/Br ratios that are less than 200 (Davis, Whittemore, and Fabryka-Martin 1998). In contrast, domestic sewage has ratios ranging from 300-600, and groundwater affected by the dissolution of halite (commonly known as rock salt) has ratios that are greater than 1,000.

The source of most of the high chloride concentrations in the shallow wells in commercial/industrial areas likely was related to the use of salt as a de-icing chemical or possibly for water softening. This study did not determine the extent of chloride-contaminated water at each of the sampled wells. Bromide, however, was analyzed in addition to chloride in most of the studies compiled for this report, and chloride/bromide (Cl/Br) ratios were computed (Davis, Whittemore, and Fabryka-Martin 1998) to determine the potential sources that were contributing the chloride to the groundwater. Almost three-quarters of the shallow wells sampled in commercial/industrial areas had a Cl/Br ratio greater than 1,000, which indicated that the chloride source was halite, which usually is applied as a deicing chemical to pavement, sidewalks, and parking lots in these areas. Salt in the form of halite also may be used in water softening to regenerate the resins in water softeners that remove the calcium and magnesium from the water. It is less likely that water softening was the source of the high chloride concentrations in commercial/industrial areas since most of the sampled wells were located in places where any wastewater from these systems would be discharged to a centralized sewage treatment system rather than the land in the immediate vicinity of the sampled monitoring wells.

The expanded monitoring showed that chloride concentrations in the shallow groundwater underlying residential areas that use SSTS and agricultural areas were similar, with median concentrations ranging from 14.1 to 16.1 mg/L. The median chloride concentration underlying residential areas that use SSTS for wastewater treatment was almost 30 mg/L lower compared to those underlying sewered residential areas. One reason that concentrations may be lower in the shallow groundwater underlying residential areas using SSTS compared to those using centralized sewage treatment systems is the low housing and road density in these areas. This would tend to spread out the chloride sources to the groundwater over a larger area compared to sewered residential areas, resulting in lower concentrations in the groundwater.

The calculated Cl/Br ratios also indicated that de-icing chemicals or water softener salt still were important chloride sources in both types of residential settings. Sixty-two percent of the shallow wells in sewered residential areas had a Cl/Br ratio that exceeded 1,000, indicating a halite source, whereas

51% of the shallow wells in the residential SSTS areas had a Cl/Br ratio suggesting that the chloride source was either a de-icing chemical or water softener salt.

De-icing chemicals or water softener salt generally did not appear to be the sources of the chloride in the groundwater underlying agricultural areas. The majority of the shallow wells contained water with Cl/Br ratios ranging from 300 to 1,000, which indicated the source of chloride was a mixture of water with different Cl/Br ratios or wastewater. Seventeen percent of the wells in agricultural areas had a Cl/Br ratio that indicated the source was either a de-icing chemical or water softener salt.

Similar to the results from the 2013 statewide groundwater quality assessment, chloride concentrations remained lowest in the shallow groundwater underlying the undeveloped, forested parts of the state. Concentrations in this setting ranged from <0.5 to 97 mg/L, with a very low median concentration of 1.1 mg/L. Most of the chloride present in these wells was contributed by natural sources. Twenty-nine of the 50 sampled wells in this setting had a Cl/Br ratio that was less than 200, which indicated a natural source.

Buried Sand and Gravel Aquifers

The available data suggested that high chloride concentrations in the buried sand and gravel aquifers within or near the TCMA were related to de-icing chemical or water softener salt use. The chloride information compiled for this report was not evenly distributed throughout the state. Ninety-four percent of the chloride data in these aquifers were from four counties (Anoka, Renville, Sherburne, and Wright) because they originally were collected by the DNR to produce county-scale maps showing the pollution sensitivity of the state’s aquifers. The median chloride concentrations in the buried sand and gravel aquifers in each of these four counties were similar, ranging from 2.2 mg/L in Wright County to 4.9 mg/L in Sherburne County. Concentrations, however, were more variable in the three counties closest to the TCMA compared to Renville County. The interquartile range (IQR), a statistic that describes the variation in the data, in the wells in Anoka, Sherburne, and Wright Counties ranged from 9.1 to 14.1 mg/L. The variation in concentrations was much lower in the aquifers in Renville County, with an IQR of 4.1 mg/L. Many of highest concentrations in Anoka County appeared to be related de-icing chemical or water softener salt use. In this county, almost three-quarters of the wells with chloride concentrations greater than 14.1 mg/L had a Cl/Br ratio that was greater than 1,000, which suggested a de-icing chemical or water softener source. In contrast, none of the wells sampled in Renville County had a Cl/Br ratio that suggested it was contaminated from these two sources.

Bedrock Aquifers

The median chloride concentration in the Prairie du Chien-Jordan aquifer was substantially higher in the available 11-county TCMA wells compared to the rest of southeastern Minnesota. The median concentration in the 11-county TCMA was 28.3 mg/L, which was calculated from 28 wells. In contrast, the median concentration in this aquifer outside of the TCMA was almost 10 times lower; 3.0 mg/L (calculated using 167 wells).

More wells in the TCMA also had a chemical signature consistent with a de-icing chemical or water softener salt compared to those located outside of this area. In the TCMA, 77% of the Prairie du Chien-Jordan wells had a Cl/Br ratio greater than 1,000. In contrast, only 5.1% of the wells outside of the TCMA had a Cl/Br ratio greater than 1,000.

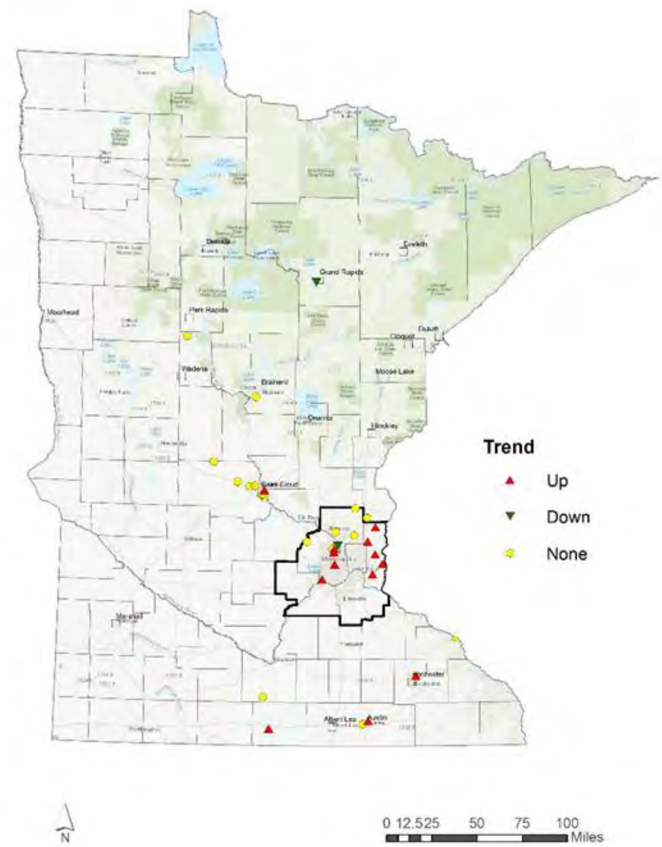
There were no distinctive geographic variations in chloride concentrations in the Galena or St. Peter aquifers (Appendix B). The chloride sources in these wells generally were not related to the use of deicing chemicals or water softener salt. About 20% of the Galena wells and 9% of the St. Peter wells had a Cl/Br ratio consistent with a de-icing chemical or water softener salt.

Temporal Trends

All wells with significantly increasing chloride trends had a chemical signature that was consistent with a human-caused source. Recent changes (2005-2017) in chloride concentrations were calculated at 35 sites that had sufficient data for analysis using the Mann-Kendall test, similar to the methods used for nitrate trends. Overall, 14 of the 35 wells (40%) tested across the state had a statistically significant upward trend in chloride concentrations from 2005-2017 (Figure 11). Eleven of these 14 wells had a Cl/Br ratio greater than 1,000, which is consistent with a de-icing chemical or water softener source. The remaining three wells with a significant upward trend had slightly lower Cl/Br ratios, ranging from 447 to 983, which are consistent with either a municipal wastewater source or a mixture of waters with different ratios.

Increasing chloride concentrations were not just restricted to the water table, but also occurred in the state's bedrock aquifers. Chloride trends in the bedrock aquifers were largely untested in the last MPCA statewide groundwater quality assessment (Kroening and Ferrey 2013) because most of the wells in the agency's monitoring network had insufficient data for this analysis. The recent analysis found that 10 of the 14 wells with increasing chloride trends were in bedrock aquifers, ranging from 90 to 340 feet deep. Seven of the 10 bedrock aquifer wells with increasing trends were installed in the Prairie du Chien aquifer. The remaining three wells were installed in the Galena and St. Peter aquifers. All except one of the 10 wells were used to provide water supplies to individual residences.

Figure 11. Temporal trends in chloride concentrations in Minnesota's groundwater, 2005-2017.



In the wells with upward trends, the changes in chloride concentrations from 2005-2017 varied considerably. In the deepest well with an upward trend, a 340-foot deep Galena well in Mower County, the change in chloride concentrations were very slight (Figure 12). In comparison, greater increases in chloride concentrations were seen in the shallower bedrock aquifer wells with upward trends, such as a 169-foot deep Galena well near the City of Austin (Figure 13).

Figure 12. Chloride concentrations in well 562727 in Mower County, Minnesota

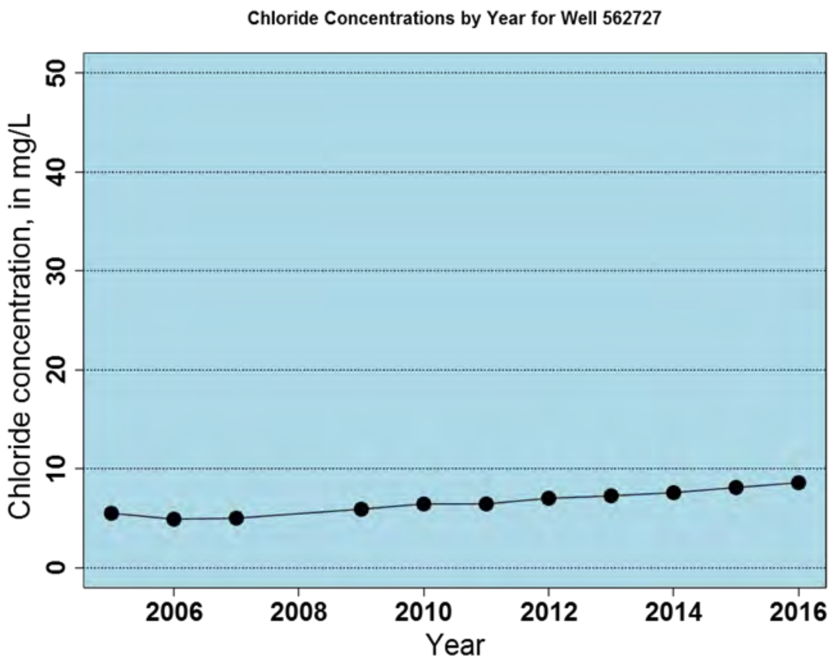
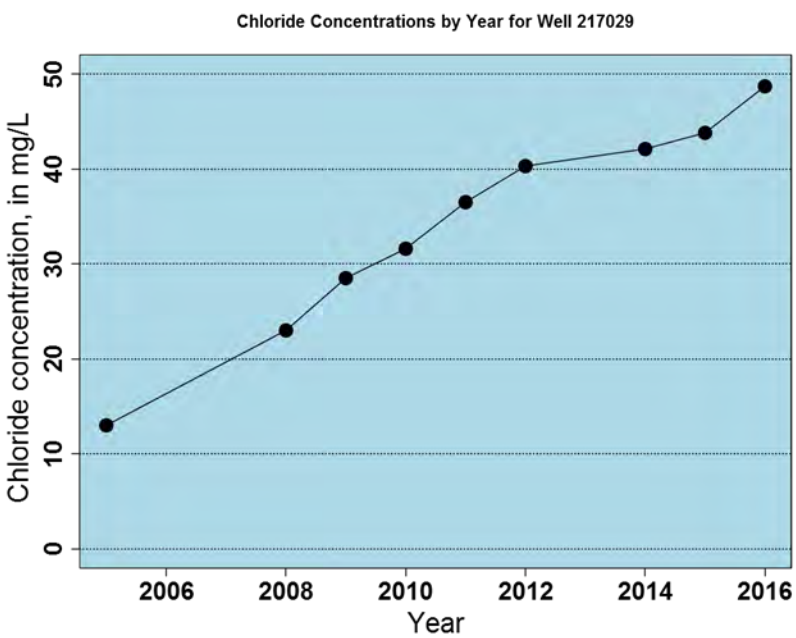


Figure 13. Chloride concentrations in well 217029 in Austin, Minnesota.



Increasing chloride trends continued to occur in some shallow sand and gravel aquifer wells in the TCMA and the City of St. Cloud. The last assessment of groundwater quality conditions, using all of the available data up to 2011, found that chloride concentrations had increased in about 30% of the wells in these aquifers. Overall, four of the 20 shallow sand and gravel aquifer wells tested for chloride trends from 2005-2017 had a statistically significant increasing trend. These four wells were located in heavily urbanized areas; three were near the urban core of the TCMA in Hennepin County, and the remaining well was located in a commercial/industrial area in the City of St. Cloud. Chloride concentrations increased at a much greater rate, with a median increase of 3.7 mg/L per year, in the shallow sand and gravel aquifer wells than the ones installed in bedrock aquifers, where the median increase was 1.38 mg/L per year.

Trace Elements

Trace elements are metals and semi-metals (e.g. arsenic) that usually are present at low concentrations in water. Both natural and human-caused sources contribute trace elements to the environment. Trace elements are different from most of the other contaminants discussed in this report because they naturally are present in rocks and soils. However, human activities also may release substantial amounts of them to the environment since these are present in many commonly used products such as steel and metal alloys, pigments, batteries, and electronic equipment. Under natural conditions, many of the compounds trace elements form are usually not very soluble and are not detected or measured at any appreciable concentrations in the groundwater. In water, trace elements typically are measured at concentrations less than 1 ug/L. However, under certain natural or human-caused geochemical conditions, such as low pH or low oxygen concentrations, some trace elements can be mobilized into the water and can occur at high concentrations.

The presence of trace elements in groundwater used for drinking is a concern because some may adversely affect human health or cause aesthetic problems. Some trace elements, such as arsenic, are known to be toxic. Others, like iron, are not known to cause adverse health effects but often form compounds that cause the water to be rust or black colored and stain plumbing fixtures and laundry.

Arsenic

Arsenic commonly is present in the groundwater throughout the upper Midwest. Several studies have reported high concentrations in the sand and gravel aquifers. Warner and Ayotte (2014) assessed arsenic in all of the sand and gravel aquifers formed by glacial processes across the nation from Washington State to Maine. Their investigation found that overall about 7% of the tested wells had arsenic concentrations that exceeded the Minnesota class 1 domestic consumption use standard of 10 ug/L. Concentrations, however, varied with region and depth. More than 20% of the wells sampled in the central part of the aquifer system, which includes the state of Minnesota, had concentrations that exceeded the Minnesota class 1 standard.

High concentrations of arsenic in groundwater used for drinking are a concern because this element is toxic. Inorganic arsenic is classified by the EPA as a known human carcinogen and has been linked to bladder, lung, skin, kidney, nasal passage, liver, and prostate cancer. The ingestion or skin exposure to water with high arsenic concentrations also may cause skin discoloration and lesions.

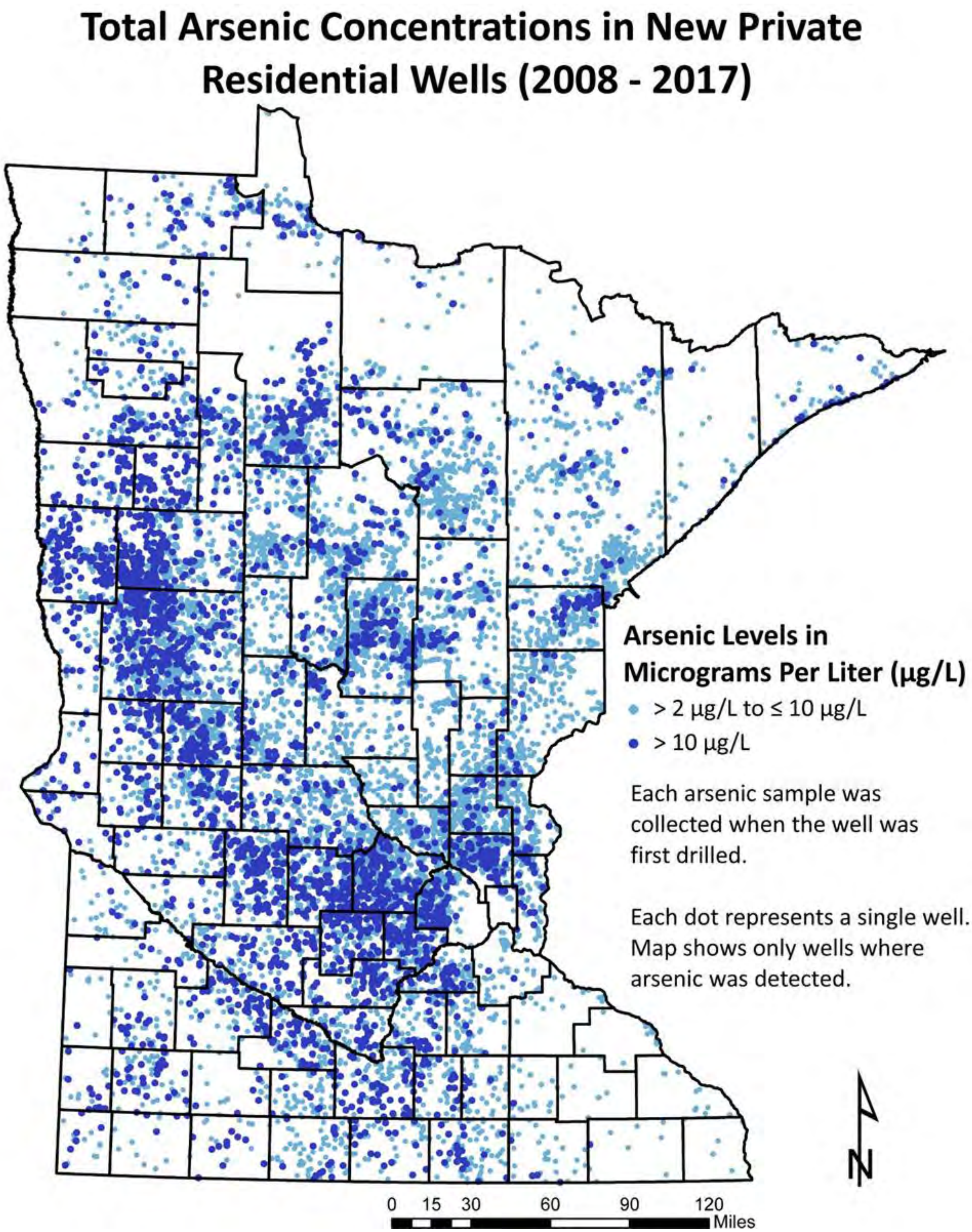
Arsenic found in Minnesota's groundwater, as well as that found elsewhere, generally is naturally occurring. In Minnesota, arsenic sorbed or "stuck" to the aquifer sediments, especially to any iron and manganese oxides that coat them, is the most important source of this element to the groundwater. Only a very small percentage of the arsenic sorbed to aquifer sediment needs to be mobilized to make water unsafe for drinking, and research in Minnesota has shown that substantial amounts of sorbed or coprecipitated arsenic can be readily released from Minnesota's aquifer sediments (Erickson and Barnes 2005a). The weathering of minerals also may naturally contribute arsenic to the groundwater. Sulfide minerals, such as arsenopyrite (FeAsS) or pyrite (FeS_2), generally are the most important sources of arsenic (Smedley and Kinniburgh 2002). Pyrite can originate from ore bodies or may be formed in aquifers and sediments when little oxygen is present.

Human activities also may occasionally contribute arsenic to the groundwater. Arsenic was used in the past to produce semiconductors and as a wood preservative (chromated copper arsenate). Arsenic also was historically applied as a pesticide, but this use has decreased over time. The EPA banned the use of lead arsenate as a pesticide in 1988 (53 Fed. Reg. 24787), and most organic arsenic pesticide uses were cancelled by the EPA in 2009 (74 Fed. Reg. 50187) (FRL-8437-7).

Some of Minnesota's groundwater contains high enough arsenic concentrations to render the water unsafe for drinking. Erickson and Barnes (2005b) found that about 14% of the sampled wells in the State have arsenic concentrations that exceed the state class 1 domestic consumption use standard of 10 ug/L. This analysis primarily was based on databases of arsenic concentrations in the groundwater that were compiled during the 1990s. A substantial number of new wells constructed in the State also are affected by high arsenic concentrations. Since 2008, the State of Minnesota has required the water from new potable water-supply wells to be tested for arsenic. The data collected from this well testing have shown that 10% of the over 20,000 new wells drilled since about 2008 have concentrations that exceeded the state class 1 standard (Minnesota Department of Health 2019a). Domestic drinking water wells, which typically supply water to a single residence, usually have higher concentrations than public water supply wells (Erickson and Barnes 2005b).

Wells with exceedances of the arsenic class 1 standard are scattered across Minnesota (Figure 14); however, some parts of the state have a high percentage of wells with water with arsenic concentrations in excess of 10 ug/L. West-Central and South-Central Minnesota are two of these regions (Minnesota Department of Health 2008, Toner et al. 2011). In West-Central Minnesota, approximately 50% of the 869 domestic drinking water wells sampled as part of MDH's Minnesota Arsenic Study had arsenic concentrations of 10 ug/L or greater (Minnesota Department of Health and United States Agency for Toxic Substances Disease Registry 2001).

Figure 14. Arsenic concentrations in new private wells in Minnesota constructed from 2008-2017 [Figure courtesy of the Minnesota Department of Health].



Research continued to identify how arsenic is naturally released from the aquifer sediments into the state's groundwater. Nicholas et al. (2017) used a novel combination of identifying the solid-phase forms of arsenic on the aquifer and confining unit sediments along with historical well water chemistry data to propose the mechanisms associated with arsenic release in the groundwater. This research confirmed that the aquitard was the source of arsenic to the groundwater at two of the three assessed sites and that arsenic was released from the aquifer sediments into the groundwater by three different mechanisms, including desorption from the sediments, reductive dissolution of iron oxides, and oxidative dissolution of iron sulfides.

Manganese

Manganese is one of the most abundant elements in rocks and soils and naturally occurs in the groundwater under the appropriate geochemical conditions. Manganese is the fifth most abundant element in the earth's crust (United States Agency for Toxic Substances Disease Registry 2008). It is found in over 100 different minerals including sulfides, oxides, carbonates, and silicates (Minnesota Ground Water Association 2015), and many of these types of minerals are present in the state's aquifers. The amount of manganese dissolved in the groundwater depends on how many manganese-bearing minerals are present in the aquifer matrix as well as its geochemical conditions.

All organisms, such as plants and animals, require some manganese to live. Manganese is an essential trace element that is needed by several enzyme systems in the human body to function properly (Kies 1987). It also is an essential nutrient needed to make carbohydrates, amino acids, and cholesterol, and it is critical for cartilage, collagen, and bone synthesis. The MDH states that children over 8 years old and adults require 1,900 to 2,600 micrograms (ug) of manganese each day and infants need 600 ug each day (Minnesota Department of Health 2019b).

Exceeding the recommended amounts of manganese is harmful to human health, especially to infants. High doses of manganese cause neurological problems similar to Parkinson's disease, such as lethargy, tremors, and slow speech (U.S. Environmental Protection Agency 2004, Minnesota Ground Water Association 2015). This myriad of health effects is referred to as "manganism" and has been found in occupationally exposed adults, such as welders and workers at dry-cell battery factories and smelters (Huang 2007). Since the early 2000s, several studies have shown the exposure of infants and young children to manganese concentrations as low as 100 ug/L in water or infant formula causes problems with learning, motor skills, as well as problems with learning, behavior, and attention (Minnesota Ground Water Association 2015).

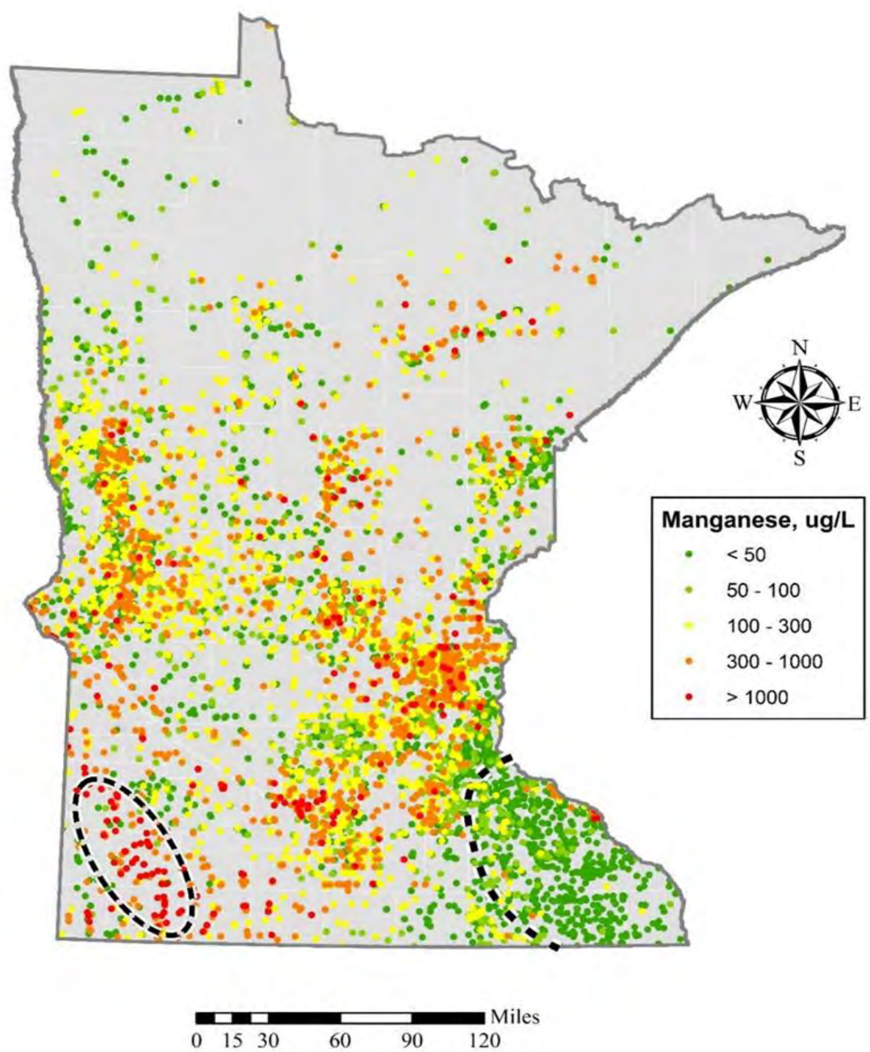
To prevent these health effects, the MDH set human health guidance for manganese in drinking water. The agency revised its human health guidance for this element in 2018 and set a health-based value (HBV) of 100 ug/L to protect children less than one year old who drink tap water or formula prepared from tap water. For households that do not include children less than one year old, the MDH states that the manganese concentration in the drinking water should be less than 300 ug/L (Minnesota Department of Health 2019b). The agency also found that water softeners may be effective at removing manganese from drinking water.

The distribution of manganese in the state's groundwater was recently assessed by the Minnesota Ground Water Association (2015) using over 8,000 records. This includes data collected by local units of government, the MPCA's ambient monitoring, the MDH's drinking water compliance and source water protection data, the DNR's County Geologic Atlas program, and the USGS's National Water-Quality Assessment. These data represent a range of aquifers that contain very young oxygenated water to those that have water that is thousands of years old.

This assessment showed that the manganese concentration in the state's groundwater is quite variable by location and aquifer. The reported concentrations ranged from less than 1 to 5,000 ug/L, and the median value was 101 ug/L. About 50% of the samples had manganese concentrations greater than 100 ug/L, and 22% had concentrations above 300 ug/L.

Concentrations in southeastern Minnesota typically were less than 50 ug/L (Figure 15). In contrast, in the southwestern part of the state concentrations typically were greater than 1,000 ug/L. An initial investigation of manganese in the state's groundwater conducted by the MDH, which used most of the same data sources as the Minnesota Ground Water Association investigation, found that manganese concentrations were higher in the state's sand and gravel aquifers compared to the Cretaceous and Paleozoic bedrock aquifers (Minnesota Department of Health 2012). The median concentrations in the state's surficial and buried artesian sand and gravel aquifers were 155 and 160 ug/L, respectively. Concentrations were lower in the Cretaceous and the bedrock aquifers composed of sandstone and carbonate rock, which had median concentrations ranging from 32 to 53 ug/L.

Figure 15. Manganese concentrations in Minnesota's groundwater [Figure from Minnesota Ground Water Association 2015].



Other Trace Elements

Many other trace elements are present to varying degrees in Minnesota's groundwater. The other trace elements routinely measured in the groundwater as part of the MPCA's Ambient Groundwater Monitoring Network, besides arsenic, iron, and manganese, are listed in table 5 along with summary statistics based on the most recent sampling of each well from 2013-2017. Similar to the results from an assessment of trace elements in all of the sand and gravel aquifers of glacial origin in the U.S. (Groschen et al. 2008), strontium and barium were the most frequently detected trace elements in the groundwater samples and lead, silver, and beryllium were detected the least, if at all.

The concentration of most of these trace elements did not exceed any applicable health guidance set by either the MDH or EPA. The MDH's 2017 risk assessment advice for boron was exceeded in water samples collected from two wells. One of these was a private drinking water well in Lyon County, and the other a monitoring well in Hennepin County. The MDH's 1994 HRL for zinc was exceeded in one shallow monitoring well in Beltrami County. This same well contained water with a cadmium concentration that approached the 2015 MDH HRL set for drinking water.

Table 5. Summary statistics of selected trace elements measured as part of the MPCA's Ambient Groundwater Monitoring Network, 2013-2017 [Summary statistics are based on the most recent sample collected from the well during this period; NA, not applicable; ND, not detected].

Element	Number of Wells with Detections	Detection Frequency	Reporting Limit	Median Concentration	Minimum Concentration	Maximum Concentration	Human health guidance
Strontium	296	98.6%	2-10 ug/L	96.8 ug/L	<2 ug/L	2,700 ug/L	3,000 ug/L[6]
Barium	266	89.9%	5-20 ug/L	46.5 ug/L	<5 ug/L	1,600 ug/L	2,000 ug/L[1,5]
Nickel	190	64.1%	1-50 ug/L	1.98 ug/L	<1 ug/L	30.1 ug/L	100 ug/L[1]
Boron	109	36.8%	20-200 ug/L	37.7 ug/L	<20 ug/L	791 ug/L	500 ug/L[2]
Chromium	81	27.5%	1-50 ug/L	1.5 ug/L	<1 ug/L	5.4 ug/L	100 ug/L[8]
Molybdenum	45	15.2%	1-5 ug/L	1.6 ug/L	<1 ug/L	8.06 ug/L	NA
Copper	43	14.5%	10-50 ug/L	21.9 ug/L	<10 ug/L	524 ug/L	1,300 ug/L[5]
Zinc	42	14.2%	10-100 ug/L	62.9 ug/L	<10 ug/L	2,060 ug/L	2000 ug/L[3]
Aluminum	32	10.8%	5-40 ug/L	46.4 ug/L	<5 ug/L	446 ug/L	NA
Cobalt	24	8.1%	1-5 ug/L	2.0 ug/L	<1 ug/L	6.6 ug/L	NA
Vanadium	19	6.4%	2-10 ug/L	3.2 ug/L	<2 ug/L	25.3 ug/L	50 ug/L[3]
Lithium	15	5.1%	20-100 ug/L	42.5 ug/L	<20 ug/L	129 ug/L	NA
Cadmium	8	2.7%	0.1-0.5 ug/L	0.18 ug/L	<0.1 ug/L	0.35 ug/L	0.5 ug/L[4] – 5 ug/L[8]
Titanium	5	1.7%	5-25 ug/L	8.0 ug/L	<5 ug/L	9.8 ug/L	NA
Lead	3	1.0%	1 ug/L	6.3 ug/L	<1 ug/L	10.8 ug/L	15 ug/L[7]
Silver	0	0.0%	0.2 – 5 ug/L	ND	<0.2 ug/L	ND	30 ug/L[1]
Beryllium	0	0%	0.4-2.0 ug/L	ND	<0.4 ug/L	ND	80 ng/L[1]- 4,000 ng/L[8]

1. MDH 1993 health risk limit
2. MDH 2017 risk assessment advice
3. MDH 1994 health risk limit
4. MDH 2015 chronic health risk limit
5. EPA primary drinking water standard
6. MDH 2019 risk assessment advice
7. EPA action level
8. Minnesota state class 1 domestic consumption use standard

The highest concentrations of barium and strontium, the two most commonly detected trace elements in the groundwater, generally occurred in parts of the state where calcareous glacial deposits were present. The concentrations of both of these trace elements had a similar pattern in the groundwater. The highest concentrations typically were measured in groundwater in the TCMA, especially Anoka and Hennepin Counties, and south central, southeastern, and western Minnesota. In these areas, barium concentrations ranged from 5.4 to 1,600 ug/L, and strontium concentrations ranged from 9.7 to 2,700 ug/L. There was a moderately strong correlation between barium and strontium concentrations (Kendall's tau-b=0.4687, p=0.0000) which suggested a common source for both elements. Data from the shallow monitoring wells in the MPCA's network found that concentrations of both elements were significantly greater in parts of the state where the sand and gravel aquifers were composed of calcareous sediments compared to those made up of siliceous materials (Table 6).

This information, combined with the general statewide distribution of both elements in the groundwater, suggested that the presence of barium and strontium in the groundwater likely was related to naturally occurring minerals in the aquifer matrix. Both elements occur in many different types of rocks. The highest barium concentrations typically occur in shale, and barium sulfate ($BaSO_4$) is the principal mineral containing this element (Salminen et al. 2006). Strontium also is known to substitute for barium in $BaSO_4$ (Salminen et al. 2006) and also is present in calcareous rocks since it readily substitutes for calcium in the component minerals. A significant correlation between sulfate concentrations and barium (tau=0.3898, p=0.0000) and strontium (tau=0.3655, p=0.0000) was found which suggested that the distributions of both of these elements may be related to the presence of sulfate minerals in the aquifer matrix.

Table 6. Median concentrations of barium and strontium in the shallow sand and gravel aquifers, 2013-2017 by glacial lobe provenance.

Element	Median Concentration in Areas with Calcareous Glacial Sediments	Median Concentration in Areas with Siliceous Glacial Sediments
Barium[1]	**51.9 ug/L**	**25.5 ug/L**
Strontium[2]	**106 ug/L**	**85.4 ug/L**

1) Barium concentrations were significantly greater in the aquifers composed of calcareous sediments compared to those with siliceous sediments (p=0.0000).
2) Strontium concentrations were significantly greater in the aquifers composed of calcareous sediments compared to those with siliceous sediments (p=0.0115).

The presence and distribution of some trace elements in the groundwater, such as nickel and chromium, may have been the result of both natural and anthropogenic factors. The analysis of the data collected from the early warning component of the MPCA's ambient monitoring network showed that concentrations of these two elements were significantly higher in the shallow groundwater underlying commercial/industrial and sewered residential areas compared to the other assessed settings. This result suggested that the increased nickel and chromium concentrations may have resulted from human uses of these metals such as in alloys, batteries, coins, and plating. These land use associations only were statistically significant for the shallow sand and gravel aquifers formed from calcareous materials. The lack of a similar statistically significant relation between these metal concentrations and land use for the aquifers composed of siliceous glacial deposits might have been related to the naturally high nickel and chromium concentrations in the soils that occur in this part of the state. In northeastern Minnesota, the high concentrations in the groundwater were consistent with soils data collected by the USGS (Smith et al. 2014) that showed the highest nickel and chromium concentrations occurred in this area.

Boron concentrations in the groundwater typically were highest in southern and western Minnesota as well as in urban areas, especially the TCMA and St. Cloud. Like nickel and chromium, human and natural sources both contribute boron to the groundwater. Chemicals containing boron have many anthropogenic uses, including cleaning aids in detergents and the manufacturing of fiberglass insulation and borosilicate glass. Boron also occurs naturally in rocks and minerals, especially evaporite minerals and sedimentary rocks formed in marine environments. Information from the early warning component of the MPCA's monitoring network found that boron concentrations varied by both the source of the glacial deposits that form the sand and gravel aquifers and land use. Concentrations were significantly greater in the shallow aquifers formed by calcareous sediments compared to those formed by siliceous sediments. This was consistent with the composition of the rocks that are the source of the state's calcareous glacial deposits, which are located to the north and west of Minnesota and contain both sedimentary rocks and evaporite deposits. Boron concentrations also varied by land use setting in the shallow groundwater. Regardless of whether the sand and gravel aquifers were composed of siliceous or calcareous materials, the boron concentrations in the shallow groundwater underlying commercial/industrial and sewered residential areas were significantly greater than those in residential areas that use SSTS and undeveloped areas, which suggested human-caused contamination.

Zinc detections in the MPCA's groundwater samples were not due to natural or human-caused contamination, but primarily were an artifact of sampling some wells with metal casings, especially galvanized steel. The high zinc concentrations in these wells likely resulted from the corrosion of the galvanized coating on the well casing, which released zinc into the well water. Zinc was detected in 42 wells from 2013-2017. The majority of these wells (35) were constructed using metal well casings, and the remainder were either constructed using plastic well casing or there was no record regarding the type of casing used. The differences in zinc concentrations among wells constructed using galvanized steel, steel, or plastic well casings were statistically significant ($p=0.000$).

The highest zinc concentrations were measured in the 13 monitoring wells that were constructed using galvanized steel casing. The median concentration in these wells was 167 ug/L, and the maximum zinc concentration reported was 2,060 ug/L.

Wells constructed using steel casing also had significantly higher zinc concentrations compared to those constructed with PVC casing. The median concentration estimated using regression on order statistics (Helsel 2005) in the steel-cased wells was 10.5 ug/L, compared to 0.02 ug/L in the wells constructed with PVC casing. Zinc only was detected in a minute number of PVC-cased wells from 2013-2017. Only five of the 206 wells tested during this period had detectable zinc concentrations in the water, and one of these wells was constructed using a steel well screen. The higher concentrations in the steel-cased wells was consistent with research showing that the water in these wells is enriched in zinc and other trace metals including cadmium, chromium, and copper (Llopis 1991).

Volatile Organic Compounds (VOCs)

VOCs comprise a wide variety of chemicals that are emitted as gases from some liquids and solids. The chemical properties of VOCs allow them to readily move between the atmosphere, soil, surface water, and groundwater. Some of these chemicals readily degrade in the environment, while others persist for decades. Most VOCs are refined from petroleum, or are otherwise synthesized, and have many industrial, commercial, and household applications. These chemicals are found in gasoline, solvents, refrigerants, and many commonly used household products such as paints, spot cleaners, and glue (McDonald et al. 2018, Nazaroff and Weschler 2004). Some VOCs also are produced when drinking water is treated with chlorine to kill organisms in the water that may cause illness.

The presence of VOCs in drinking water or indoor air is a cause for concern because many of these chemicals are toxic and can persist for long periods of time once they reach the groundwater. Some VOCs, such as trichloroethylene (TCE), are known carcinogens. Others may harm the nervous system, liver, or kidneys or cause lung and skin irritation (Minnesota Department of Health 2019c). VOCs are not naturally occurring in the groundwater, so the detection of any of these chemicals indicates human impact.

Sources and Fate of VOCs in Groundwater

VOCs readily leach into the underlying groundwater once released into the soil and degrade over time, depending on aquifer conditions. The VOCs that contain more than two chlorine atoms, such as tetrachloroethylene (PERC) or TCE, slowly degrade only when the groundwater contains no oxygen. If the groundwater is oxygenated, these chemicals typically persist for many years.

Groundwater can become contaminated by VOCs when solvents are disposed of improperly, chemical or gasoline storage tanks leak, or chemicals are spilled on soil. Prior to our understanding that VOCs could easily contaminate groundwater, these chemicals were typically disposed by burying in landfills or simply dumping them on the ground. In the 1970s, passage of the federal Resource Conservation and Recovery Act (RCRA) and its amendments made it illegal to dispose of VOCs in this manner. Waste products containing VOCs are now collected and handled as hazardous waste.

In some circumstances, VOCs present in the groundwater may migrate upward through the soil and into the basements of buildings. This phenomenon is known as vapor intrusion, and people’s health can be adversely affected by inhaling these chemical vapors. Vapor intrusion can result from spills of chlorinated solvents like TCE or petroleum-related chemicals. However, chlorinated solvents typically are the most common sources (Minnesota Pollution Control Agency 2019) because the relatively rapid degradation of petroleum-related chemicals often limits their potential for vapor intrusion (U.S. Environmental Protection Agency 2012).

Sites where large quantities of VOCs were disposed of in the past are the major focus of groundwater remediation. Over the past 20 years, state or federal programs have addressed contamination from VOCs at thousands of chemical release sites across Minnesota. The remediation efforts at these sites are managed by either federal environmental cleanup programs such as the hazardous waste (RCRA) and Superfund programs, or Minnesota state cleanup programs such as the state Superfund Program, the Voluntary Cleanup and Investigation program, and the Petroleum Remediation Program. Over the years, these remediation programs have worked on almost 21,000 sites across Minnesota. The majority of these sites no longer require active remediation and monitoring. There are about 1,700 active remediation sites in Minnesota. These sites mostly are relatively small, and most of them have a less than one acre of land where the underlying groundwater is contaminated.

The atmosphere is another source of VOCs to the groundwater. Emissions of non-combusted and partially-combusted fuels from vehicles are a major source of VOCs to the air. Non-vehicular VOC sources, however, are becoming increasingly important VOC sources as vehicle emissions have decreased over time due to pollution prevention efforts (McDonald et al. 2018). Once emitted into the air, the VOCs are quickly scavenged by raindrops (Slinn et al. 1978) and can enter the groundwater by infiltrating precipitation (Pankow et al. 1997, Yu et al. 2017). The incomplete combustion of fuels results in VOCs being deposited on surfaces (Revitt et al. 2014), which can be transported to the groundwater by infiltrating water.

Occurrence and Distribution in Minnesota's Groundwater

From 2013-2017, the MPCA sampled its ambient groundwater monitoring network for 68 different VOCs. The measured chemicals, along with common sources and the laboratory reporting limits, are listed in Appendix C.

VOCs were not detected very frequently. From 2013-2017, the MPCA tested 275 ambient network wells for these chemicals. The percentage of the sampled wells with detectable VOC concentrations ranged from 5% in 2015 to 8% in 2013 and 2014.

Detected concentrations of VOCs in ambient groundwater were typically low (less than 1 ug/L). Seventy-five percent of the VOCs detected in Minnesota's ambient groundwater were at this concentration or less. This was very similar to the results from a national-scale assessment. Zogorski et al. (2006) reported that 90% of the VOC concentrations measured throughout the U.S. were less than 1 ug/L.

Most of the VOCs detected in Minnesota's ambient groundwater were found in shallow wells. VOCs were detected at least once in 51 ambient monitoring network wells from 2013-2017, and 88% of these were monitoring wells that were screened near the water table. The median well depth was 20 feet. The water in these wells was not used for drinking. VOCs were detected in a few of the sampled bedrock aquifer wells. Six of the 39 sampled bedrock aquifer wells had VOCs detected in them. One of these wells was shallow (52 feet deep), and another one was near a known contaminant plume in the eastern TCMA.

Very few of the VOCs that were on the extensive list analyzed by the MPCA were detected in the ambient groundwater. From 2013-2017, 22 of the 68 analyzed VOCs (32%) were detected at least once during this period, and only 13 of the 68 analyzed VOCs (19%) were detected more than once (Table 7). The more frequently detected VOCs (excluding the xylenes and chloromethane) were the disinfection byproduct, chloroform; the solvents PERC, TCE, and their degradation product cis-1,2-dichloroethylene. The occurrence and distribution of these chemicals in the groundwater will be discussed more in the subsequent sections of this report.

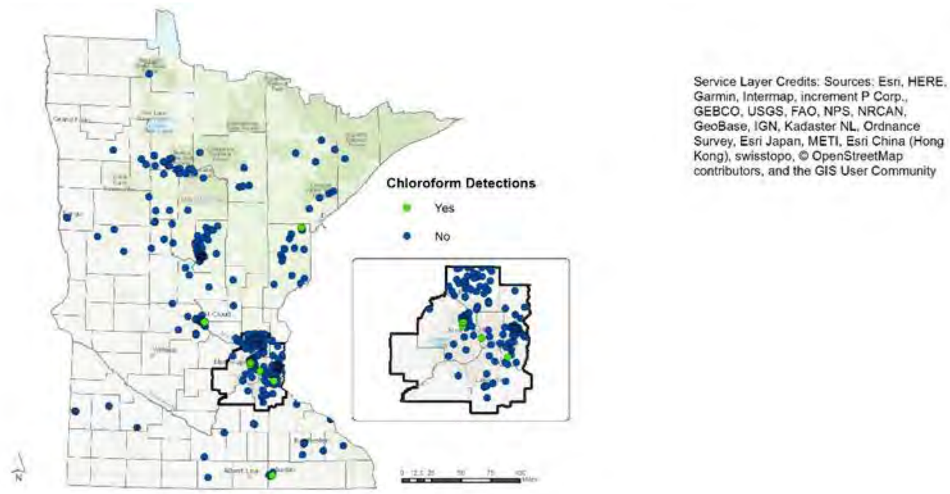
Table 7. Detection frequencies and concentration ranges for volatile organic compounds detected in the ambient groundwater, 2013-2017 [statistics are based on the most recent sampling of the well during this period].

Chemical Name	CAS Number	Median Concentration	Detection Frequency	Range in Detected Concentrations	Method Reporting Limit
Chloroform	67-66-3	0.23 ug/L	2.1 %	0.10 – 11.0 ug/L	0.1 – 0.2 ug/L
Tetrachloroethylene	127-18-4	0.55 ug/L	1.3 %	0.21 – 3.9 ug/L	0.2 – 0.4 ug/L
Trichloroethylene	79-01-6	1.0 ug/L	1.0 %	0.10 – 46.0 ug/L	0.1 – 0.2 ug/L
Cis-1,2-Dichloroethylene	156-59-2	0.64 ug/L	0.9 %	0.23 – 1.5 ug/L	0.2 – 0.4 ug/L
Toluene	108-88-3	0.62 ug/L	0.9 %	0.21 – 8.3 ug/L	0.2 – 0.4 ug/L
m-Dichlorobenzene	541-73-1	0.27 ug/L	0.5 %	0.21 – 1.3 ug/L	0.2 – 0.4 ug/L
Ethylbenzene	100-41-4	0.68 ug/L	0.4 %	0.51 – 3.2 ug/L	0.5 – 1.0 ug/L
Benzene	71-43-2	0.59 ug/L	0.3 %	0.35 – 0.91 ug/L	0.2 – 0.4 ug/L
1,1-Dichloroethane	75-34-3	0.32 ug/L	0.2 %	0.28 – 0.37 ug/L	0.2 – 0.4 ug/L
Dichlorobromomethane	75-27-4	0.99 ug/L	0.2%	0.24 – 1.0 ug/L	0.2 – 0.4 ug/L
Dichlorodifluoromethane	75-71-8	1.5 ug/L	0.2 %	1.3 – 2.1 ug/L	1.0 – 2.0 ug/L
p-Isopropyltoluene	99-87-6	0.85 ug/L	0.2 %	0.81 – 1.2 ug/L	0.5 – 1.0 ug/L
Trans-1,2-Dichloroethylene	156-60-5	0.12 ug/L	0.2 %	0.12 – 0.13 ug/L	0.1 – 0.2 ug/L
1,2,4-Trimethylbenzene	95-63-6	6.9 ug/L	0.07 %	6.90 ug/L	0.5 – 1.0 ug/L
1,3,5-Trimethylbenzene	108-67-8	1.4 ug/L	0.07 %	1.40 ug/L	0.5 – 1.0 ug/L
Acetone	67-64-1	25 ug/L	0.07 %	25 ug/L	20 – 40 ug/L
Cumene	98-82-8	1.1 ug/L	0.07 %	1.10 ug/L	0.5 – 1.0 ug/L
Methyl ethyl ketone	78-93-3	23 ug/L	0.07 %	23 ug/L	10 – 20 ug/L
n-Propylbenzene	103-65-1	2.0 ug/L	0.07 %	2.0 ug/L	0.5 – 1.0 ug/L
Naphthalene	91-20-3	1.6 ug/L	0.07 %	1.6 ug/L	1.0 – 2.0 ug/L
Sec-Butylbenzene	135-98-8	1.6 ug/L	0.07 %	1.6 ug/L	0.5 – 1.0 ug/L
Tetrahydrofuran	109-99-9	14 ug/L	0.07 %	14 ug/L	10 – 20 ug/L

Chloroform

Chloroform was the most-frequently detected VOC in Minnesota's ambient groundwater. This chemical is formed by the chlorination of drinking water, wastewater, and swimming and whirlpool water (Research Triangle Institute and United States Agency for Toxic Substances Disease Registry 1997). It also can be released into the environment during its manufacture and use. Detections of this chemical generally were sporadic. In the majority of the wells with detections, chloroform was only detected once in all of the samples collected from 2013-2017. The wells with chloroform detections also were shallow and ranged from 14 to 72 feet deep. Most of them also were constructed specifically for monitoring the groundwater. The wells with chloroform detections were mainly located in urban areas including the TCMA, St. Cloud, and a few smaller cities (Figure 16).

Figure 16. Chloroform detections in the ambient groundwater, 2013-2017 [Map shows the most recent chloroform detection at each sampled well].



The measured chloroform concentrations were all lower than the 20 ug/L HRL set by the MDH in 2018 to prevent against liver damage, developmental problems, and suppression of the immune system. Eighty-nine percent of the detected concentrations were less than 1 ug/L, and the highest concentration measured was 11 ug/L.

The use of disinfected public water and its eventual recharge into the groundwater was the likely source of the chloroform found in the ambient groundwater. The one common feature among all of the wells with any chloroform detections from 2013-2017 was that they were located in areas served by municipal water-supply systems that disinfect their water using chlorine or chloramines (Austin Utilities 2016, City of Brooklyn Center 2018, City of Baxter 2019, City of Cloquet 2018, City of St. Cloud 2018, City of Saint Paul 2018, City of Sturgeon Lake 2011, Lincoln-Pipestone Rural Water 2017, Rochester Public Utilities 2017). It is likely that some of the disinfected drinking water recharged the groundwater after it was used for activities like lawn, golf course, athletic field, and garden irrigation. Disinfected waters also may have entered the groundwater through leaking water distribution or sewer pipes.

Tetrachloroethylene

PERC was the second most-commonly detected VOC in the ambient groundwater. This chemical is a solvent whose major uses are dry cleaning and metal parts degreasing (World Health Organization 2006). The MPCA detected PERC in six wells from 2013-2017. Five of these were shallow monitoring wells (19.5 to 48 feet deep) that were located within or less than one-half mile from commercial/industrial areas. Four of these wells were located within the TCMA, and the other was located in southern Minnesota. The only other well where PERC was detected was a 133-foot deep water supply well in the eastern part of the TCMA.

None of the measured concentrations exceeded the 4 ug/L HBV set by the MDH in 2014 to prevent cancer. However, the concentration measured in one shallow monitoring well in St. Paul (3.9 ug/L) was very close to the HBV.

Only one of the tested wells had sufficient data to determine trends in PERC concentrations. This was the 133-foot deep water supply well in the eastern TCMA. The MPCA sampled this well from 2004-2017 and the concentrations did not significantly change during this period (p=0.1177).

Trichloroethylene

TCE, a solvent whose major use is to degrease metal parts, was detected in five wells from 2013-2017. Similar to the results for PERC, TCE mostly was detected in shallow monitoring wells, ranging from 16 to 48 feet deep that were located near or within commercial/industrial areas. Two of these wells also had PERC detected in them; these two wells were located a few hundred feet apart and were approximately one-half mile south of a commercial/industrial area in St. Paul. The two other monitoring wells with TCE detections were located in commercial/industrial areas in Wadena and Sherburne Counties.

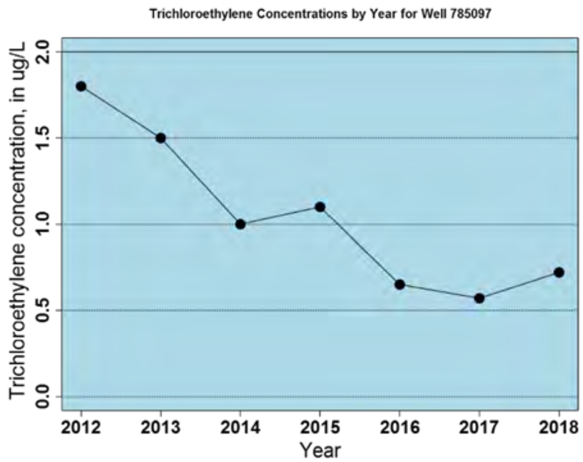
The highest TCE concentrations were measured in the two monitoring wells in St. Paul. In these wells, concentrations as high as 46 ug/L were reported.

TCE was detected in one of the sampled domestic wells. This well was 285 feet deep and was located within the TCE contamination plume that emanates from the Baytown Township Groundwater Contamination site. This well-known source of groundwater contamination in the TCMA encompasses 12.5 square miles in Washington County (Minnesota Pollution Control Agency 2007). The TCE in this well water likely was not consumed because the water samples for this study were drawn from the untreated outside water spigot, and the residence's drinking water-supply has had a carbon filter installed on it since 2004 to remove any TCE from it (K. Schroeder, Minnesota Pollution Control Agency, personal communication, 2016).

Most of the measured TCE concentrations exceeded the MDH's recently updated human health guidance. Since the MPCA published its last Groundwater Condition Report in 2013, the MDH lowered its human health guidance for TCE by more than 10 times due to new toxicity and health effects data (Minnesota Department of Health 2013). These new human health guidance values were promulgated as HRLs in 2015. The updated chronic value was lowered to 0.4 ug/L to prevent against developmental and immune system effects, such as heart defects in a developing fetus during the first trimester, hypersensitivity, or developing an autoimmune disease. The cancer value was lowered to 2 ug/L. All five of the wells with TCE detections had concentrations that exceeded the 0.4 ug/L HRL set for chronic exposure at least once from 2013-2017. In three of the five sampled wells, TCE concentrations exceeded the 2 ug/L cancer HRL set by the MDH in 2015. One of these three wells was the previously discussed well near the Baytown Township Groundwater Contamination site, and the other two were monitoring wells located south of a commercial/industrial area in St. Paul.

One of the wells had sufficient data to determine whether TCE concentrations changed over time. This was a monitoring well in Elk River, which was sampled from 2012-2017. TCE concentrations in this well have steadily decreased from 1.8 ug/L in 2012 to 0.57 ug/L in 2017, which was statistically significant (p=0.0355) (Figure 17).

Figure 17. Trichloroethlyene concentration declines at monitoring well 785097 in Sherburne County, Minnesota.



Cis-1,2-Dichloroethylene

Many of the same wells with TCE detections also had cis-1,2-dichloroethylene detected in the water. The measured concentrations all were less than the chronic HRL of 6 ug/L set by the MDH in 2018. This chemical was the fourth most-commonly detected VOC in the groundwater and is produced when TCE or PERC is degraded in the environment (World Health Organization 2006). This chemical also is used to manufacture solvents and chemical mixtures (United States Agency for Toxic Substances Disease Registry 1997). The MPCA detected cis-1,2-dichloroethylene in four monitoring wells that ranged from 15 to 48 feet deep. All of these wells were located near or within commercial/industrial areas in the City of St. Paul, Sherburne County, and Wadena County. Three of the four wells with cis-1,2-dichloroethylene detections also had TCE in them, which suggested that the cis-1,2-dichloroethylene present in these three wells may have resulted from TCE degradation.

Per - and Polyfluorinated Alkyl Substances (PFAS)

PFAS are a class of over 6,000 manmade chemicals used worldwide to manufacture products that are heat and stain resistant and repel water. These chemicals are in a wide variety of products including water- and stain-resistant fabric; carpet; coatings on paper products such as popcorn bags, chip bags, or fast-food wrappers; floor polish; personal care products; non-stick cookware; fire-fighting foam; and certain insecticides.

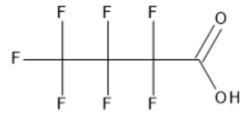
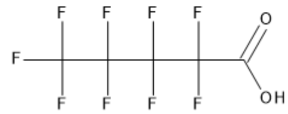
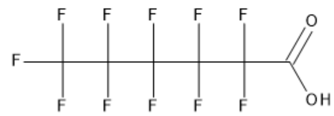
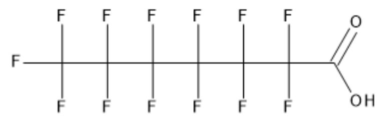
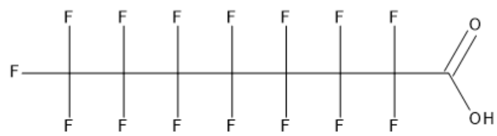
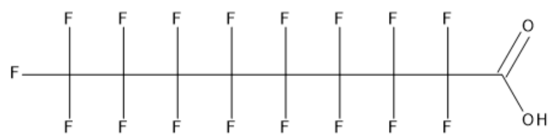
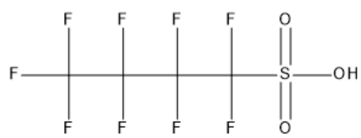
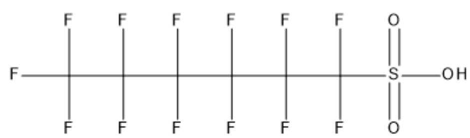
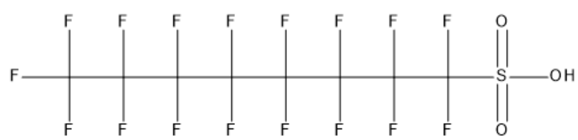
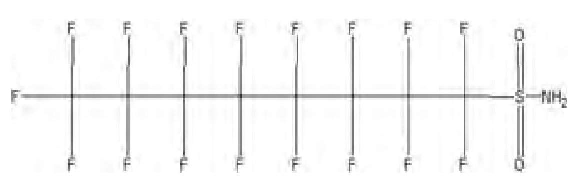
The presence of PFAS in the environment and the resulting exposure is a concern because these chemicals accumulate in humans and animals and several of them are known to be toxic. PFAS have been found in fish, reptiles, and mammals all over the globe, and these chemicals biomagnify in birds and marine mammals (Houde et al. 2011). In addition, PFAS are persistent in the environment and do not readily break down. Perfluorooctanoic acid (PFOA) and perfluorooctane sulfonate (PFOS) are the two most studied PFAS. Toxicity studies indicate these cause developmental problems to fetuses, cancer, liver damage, and immune and thyroid effects. The EPA set lifetime health advisories for PFOA and PFOS at 70 ng/L in drinking water in May 2016. In Minnesota, the MDH has established human health guidance for PFAS in drinking water since 2002, which are periodically updated after new toxicological information are published. In May 2017, the MDH revised its human health guidance for PFOA, setting a HRL of 35 ng/L. In 2019, the agency lowered its guidance for PFOS, setting a HBV of 15 ng/L. These values, much lower than EPA's, are meant to protect the health of breastfeeding infants. The MDH also has set human health guidance for three other PFAS, perfluorobutanoic acid (PFBA), perfluorobutane sulfonate (PFBS), and perfluorohexane sulfonate (PFHxS). In 2017, the MDH lowered its human health guidance for PFBS, setting a HBV of 2,000 ng/L. The agency also reevaluated its human health guidance for PFBA at the same time; however, the HRL set in 2018 remained at 7,000 ng/L. In 2019, the MDH set a HBV of 47 ng/L for PFHxS.

In Minnesota, PFAS are of particular interest because this is one of the few places in the nation where these chemicals are made. Two well-known PFAS, PFOS and PFOA, were manufactured at a 3M facility in the city of Cottage Grove from the late 1940s until 2002 when the company voluntarily phased out the production of these chemicals. The disposal of fluorochemical manufacturing wastes from this facility prior to the enactment of hazardous waste laws several decades ago caused contamination of the area's aquifers as well as surface waters and fish.

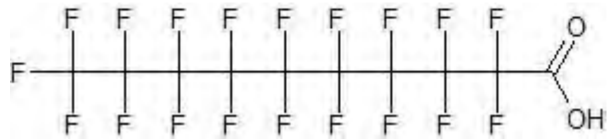
The MPCA periodically sampled the groundwater for PFAS outside of this known area with industrial contamination to determine the occurrence and distribution of these chemicals in the ambient environment. The agency sampled the ambient groundwater twice for PFAS between 2013 and 2017. The first sampling event was the largest and was conducted in 2013. During this time, the MPCA still was actively installing new wells to its monitoring network, so the PFAS investigation only included the network wells that were in existence at that time, which was almost 200. A more limited follow-up PFAS sampling was conducted in 2017. This event focused on 12 wells that had the highest concentrations in 2013 primarily to determine whether concentrations had changed.

Both of these studies measured a small number of the known PFAS. The 2013 and 2017 MPCA ambient groundwater assessments monitored for 13 PFAS; these primarily were perfluoroalkyl acids (Table 8). These PFAS consist mainly of a carboxylate (COOH) or sulfonate (SO_3H) functional group attached to a "perfluorinated chain" of varying length. The perfluoroalkyl acids that contain seven or more carbon atoms in their perfluorinated chain, such as PFOA and PFOS, are termed "long-chain PFAS" and are recognized as bioaccumulative and toxic in the environment (Scheringer et al. 2014).

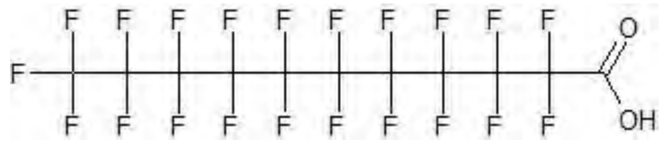
Table 8. Perfluorinated Substances Measured in the 2013 and 2017 MPCA Ambient Groundwater Assessments.

Chemical Name	Structure
Perfluorobutanoic acid (PFBA)	
Perfluoropentanoic acid (PFPeA)	
Perfluorohexanoic acid (PFHxA)	
Perfluoroheptanoic acid (PFHpA)	
Perfluorooctanoic acid (PFOA)	
Perfluorononanoic acid (PFNA)	
Perfluorobutanesulfonate (PFBS)	
Perfluorohexanesulfonate (PFHxS)	
Perfluorooctanesulfonate (PFOS)	
Perfluorooctanesulfonamide (PFOSA)	

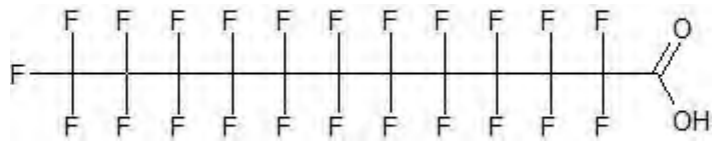
Perfluorodecanoate (PFDA)



Perfluoroundecanoate (PFUnA)



Perfluorododecanoate (PFDoDA)



The use of many of the PFAS analyzed as part of these two investigations has declined or ceased in the U.S. and other countries (Ritter 2010). Since 2006, the EPA worked with the leading companies that produce PFAS to participate in a global stewardship program to achieve the goal of eliminating PFOA and other similar chemicals with long perfluorinated chains by 2015. Long-chain PFAS are considered by the EPA to be perfluoroalkyl carboxylic acids containing eight or more carbon atoms (e.g. PFOA), and perfluoroalkylsulfonates containing six or more carbon atoms (e.g. PFHxS and PFOS). Eight long-chain PFAS were part of the 13 analyzed in the water samples for this investigation. The EPA also regulated 191 PFAS, including the long-chain PFAS, through orders and significant new use rules (U.S. Environmental Protection Agency 2019) under the Toxic Substances Control Act. Despite these changes, it still remains important to assess the presence of these types of PFAS in the environment because of their extreme persistence.

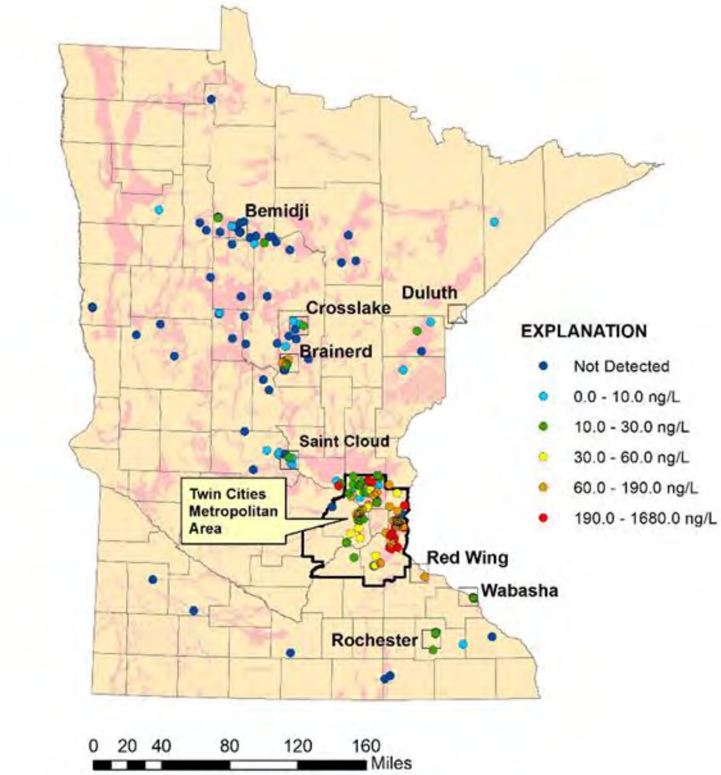
The replacement chemicals for the long-chain PFAS were not monitored in Minnesota's ambient groundwater. A number of new PFAS were developed and marketed since the phase-out of PFOA, PFOS, and their related chemicals. HFPO-DA (the major component of GenX) and ADONA are two perfluoropolyethers that are now used to manufacture fluorinated polymers. Another replacement chemical is F-53B, which is a chlorinated polyfluorinated ether sulfonate used in metal plating. F-53B has been produced for several decades but was first detected in the environment in 2013. Replacement PFAS in AFFF include fluorotelomer sulfonamide alkylbetaines and fluorotelomer sulfonamide aminoxides.

2013 Statewide Investigation

The 2013 investigation (Kroening 2017) found that PFBA was the most commonly detected PFAS in the ambient groundwater, being found in almost 70% of the sampled wells (Figure 18). Again, most of the wells sampled for this study primarily were located in areas susceptible to groundwater contamination from the land surface and contained water that was recently recharged from the land surface. The highest PFBA concentration measured was 1,680 ng/L, which was detected in a domestic water supply well in Washington County. This concentration, however, was well below the 7,000 ng/L human health limit set by the MDH.

PFAS detections and concentrations in the ambient groundwater also were associated with urban land use. The 2013 study found that one or two PFAS typically were detected in the ambient groundwater in urban areas, but these chemicals typically were not detected in the groundwater underlying forested, undeveloped areas. This suggests that most of the PFAS measured in the ambient groundwater originated from the chemicals being disposed to the land surface rather than regional atmospheric deposition.

Figure 18. Perfluorobutanoic acid in Minnesota's ambient groundwater, 2013 [Figure from Kroening (2017)].



PFOA was detected in about 30% of the wells tested in 2013. Eight of these wells contained water with concentrations that exceeded the HBV of 35 ng/L set by the MDH in 2017. Some of the wells with water exceeding the PFOA HBV were located in Washington County, where there was known industrial PFAS contamination. The concentrations in these wells ranged from 38 to 64 ng/L. The other wells with concentrations exceeding the PFOA HBV were located near the cities of Brainerd and Wabasha. The well in Brainerd, a 44-foot deep monitoring well in a residential area, contained water with a PFOA concentration of 61 ng/L. The well in the vicinity of Wabasha was a 58-foot deep domestic water supply well and contained water with a PFOA concentration of 74 ng/L.

PFOS was detected in about 12% of the sampled wells tested in 2013, and seven of these wells contained water with concentrations that exceeded the 15 ng/L HBV set by the MDH in 2019. Four of the wells with concentrations exceeding the HBV were located in the TCMA, and the remaining three were located in the vicinity of the cities of Brainerd and Wabasha. The highest PFOS concentrations (98 – 98.8 ng/L) were measured in two shallow monitoring wells (15-19 feet deep) in Anoka and Hennepin Counties. The two wells in the vicinity of Brainerd with exceedances of the PFOS HBV also were shallow (18-44 feet deep) and intersected the water table. The 44-foot deep well near Brainerd was the same one that contained water with a PFOA concentration that exceeded the MDH HBV. Two of the sampled domestic water supply wells contained water with PFOS concentrations that exceeded the HBV. One of these wells was located near the known industrial contamination in Washington County, and the other was a 66-foot deep domestic water supply well in the vicinity of Wabasha. The well near the City of Wabasha was located in the same neighborhood as the domestic well that had a PFOA concentration that exceeded the HBV.

PFHxS was detected in about 11 percent of the wells sampled in 2013. Three of the sampled wells contained water with concentrations greater than 47 ng/L, the HBV set by MDH in 2019. Two of the wells with concentrations exceeding the HBV were shallow monitoring wells (16-18 feet deep) in the TCMA, and the other was a shallow monitoring well (44 feet deep) located in the vicinity of Brainerd.

A couple of the sampled wells had a notable number of PFAS detections or high concentrations of some of the chemicals. All of the 13 analyzed PFAS were measured in the 44-foot deep monitoring well in the vicinity of Brainerd that also contained the high PFOA, PFOS, and PFHxS concentrations. This well also contained the highest measured PFPeA (87.4 ng/L) and PFHpA (123 ng/L) concentrations. A monitoring well in Anoka County contained water with the highest PFHxS (3,580 ng/L) and PFBS concentrations (555 ng/L) measured in the 2013 investigation. The PFHxS concentration in this well was over 10 times greater than those measured of any other sampled wells.

2017-Limited Follow-up Sampling

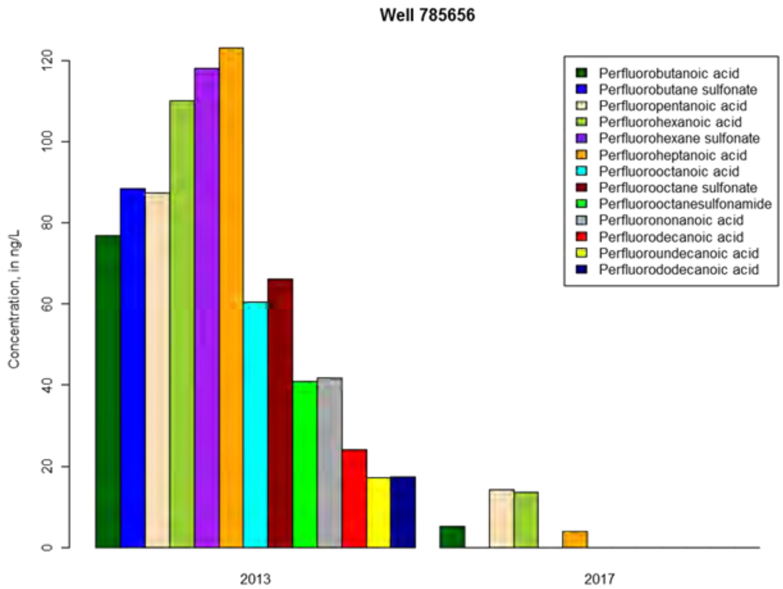
The limited follow-up sampling in 2017 showed that PFAS detections and concentrations did not remain the same in many of the resampled wells. Changes in the occurrence and distribution of these chemicals in the ambient groundwater were not unexpected since the types of PFAS used in products changed over the last 10 years. In addition, most of the sampled wells intersected the water table and contained very young groundwater that would be expected to respond rapidly to changes in pollutant inputs. Even the few deep domestic water-supply wells that were resampled were located in aquifers that are vulnerable to contamination from the land surface.

This sampling showed that the number of PFAS detections drastically declined in the monitoring well located near the City of Brainerd that had all 13 analyzed PFAS were detected in it in 2013. Only four PFAS were detected in this well in 2017, and the measured concentrations were at least five times lower than the concentrations measured in 2013 (Figure 19, Table 9).

Table 9. Concentrations of selected PFAS measured in well 785656 in Crow Wing County in 2013 and 2017.

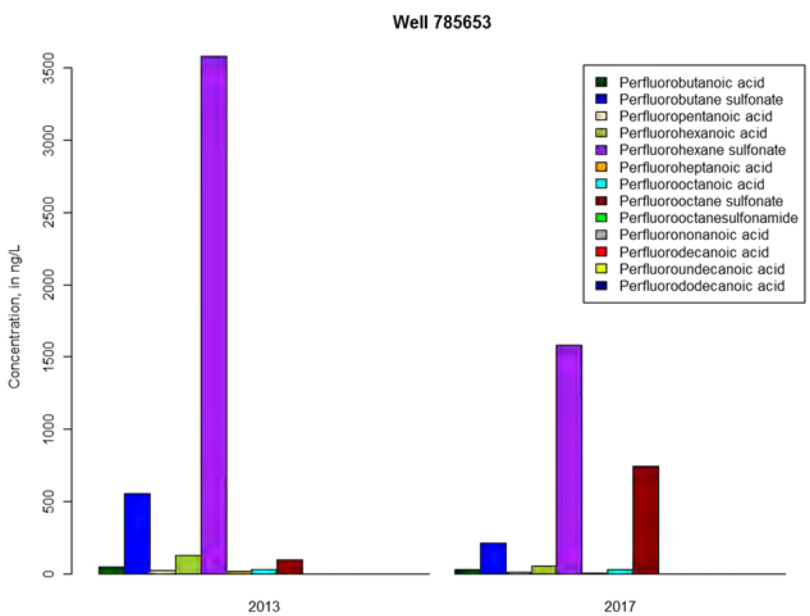
Chemical	2013 Concentration	2017 Concentration
PFBA	76.9 ng/L	5.2 ng/L
PFPeA	87.4 ng/L	14.3 ng/L
PFHxA	110 ng/L	13.5 ng/L
PFHpA	123 ng/L	3.96 ng/L

Figure 19. PFAS concentrations in monitoring well 785656 in Crow Wing County, 2013 and 2017



Large changes in PFAS concentrations also were seen in a shallow monitoring well in Anoka County. In 2013, this well had the highest measured PFHxS concentration (3,580 ng/L); however, the concentration decreased by more than one-half to 1,580 ng/L in 2017 (Figure 20). The concentrations of a few other PFAS in this well also had notable declines from 2013 to 2017. The PFBS concentration in this well decreased from 555 to 215 ng/L, and the PFHxA concentration decreased from 124 to 50.7 ng/L.

Figure 20. PFAS detections in monitoring well 785653 in Anoka County, 2013 and 2017.



This same well, however, showed an increase in the PFOS concentration. In 2017, the concentration in this well increased substantially to 745 ng/L. This was over 25 times greater than the HBV set by MDH in 2017. The exact cause of the increased concentration in this well was not known, but it might have been due to the use of products in which PFOS still is permitted, such as mist suppressants for plating operations, or the use old stocks of PFOS-containing chemicals.

The 2017 resampling also showed that PFHxS, PFOA, or PFOS concentrations decreased by more than one-half in most of the wells sampled outside of Washington County (Table 10). The domestic water-supply wells near Wabasha that contained water with PFOA or PFOS concentrations that exceeded the 2017 HBVs set by the MDH could not be accessed for resampling. Another water supply well in the same vicinity of these two wells was resampled in 2017, and the PFOS concentration in it decreased by more than one-half from 2013-2017.

The concentrations of most of these chemicals largely stayed the same or even increased in the monitoring and domestic water-supply wells in Washington County. The PFOA and PFOS concentrations increased by more than 50% in one monitoring well in Washington County (well #778336, Table 10).

Table 10. PFHxS, PFOA, and PFOS concentrations measured in selected wells in 2013 and 2017.

Well	County	PFHxS		PFOA		PFOS	
		2013	2017	2013	2017	2013	2017
404244	Washington	<5.68	<5.0	8.51-12.8	14.6	<4.72-7.05	8.66
406163	Washington	< 4.93	5.12	29.3	27.3	31.4	29
474571	Wabasha	< 4.51	< 5.1	2.49	< 2.55	23.2	10.6
560422	Hennepin	337	27.3	25	12.4	45.9	16.9
560426	Hennepin	26.6	39.1	11.4	5.6	98.8	114
778334	Washington	9.23	11.2	45.1	67.8	< 5.01	< 4.83
778336	Washington	< 5.22	6.76	26.7	69.2	10.3	63.1
778353	Washington	<6.11	<4.89	43.8	29.2	< 6.11	< 4.89
785653	Anoka	3580	1580	26.7	26.4	98	745
785656	Crow Wing	118	<5.03	60.5	<2.52	66.1	< 5.03
786964	Crow Wing	9.99	<4.83	7.58	2.64	59.4	14.6

Contaminants of Emerging Concern

Contaminants of Emerging Concern (CECs) are synthetic or naturally occurring chemicals that have not been commonly monitored or regulated in the environment. Common classes of these chemicals include antibiotics, detergents, fire retardants, hormones, personal care products, and pharmaceuticals. CECs are not necessarily newly manufactured chemicals. In some cases, the release of these chemicals into the environment has occurred for a long time, but laboratory techniques sensitive enough to detect them in the environment only were developed within the last decade.

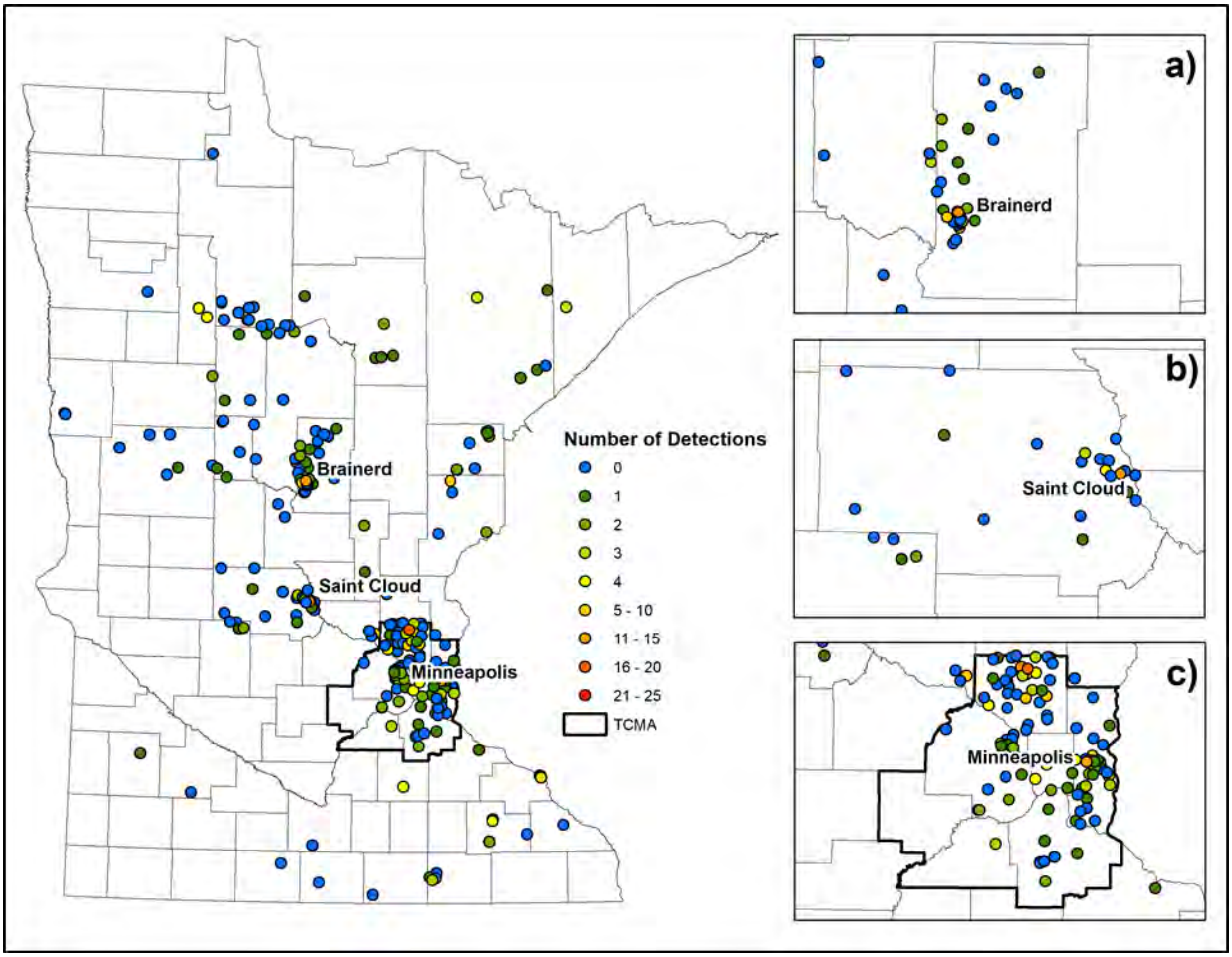
The release of CECs into the environment is of a particular concern because they may affect ecological or human health. The effect of chronic exposure to low levels of most of these chemicals to human or aquatic life often is not known. In addition, some of these chemicals function as endocrine active chemicals (EACs). EACs are natural or synthetic chemicals that mimic or block the function of the natural hormone systems in humans and animals. EACs also are referred to as endocrine disrupting chemicals or EDCs in the scientific literature; however, scientists are increasingly adopting the usage of the term EAC as a more accurate description for contaminants that affect the endocrine system.

The MPCA has analyzed water samples collected from its Ambient Groundwater Monitoring Network for CECs since 2009. Due to the high cost of these chemical analyses, only a subset of the network wells (about 40) were sampled each year for this suite of chemicals. From 2009-2014, US Geological Survey laboratories in Denver, Colorado and Lawrence, Kansas analyzed the MPCA's groundwater samples for a suite of over 200 CECs. Since 2015, the groundwater samples have been analyzed for 132 CECs by SGS

AXYS Analytical Services in British Columbia. This change was made to maintain consistency between the CECs analyzed in the agency's groundwater and surface water monitoring programs. A complete list of contaminants analyzed and the analytical methods are included in Appendix D.

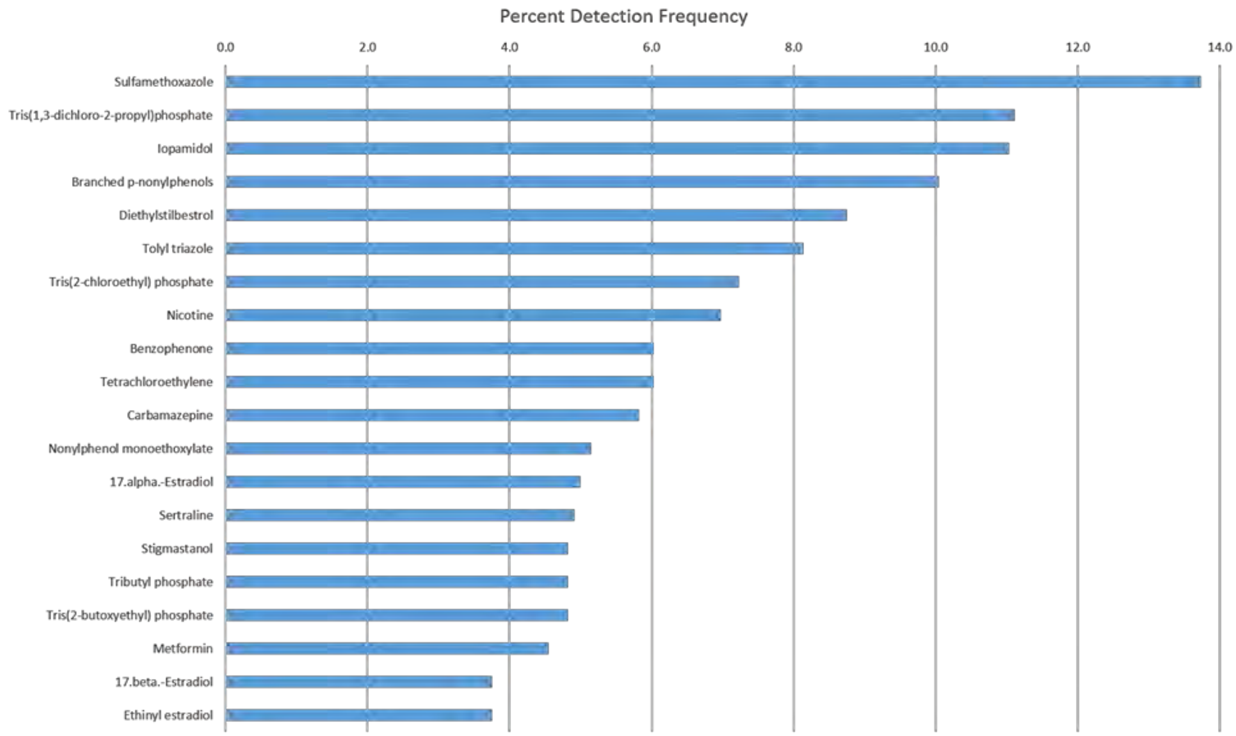
CECs were detected in a substantial number of the network wells, which again mainly were located in settings that are naturally vulnerable to human-caused pollution. From 2013-2017, CECs were detected in 124 of the 262 wells sampled for these chemicals (Figure 21). The number of CEC detections in these wells ranged from one to 23. The two wells with the greatest number of detections specifically were installed to monitor contamination near old, unlined landfills, which are a known CEC source (Cordy et al. 2004, Masoner et al. 2016). The number of CEC detections was smaller in most of the other sampled wells. Ninety-five percent of the sampled wells had seven or fewer CEC detections in them, and the average number detected in a well was 1.6.

Figure 21. Number of contaminants of emerging concern detected in the ambient groundwater statewide and in three urban areas, 2013-2017. a) Brainerd, b) Saint Cloud, and c) Minneapolis-St. Paul Metropolitan Area



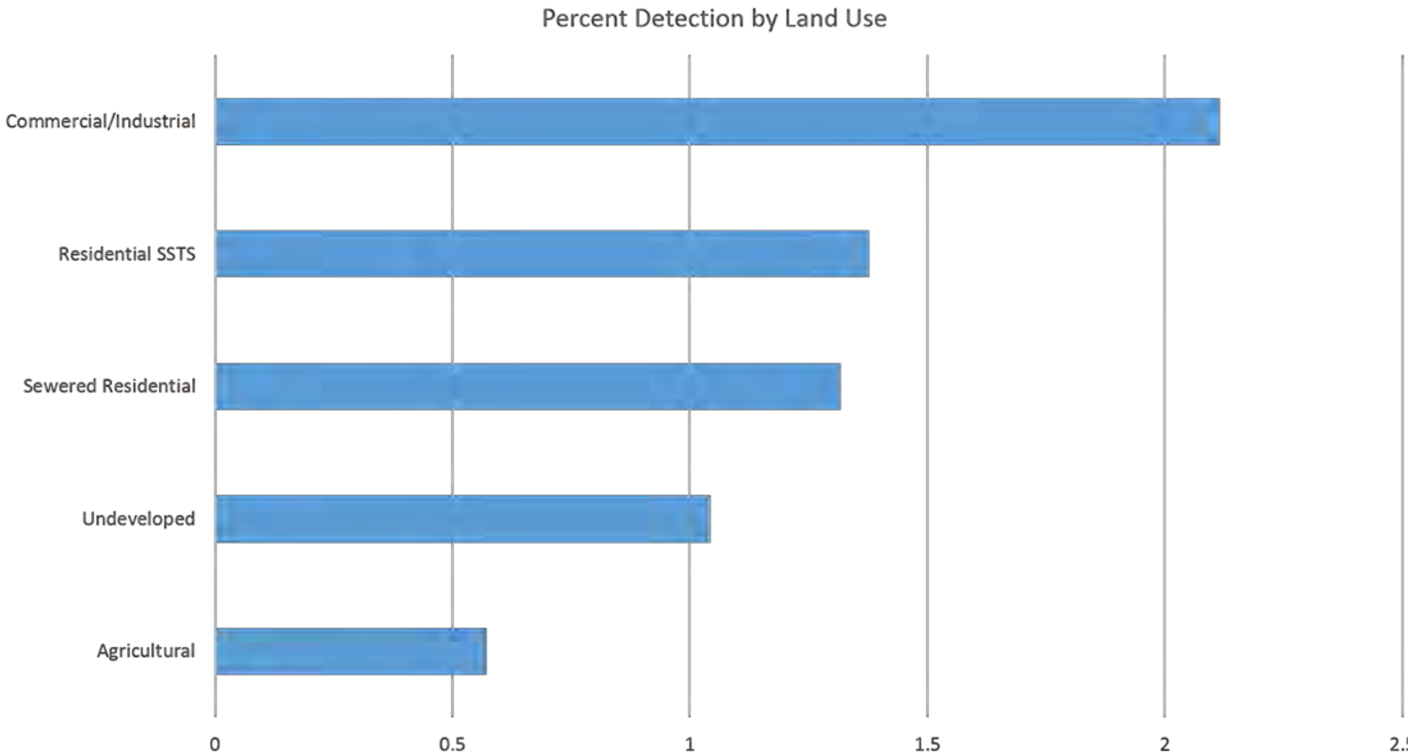
The most commonly detected CECs in the ambient groundwater were chemicals that are known to be persistent in the environment. Seventy-seven CECs were detected in the groundwater from 2013-2017 with frequency of 1.0% and greater. The most-frequently detected CECs were sulfamethoxazole, tris (1,3-dichloro-2-propyl)phosphate (TDCPP), iopamidol, and branched p-nonylphenols (Figure 22). These chemicals have very different uses. Sulfamethoxazole is an antibiotic used to treat bacterial infections. Iopamidol is a radio-opaque contrast agent, which is used for x-ray imaging, such as computed tomography (CTs), projectional radiography, and fluoroscopy. TDCPP is a chlorinated organophosphate and is commonly used as a flame retardant as well as a pesticide, plasticizer, and nerve gas. Branched p-nonylphenols are not a single chemical but a mixture of nonylphenols (U.S. Environmental Protection Agency 2010). These chemicals consist of a phenol ring that typically has a branched nonylphenol group attached to it in the *para*- position. The main use of nonylphenols is to manufacture nonanionic surfactants and nonylphenol ethoxylates (NPE), but they also are found in lubricants. NPE was used to make both household and industrial detergents; however, its use in household detergents has been eliminated (U.S. Environmental Protection Agency 2010). Nonylphenols also are considered an EAC. Common features among these four CECs is that they are widely used, resistant to degradation, and persist in the environment (Ternes and Hirsch 2000, Mao et al. 2012, Saint-Hilaire and Jans 2013, Wendel et al. 2014). All detections were within the applicable human health limits set by the EPA and MDH.

Figure 22. Detection frequencies for selected CECs in the ambient groundwater, 2013-2017.



Land use also was a factor in the number of CECs detected in the groundwater. To better understand the effect of land use on the occurrence of CECs in the groundwater, the data from the MPCA's early warning subnetwork and data collected from fifteen wells in the MDA's ambient monitoring network in 2015 was analyzed. The MDA network wells selected for sampling generally were located in the immediate vicinity of confined animal feeding operations, although none were specifically installed to monitor contamination emanating from a known plume. The results indicate that commercial/industrial land use had the greatest percent detection of CECs (2.12%), followed by residential SSTS (1.38%), sewered residential (1.32%), undeveloped land use (1.04%), and agricultural (0.57%) (Figure 23). This assessment of CECs did not assess other settings susceptible to contamination, such as feedlot plumes (Meyer et al. 2000) or agricultural lands amended with biosolids from wastewater treatment facilities (Kinny et al. 2006).

Figure 23. Percent detection of CECs by land use [the number next to each bar is the number of wells]



Pesticides

Pesticides are chemical substances, biological agents, or mixtures of substances that prevent, destroy, repel, or lessen the damage of any pest. Pesticides often are used to control weeds, insects, and plant diseases. Many agricultural producers use pesticides to protect crops and increase yields. Homeowners and municipalities use pesticides to manage pests around homes and in lawns, gardens, and parklands. Lake managers and lakeshore owners also use pesticides at times to control aquatic plants or other aquatic organisms that are causing nuisance conditions.

The MDA's ambient groundwater program monitoring data from 2017 showed that herbicide degradates were the most frequently detected pesticide-related compound (Minnesota Department of Agriculture 2018). Over sixty-five percent of the detections were degradates of acetochlor, alachlor, atrazine, metolachlor, and metribuzin. These pesticides have been placed in "common detection" status by the MDA. The common detection designation triggers heightened scrutiny and management activities, such as the development and promotion of pesticide-specific best management practices (BMPs). Three neonicotinoid insecticides (clothianidin, imidacloprid, and thiamethoxam), as well as the fungicide metalaxyl, were also among the top pesticide detections, based on the 2017 MDA groundwater data. These compounds were detected in eight to 16% of the groundwater samples that were analyzed.

The MDA's Private Well Pesticide Sampling (PWPS) Project has also showed that the majority of the wells sampled had a pesticide detection. Based on the data collected in 2017 for the PWPS project, pesticides were detected in 64% of the wells (Minnesota Department of Agriculture 2018). Thirty-eight percent of the well water samples had between two to six pesticide detections. Herbicide degradates were also the type of pesticide that was detected most frequently in the private well groundwater samples. Much like the wells in the agency's ambient groundwater monitoring network, the private wells sampled were located in agricultural areas considered to be vulnerable to contamination from the land surface.

Pesticide concentrations in the state's groundwater generally did not exceed any applicable human health-based guidance set by the MDH. No concentrations measured in the MDA's ambient groundwater monitoring network in 2017 exceeded an applicable MDH human health-based guidance. Only two of the 1,103 samples collected as part of the MDA's PWPS Project had a pesticide concentration that was greater than a human health-based guidance value. It should be noted, however, that confirmation sampling performed later at these two wells showed that the pesticides in question were not detected.

Appendix A

Regional Kendall Nitrate Temporal Trends Test Results

Trend Test Results for Nitrate Concentrations in the Ambient Groundwater by Selected Major Watersheds, 2005-2017

Region	Number of Sites	Rate of Change per year (in mg/L/year)	Kendall's tau	p-value
Minnesota River Basin	8	0.0000	-0.0633	0.3026
Lower Mississippi River Basin	9	0.0263	0.1536	0.0263
Red River Basin	13	0.0000	-0.0564	0.2551
Twin Cities Metropolitan Area	29	0.0000	-0.1013	0.0054
Upper Mississippi River Basin	55	-0.0005	-0.0274	0.2637

There were insufficient data in the Big Sioux and Rock, Des Moines, Little Sioux, Rainy, St. Croix, Upper Iowa, Wapsipnicon, and Western Lake Superior River Basins to determine temporal trends in nitrate concentrations in the ambient groundwater.

Trend Test Results for Nitrate Concentrations in the Ambient Groundwater by Selected Major Watersheds, 2005-2017

Land Use	Number of Sites	Rate of Change per year (in mg/L/year)	Kendall's tau	p-value
Agricultural	55	0.0000	-0.0217	0.3754
Sewered Residential	14	0.0000	-0.0924	0.0695

There were insufficient data in the commercial/industrial, residential areas using subsurface sewage treatment systems for wastewater treatment and disposal, and undeveloped areas for trend analysis.

Appendix B

Chloride Concentrations in the Galena and St. Peter aquifers, 2013-2017

Figure B 1. Chloride concentrations in the Galena Aquifer, 2013-2017.

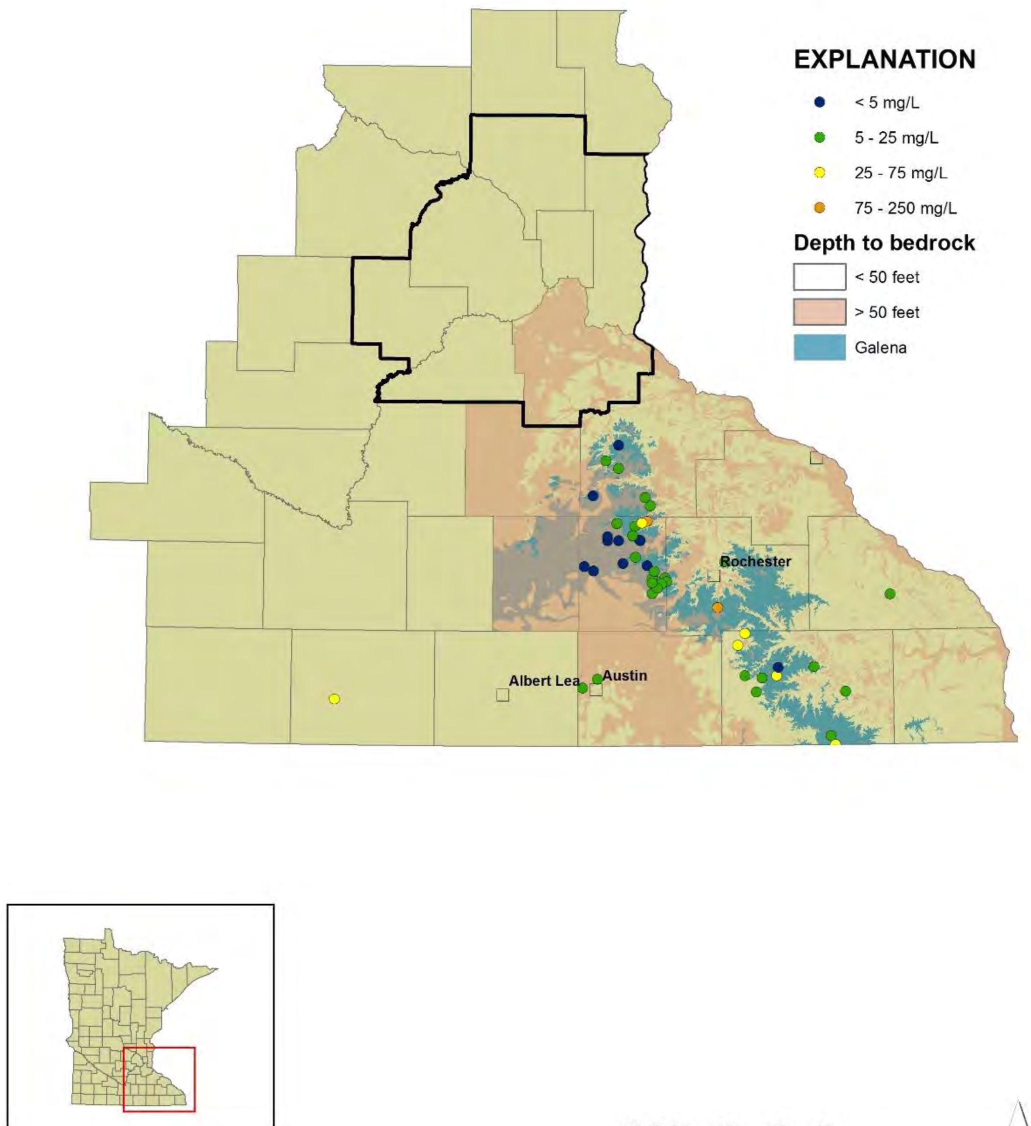
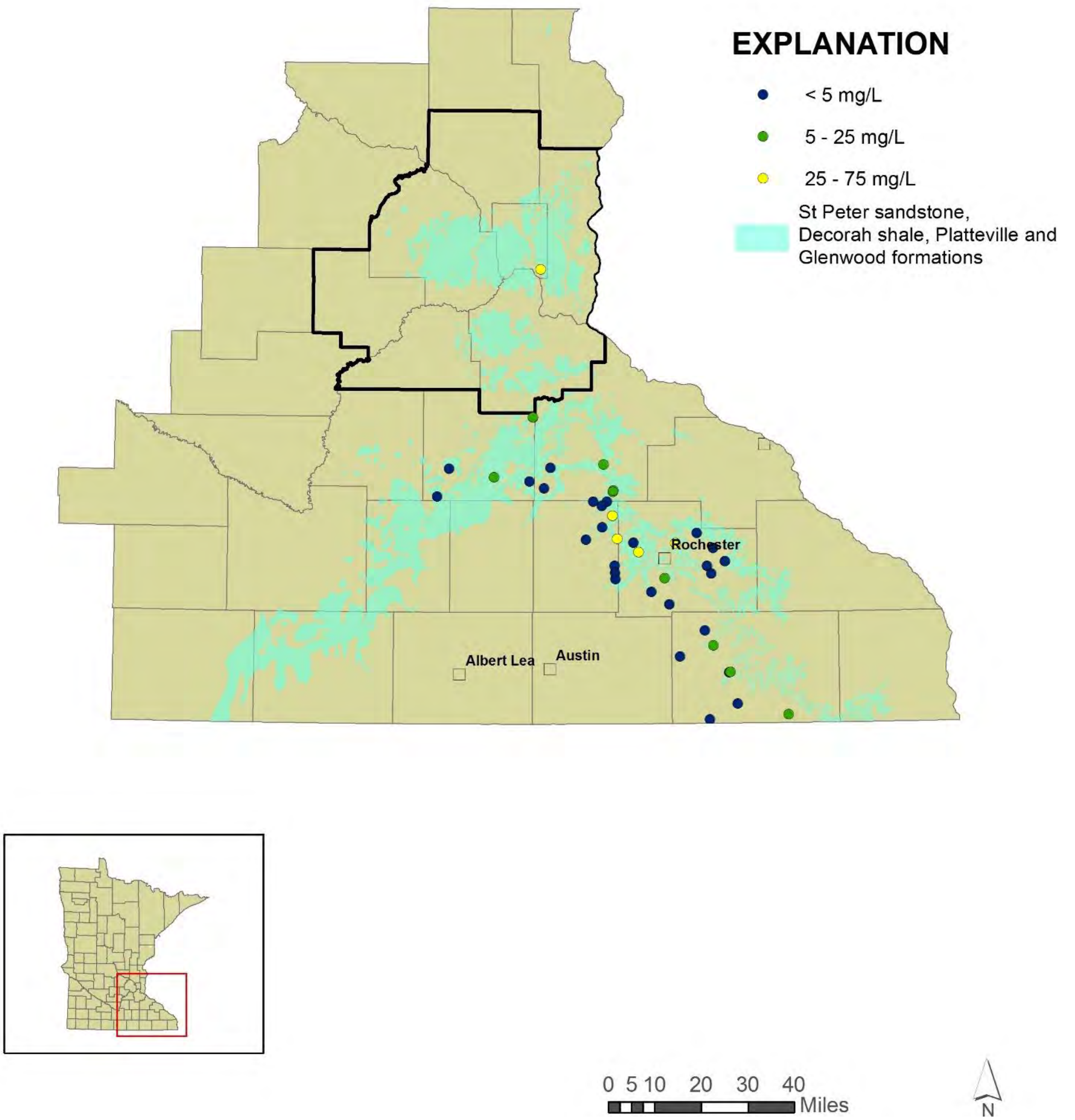


Figure B 2. Chloride concentrations in the St. Peter Aquifer, 2013-2017.



Appendix C

Volatile Organic Compounds Analyzed in Water Samples Collected for the Minnesota Pollution Control Agency's Ambient Groundwater Monitoring Network, 2013-2017

Chemical	CAS number	Reporting Limit	Human health guidance value	Use/Source
1,1,1,2-Tetrachloroethane	630-20-6	0.2 – 0.4 ug/L	70 ug/L (HRL_{93})	Solvent and in the production of wood stains and varnishes
1,1,1-Trichloroethane	71-55-6	0.2 – 0.4 ug/L	5,000 ug/L (HRL_{18})	Solvent
1,1,2,2-Tetrachloroethane	79-34-5	0.2 - 0.4 ug/L	2 ug/L (HRL_{94})	Solvent, Refrigerant
1,1,2-Trichloroethane	79-00-5	0.2 – 0.4 ug/L	3 ug/L (HRL_{93})	Solvent, Chemical synthesis
1,1-Dichloroethane	75-34-3	0.2 – 0.4 ug/L	80 ug/L (RAA_{16})	Chemical synthesis, Solvent, Degreaser
1,1-Dichloroethylene	75-35-4	0.5 – 1.0 ug/L	200 ug/L (HRL_{11})	Chemical synthesis
1,1-Dichloropropene	563-58-6	0.2 – 0.4 ug/L		Not available
1,2,3-Trichlorobenzene	87-61-6	1-2 ug/L		Solvent
1,2,3-Trichloropropane	96-18-4	0.5 – 1 ug/L	0.003 ug/L (HRL_{13})	Solvent
1,2,4-Trichlorobenzene	120-82-1	0.5 – 1 ug/L	4 ug/L (HRL_{13})	Solvent
1,2,4-Trimethylbenzene	95-63-6	0.5 – 1 ug/L	30 ug/L (HBV_{19})	Occurs naturally in coal tar and petroleum, Gasoline additive, Sterilizing agent, Manufacture of dyes, perfumes, and resins
1,2-Dibromo-3-chloropropane	96-12-8	2 – 4 ug/L		Soil fumigant
1,2-Dichloroethane	107-06-2	0.2 – 0.4 ug/L		Chemical synthesis, Solvent
1,2-Dichloropropane	78-87-5	0.2 – 0.4 ug/L	5 ug/L (HRL_{94})	Chemical synthesis, Soil Fumigant, Solvent
1,3,5-Trimethylbenzene	108-67-8	0.5 – 1.0 ug/L	30 ug/L (HBV_{19})	Solvent, Combustion product
1,3-Dichloropropane	142-28-9	0.2 – 0.4 ug/L		Soil Fumigant, Nematicide
2,2-Dichloropropane	594-20-7	0.5 – 1.0 ug/L		Not available
Acetone	67-64-1	20 – 40 ug/L	3,000 ug/L (HBV_{17})	Solvent, Active ingredient in nail polish remover

Chemical	CAS number	Reporting Limit	Human health guidance value	Use/Source
Allyl Chloride	107-05-1	0.5 – 1.0 ug/L	30 ug/L (HRL_{94})	Chemical synthesis
Benzene	71-43-2	0.2 – 0.4 ug/L	2 ug/L (HRL_{09})	Natural constituent of crude oil, gasoline, and cigarette smoke; Chemical synthesis
Bromobenzene	108-86-1	0.2 – 0.4 ug/L		Chemical synthesis
Carbon Tetrachloride	56-23-5	0.2 – 0.4 ug/L	1 ug/L (HRL_{13})	Chemical synthesis, Solvent, Refrigerant
CFC-11 (trichlorofluoromethane)	75-69-4	0.5 – 1.0 ug/L	2,000 ug/L (HRL_{93})	Refrigerant
CFC-113	76-13-1	0.2 - 0.4 ug/L		Refrigerant
CFC-12 (dichlorodifluoromethane)	75-71-8	1 – 2 ug/L	500 ug/L (RAA_{17})	Refrigerant
Chlorobenzene	108-90-7	0.2 – 0.4 ug/L	100 ug/L (HRL_{93})	Chemical synthesis, Solvent
Chlorodibromomethane	124-48-1	0.5 – 1.0 ug/L	10 ug/L (HRL_{93})	Disinfection byproduct, Flame retardant
Chloroethane	75-00-3	0.5 – 1.0 ug/L	Narrative RAA_{16}	Chemical synthesis
Chloroform	67-66-3	0.1 – 0.2 ug/L	20 ug/L (HRL_{18})	Disinfection byproduct, Chemical synthesis, Solvent
Chloromethane	74-87-3	1 – 2 ug/L		Disinfection byproduct, Refrigerant, Chemical Synthesis
cis-1,2-Dichloroethylene	156-59-2	0.2 – 0.4 ug/L	6 ug/L (HRL_{18})	Degradation product of tetrachloroethylene or trichloroethylene
cis-1,3-Dichloropropene	10061-01-5	0.2 – 0.4 ug/L		Soil Fumigant
Cumene (isopropyl benzene)	98-82-8	0.5 – 1.0 ug/L	300 ug/L (HRL_{93})	Constituent of crude oil and gasoline
Dibromomethane	74-95-3	0.5 – 1.0 ug/L		Disinfection byproduct, Solvent, Chemical synthesis
Dichlorobromomethane	75-27-4	0.2 – 0.4 ug/L	3 ug/L (HBV_{18})	Disinfection byproduct, Flame retardant
Ethyl ether	60-29-7	2 – 4 ug/L	200 ug/L (RAA_{16})	Solvent
Ethylbenzene	100-41-4	0.5 – 1.0 ug/L	40 ug/L (HBV_{19})	Constituent in crude oil and gasoline
Ethylene dibromide	106-93-4		0.004 ug/L (HRL_{93})	Gasoline additive, Fumigant
Halon 1011 (bromochloromethane)	74-97-5	0.5 – 1.0 ug/L		Refrigerant

Chemical	CAS number	Reporting Limit	Human health guidance value	Use/Source
HCFC-21 (dichlorofluoromethane)	75-43-4	0.5 – 1.0 ug/L	20 ug/L (RAA_{17})	Refrigerant
Hexachlorobutadiene	87-68-3	1 – 2 ug/L	1 ug/L (HRL_{93})	Chemical synthesis, Solvent
m-Dichlorobenzene	541-73-1	0.2 – 0.4 ug/L		Chemical synthesis
Methyl bromide	74-83-9	1 – 2 ug/L	10 ug/L (HRL_{93})	Soil fumigant
Methyl ethyl ketone	78-93-3	10 – 20 ug/L	4,000 ug/L (HRL_{94})	Solvent
Methyl isobutyl ketone	108-10-1	5 – 10 ug/L	300 ug/L (HRL_{94})	Solvent
Methyl tert-butyl ether	1634-04-4	2 – 4 ug/L	60 ug/L (RAA_{13})	Gasoline additive
Methylene Chloride	75-09-2	0.5 – 1.0 ug/L	5 ug/L (HRL_{MCL})	Solvent, Chemical synthesis, Degreaser
Naphthalene	91-20-3	1 – 2 ug/L	70 ug/L (HRL_{13})	Natural constituent of coal and crude oil, Mothballs
n-Butylbenzene	104-51-8	0.5 – 1.0 ug/L		Not available
n-Propylbenzene	103-65-1	0.5 – 1.0 ug/L		Chemical synthesis, Solvent, Textile dyeing and printing, Fuel combustion
o-Chlorotoluene	95-49-8	0.5 – 1.0 ug/L		Solvent, Chemical synthesis
o-Dichlorobenzene	95-50-1	0.2 – 0.4 ug/L	600 ug/L (HRL_{93})	Solvent, Chemical Synthesis
o-Xylene	95-47-6	0.2 – 0.4 ug/L	300 ug/L (HRL_{11})	Constituent of crude oil and gasoline
p-Chlorotoluene	106-43-4	0.5 – 1.0 ug/L		Solvent, Chemical synthesis
p-Cymene (p-isopropyl toluene)	99-87-6	0.5 – 1.0 ug/L		Gasoline or oil combustion
p-Dichlorobenzene	106-46-7	0.2 – 0.4 ug/L	10 ug/L (HRL_{94})	Fumigant, Deodorant
sec-Butylbenzene	135-98-8	0.5 – 1.0 ug/L		Constituent of gasoline, Solvent, Chemical synthesis
tert-Butylbenzene	98-06-6	0.5 – 1.0 ug/L		Chemical synthesis, Solvent
Tetrachloroethylene	127-18-4	0.2 – 0.4 ug/L	4 ug/L (HBV_{14})	Solvent, Degreaser
Tetrahydrofuran	109-99-9	10 – 20 ug/L	600 ug/L (HRL_{18})	Solvent, Chemical synthesis
Toluene	108-88-3	0.2 – 0.4 ug/L	200 ug/L (HRL_{11})	Constituent of crude oil and gasoline, Solvent, Chemical synthesis

Chemical	CAS number	Reporting Limit	Human health guidance value	Use/Source
trans-1,2-Dichloroethylene	156-60-5	0.1 – 0.2 ug/L	40 ug/L (HRL_{13})	Degradation product of tetrachloroethylene or trichloroethylene
trans-1,3-Dichloropropene	10061-02-6	0.2 – 0.4 ug/L		Fumigant, Nematicide,
Tribromomethane (Bromoform)	75-25-2	0.5 – 1.0 ug/L	40 ug/L (HRL_{93})	Disinfection byproduct
Trichloroethylene	79-01-6	0.1 – 0.2 ug/L	0.4 ug/L (HRL_{15})	Solvent, Degreaser
Vinyl chloride	75-01-4	0.2 – 0.4 ug/L	0.2 ug/L (HRL_{18})	Chemical synthesis; Degradation product of tetrachloroethylene or trichloroethylene
meta and para Xylene mix	179601-23-1	0.3 – 0.6 ug/L	300 ug/L (HRL_{11})	Constituent of crude oil and gasoline
Styrene	100-42-5	0.5 – 1.0 ug/L		Chemical synthesis

Appendix D

Contaminants of Emerging Concern Analyzed in Water Samples Collected for the Minnesota Pollution Control Agency's Ambient Groundwater Monitoring Network, 2013-2017

Chemical name	CAS number	Analytical method	Reporting limit
Menthol	89-78-1	USGS METHOD O-1433-01	320 ng/L
beta-Sitosterol	83-46-5	USGS METHOD O-1433-01	4000 ng/L
Galaxolide	1222-05-5	USGS METHOD O-1433-01	52 ng/L
1,7-Dimethylxanthine	611-59-6	SGS AXYS METHOD MLA-075	58.1 - 120.0 ng/L
		USGS RESEARCH METHOD 9017	87.7 ng/L
		USGS METHOD O-2080-08	100 ng/L
		USGS METHOD O-2440-14	87.7 ng/L
11-Ketotestosterone	564-35-2	USGS METHOD 2434	2.0 ng/L
17 α-Estradiol	57-91-0	USGS METHOD 2434	0.8 ng/L
17 β-Estradiol	50-28-2	USGS METHOD 2434	0.8 ng/L
1-Methylnaphthalene	90-12-0	USGS METHOD O-1433-01	22 ng/L
2,6-Dimethylnaphthalene	581-42-0	USGS METHOD O-1433-01	60 ng/L
2-Methylnaphthalene	91-57-6	USGS METHOD O-1433-01	36 ng/L
3-Methylindole	83-34-1	USGS METHOD O-1433-01	36 ng/L
4-Androstenedione	63-05-8	USGS METHOD 2434	0.8 ng/L
4-tert-Octylphenol	140-66-9	USGS METHOD O-1433-01	0.14 µg/L
4-tert-Octylphenol diethoxylate	2315-61-9	USGS METHOD O-1433-01	1,000 ng/L
4-tert-Octylphenol monoethoxylate	2315-67-5	USGS METHOD O-1433-01	1,000 ng/L
5-Methyl-1H-Benzotriazole	136-85-6	USGS METHOD O-1433-01	1,200 ng/L
Abacavir	136470-78-5	USGS RESEARCH METHOD 9017	8.21 ng/L
		USGS METHOD O-2440-14	8.21 ng/L
Acetaminophen	103-90-2	SGS AXYS METHOD MLA-075	14.5-30.0 ng/L
		USGS RESEARCH METHOD 9017	7.13 ng/L
		USGS METHOD O-2080-08	120 ng/L
		USGS METHOD O-2440-14	7.13-80.0 ng/L
Acetophenone	98-86-2	USGS METHOD O-1433-01	400 ng/L
Acyclovir	59277-89-3	USGS RESEARCH METHOD 9017	22.2 ng/L
		USGS METHOD O-2440-14	22.2 ng/L
AHTN	21145-77-7	USGS METHOD O-1433-01	28 ng/L
Albuterol	18559-94-9	SGS AXYS METHOD MLA-075	0.293-3.28 ng/L
		USGS RESEARCH METHOD 9017	6.06 ng/L

Chemical name	CAS number	Analytical method	Reporting limit
		USGS METHOD O-2080-08	80 ng/L
		USGS METHOD O-2440-14	6.7 ng/L
Alprazolam	28981-97-7	SGS AXYS METHOD MLA-075	0.281-0.589 ng/L
		USGS RESEARCH METHOD 9017	21.3 ng/L
		USGS METHOD O-2440-14	21.3 ng/L
Amitriptyline	50-48-6	SGS AXYS METHOD MLA-075	0.281-6.98 ng/L
		USGS RESEARCH METHOD 9017	37.2 ng/L
		USGS METHOD O-2440-14	37.2-80.0 ng/L
Amlodipine	88150-42-9	SGS AXYS METHOD MLA-075	1.41-2.95 ng/L
Amphetamine	300-62-9	SGS AXYS METHOD MLA-075	1.47-2.41 ng/L
		USGS RESEARCH METHOD 9017	8.14 ng/L
		USGS METHOD O-2440-14	8.14-80.0 ng/L
Amsacrine	51264-14-3	SGS AXYS METHOD MLA-075	0.0750-4.33 ng/L
Androsterone	53-41-8	USGS METHOD 2434	0.8-3.13 ng/L
Anthracene	120-12-7	USGS METHOD O-1433-01	10 ng/L
Anthraquinone	84-65-1	USGS METHOD O-1433-01	160 ng/L
Antipyrine	60-80-0	USGS RESEARCH METHOD 9017	116 ng/L
		USGS METHOD O-2440-14	116 ng/L
Atenolol	29122-68-7	SGS AXYS METHOD MLA-075	0.586-2.07 ng/L
		USGS RESEARCH METHOD 9017	13.3 ng/L
		USGS METHOD O-2440-14	13.3-80.0 ng/L
Atorvastatin	134523-00-5	SGS AXYS METHOD MLA-075	1.47-5.39 ng/L
Atrazine	1912-24-9	USGS RESEARCH METHOD 9017	19.4 ng/L
		USGS METHOD O-2440-14	19.4 ng/L
Azathioprine	446-86-6	SGS AXYS METHOD MLA-075	1.87-4.15 ng/L
Azithromycin	83905-01-5	SGS AXYS METHOD MLA-075	1.45-5.14 ng/L
		USGS OGRL LCAB	5 ng/L
Benzo[a]pyrene	50-32-8	USGS METHOD O-1433-01	60 ng/L
Benzophenone	119-61-9	USGS METHOD O-1433-01	80 ng/L
Benzoylecgonine hydrate	519-09-5	SGS AXYS METHOD MLA-075	0.281-0.589 ng/L
Benztropine	86-13-5	SGS AXYS METHOD MLA-075	0.469-3.33 ng/L
		USGS RESEARCH METHOD 9017	15.8 ng/L
		USGS METHOD O-2440-14	24.0 ng/L
Betamethasone	378-44-9	SGS AXYS METHOD MLA-075	1.41-9.82 ng/L
		USGS RESEARCH METHOD 9017	114.0 ng/L
		USGS METHOD O-2440-14	114.0 ng/L
Bisphenol A	80-05-7	SGS AXYS METHOD MLA-075	469.0-538.0 ng/L
		AXYS METHOD MLA-082	1.08-5.76 ng/L
		USGS METHOD 2434	100.0 ng/L
Branched p-nonylphenols	84852-15-3	AXYS METHOD MLA-004	0.918-9.78 ng/L

Chemical name	CAS number	Analytical method	Reporting limit
		USGS METHOD O-1433-01	2,000 ng/L
Bromacil	314-40-9	USGS METHOD O-1433-01	360 ng/L
Bupropion	34911-55-2	USGS RESEARCH METHOD 9017	17.8-20.0 ng/L
		USGS METHOD O-2440-14	17.8 ng/L
Busulfan	55-98-1	SGS AXYS METHOD MLA-075	2.09-19.3 ng/L
Butylated hydroxyanisole	25013-16-5	USGS METHOD O-1433-01	600 ng/L
Caffeine	58-08-2	SGS AXYS METHOD MLA-075	14.5-30.0 ng/L
		USGS RESEARCH METHOD 9017	90.7 ng/L
		USGS METHOD O-1433-01	60 ng/L
		USGS METHOD O-2080-08	60 ng/L
		USGS METHOD O-2440-14	90.7-128.0 ng/L
Camphor	76-22-2	USGS METHOD O-1433-01	44 ng/L
Carbadox	6804-07-5	SGS AXYS METHOD MLA-075	1.45-9.1 ng/L
Carbamazepine	298-46-4	SGS AXYS METHOD MLA-075	1.47-3.0 ng/L
		USGS RESEARCH METHOD 9017	4.18 ng/L
		USGS OGRL LCAB	5 ng/L
		USGS METHOD O-2080-08	60 ng/L
		USGS METHOD O-2440-14	11.0 ng/L
Carbaryl	63-25-2	USGS METHOD O-1433-01	160 ng/L
Carbazole	86-74-8	USGS METHOD O-1433-01	30 ng/L
Carisoprodol	78-44-4	USGS RESEARCH METHOD 9017	12.5 ng/L
		USGS METHOD O-2440-14	12.5-80.0 ng/L
Cefotaxime	63527-52-6	SGS AXYS METHOD MLA-075	1.89-43.3 ng/L
Chloramphenicol	56-75-7	USGS OGRL LCAB	100 ng/L
Chlorpheniramine	132-22-9	USGS RESEARCH METHOD 9017	4.68 ng/L
		USGS METHOD O-2440-14	4.68 ng/L
Chlorpyrifos	2921-88-2	USGS METHOD O-1433-01	160 ng/L
Chlortetracycline	57-62-5	USGS OGRL LCAB	10 ng/L
Cholesterol	57-88-5	USGS METHOD 2434	200.0 ng/L
		USGS METHOD O-1433-01	2,000 ng/L
Cimetidine	51481-61-9	SGS AXYS METHOD MLA-075	0.593-1.25 ng/L
		USGS RESEARCH METHOD 9017	27.8 ng/L
		USGS METHOD O-2440-14	27.8-80.0 ng/L
Ciprofloxacin	85721-33-1	SGS AXYS METHOD MLA-075	5.81-57.3 ng/L
		USGS OGRL LCAB	5 ng/L
Citalopram	59729-33-8	SGS AXYS METHOD MLA-075	0.375-3.31 ng/L
		USGS RESEARCH METHOD 9017	6.58 ng/L
		USGS METHOD O-2440-14	6.58-80.0 ng/L
Clarithromycin	81103-11-9	SGS AXYS METHOD MLA-075	1.45-3.0 ng/L
Clinafloxacin	105956-97-6	SGS AXYS METHOD MLA-075	6.03-91.0 ng/L

Chemical name	CAS number	Analytical method	Reporting limit
Clonidine	4205-90-7	SGS AXYS METHOD MLA-075	1.47-2.41 ng/L
		USGS RESEARCH METHOD 9017	60.8 ng/L
		USGS METHOD O-2440-14	60.8-80.0 ng/L
Clotrimazole	23593-75-1	SGS AXYS METHOD MLA-075	0.375-0.796 ng/L
Cloxacillin	61-72-3	SGS AXYS METHOD MLA-075	2.9-6.0 ng/L
Cocaine	50-36-2	SGS AXYS METHOD MLA-075	0.141-0.402 ng/L
Codeine	76-57-3	SGS AXYS METHOD MLA-075	2.93-4.82 ng/L
		USGS RESEARCH METHOD 9017	88.3 ng/L
		USGS METHOD O-2080-08	46 ng/L
		USGS METHOD O-2440-14	88.3 ng/L
Colchicine	64-86-8	SGS AXYS METHOD MLA-075	0.787-17.5 ng/L
Coprostanol	360-68-9	USGS METHOD 2434	200.0 ng/L
		USGS METHOD O-1433-01	1,800 ng/L
Cotinine	486-56-6	SGS AXYS METHOD MLA-075	1.47 - 2.41 ng/L
		USGS RESEARCH METHOD 9017	6.37 ng/L
		USGS METHOD O-1433-01	800 ng/L
		USGS METHOD O-2080-08	38 ng/L
		USGS METHOD O-2440-14	6.37-80.0 ng/L
Cumene	98-82-8	USGS METHOD O-1433-01	300 ng/L
Cyclophosphamide	50-18-0	SGS AXYS METHOD MLA-075	0.75-1.66 ng/L
Daunomycin	20830-81-3	SGS AXYS METHOD MLA-075	7.5-26.5 ng/L
DEET	134-62-3	SGS AXYS METHOD MLA-075	0.805-6.48 ng/L
		USGS METHOD O-1433-01	60 ng/L
Dehydronifedipine	67035-22-7	SGS AXYS METHOD MLA-075	0.581-2.08 ng/L
		USGS RESEARCH METHOD 9017	24.5 ng/L
		USGS METHOD O-2080-08	80 ng/L
		USGS METHOD O-2440-14	24.5 ng/L
Desmethyldiltiazem	84903-78-6	SGS AXYS METHOD MLA-075	0.141 - 2.5 ng/L
		USGS RESEARCH METHOD 9017	12.4 ng/L
		USGS METHOD O-2440-14	12.4 ng/L
Desvenlafaxine	93413-62-8	USGS RESEARCH METHOD 9017	7.49 ng/L
		USGS METHOD O-2440-14	7.49 ng/L
Dextromethorphan	125-71-3	USGS RESEARCH METHOD 9017	8.2 ng/L
		USGS METHOD O-2440-14	8.2 ng/L
Diatrizoic acid	117-96-4	SGS AXYS METHOD MLA-075	22.5-218.0 ng/L
Diazepam	439-14-5	SGS AXYS METHOD MLA-075	0.281-1.02 ng/L
		USGS RESEARCH METHOD 9017	2.24 ng/L
		USGS METHOD O-2440-14	2.24-4.0 ng/L
Diazinon	333-41-5	USGS METHOD O-1433-01	160 ng/L
Diethylstilbestrol	56-53-1	USGS METHOD 2434	0.8 ng/L

Chemical name	CAS number	Analytical method	Reporting limit
Digoxigenin	1672-46-4	SGS AXYS METHOD MLA-075	5.93-267.0 ng/L
Digoxin	20830-75-5	SGS AXYS METHOD MLA-075	5.81-20.8 ng/L
Dihydrotestosterone	521-18-6	USGS METHOD 2434	4.0 ng/L
Diltiazem	42399-41-7	SGS AXYS METHOD MLA-075	0.29-1.02 ng/L
		USGS RESEARCH METHOD 9017	10.2 ng/L
		USGS METHOD O-2080-08	60 ng/L
		USGS METHOD O-2440-14	10.2-80.0 ng/L
Diphenhydramine	58-73-1	SGS AXYS METHOD MLA-075	0.581-2.05 ng/L
		USGS RESEARCH METHOD 9017	5.79 ng/L
		USGS METHOD O-2080-08	58 ng/L
		USGS METHOD O-2440-14	5.79 ng/L
D-Limonene	5989-27-5	USGS METHOD O-1433-01	80 ng/L
Doxorubicin	23214-92-8	SGS AXYS METHOD MLA-075	22.5-47.8 ng/L
Doxycycline	564-25-0	USGS OGRL LCAB	10 ng/L
Drospirenone	67392-87-4	SGS AXYS METHOD MLA-075	7.5 - 16.4 ng/L
Duloxetine	136434-34-9	USGS RESEARCH METHOD 9017	36.6 ng/L
		USGS METHOD O-2440-14	36.6-80 ng/L
Enalapril	75847-73-3	SGS AXYS METHOD MLA-075	0.293-3.03 ng/L
Enrofloxacin	93106-60-6	SGS AXYS METHOD MLA-075	2.9-30.8 ng/L
		USGS OGRL LCAB	5 ng/L
Epi-chlorotetracycline	14297-93-9	USGS OGRL LCAB	10 ng/L
Epi-iso-chlorotetracycline	EICTC	USGS OGRL LCAB	10 ng/L
Epi-oxytetracycline	14206-58-7	USGS OGRL LCAB	10 ng/L
Epitestosterone	481-30-1	USGS METHOD 2434	2.0 ng/L
Epi-tetracycline	23313-80-6	USGS OGRL LCAB	10 ng/L
Equilenin	517-09-9	USGS METHOD 2434	2.0 ng/L
Equilin	474-86-2	USGS METHOD 2434	8.0 ng/L
Erythromycin	114-07-8	USGS RESEARCH METHOD 9017	53.1 ng/L
		USGS OGRL LCAB	8 ng/L
		USGS METHOD O-2440-14	53.1-200.0 ng/L
Erythromycin-H20	114078-H2O	SGS AXYS METHOD MLA-075	2.23-4.6 ng/L
		USGS OGRL LCAB	5 ng/L
Estriol	50-27-1	USGS METHOD 2434	2.0 ng/L
Estrone	53-16-7	USGS METHOD 2434	0.8-4.87 ng/L
Ethinyl estradiol	57-63-6	USGS METHOD 2434	0.8-1.05 ng/L
Etoposide	33419-42-0	SGS AXYS METHOD MLA-075	1.87 - 4.01 ng/L
Ezetimibe	163222-33-1	USGS RESEARCH METHOD 9017	63.5 ng/L
		USGS METHOD O-2440-14	63.5-200.0 ng/L
Fadrozole	102676-47-1	USGS RESEARCH METHOD 9017	7.32 ng/L
		USGS METHOD O-2440-14	7.32 ng/L

Chemical name	CAS number	Analytical method	Reporting limit
Famotidine	76824-35-6	USGS RESEARCH METHOD 9017	10.7 ng/L
		USGS METHOD O-2440-14	10.7-80.0 ng/L
Fenofibrate	49562-28-9	USGS RESEARCH METHOD 9017	6.28 ng/L
		USGS METHOD O-2440-14	6.28-80.0 ng/L
Fexofenadine	83799-24-0	USGS RESEARCH METHOD 9017	19.9 ng/L
		USGS METHOD O-2440-14	19.9 ng/L
Fluconazole	86386-73-4	USGS RESEARCH METHOD 9017	71.0 ng/L
		USGS METHOD O-2440-14	71.0-80.0 ng/L
Flumequine	42835-25-6	SGS AXYS METHOD MLA-075	1.45-5.24 ng/L
Fluocinonide	356-12-7	SGS AXYS METHOD MLA-075	5.62-52.8 ng/L
Fluoranthene	206-44-0	USGS METHOD O-1433-01	24 ng/L
Fluoxetine	54910-89-3	SGS AXYS METHOD MLA-075	1.45-5.22 ng/L
		USGS RESEARCH METHOD 9017	26.9 ng/L
		USGS METHOD O-2440-14	26.9-80.0 ng/L
Fluticasone propionate	80474-14-2	SGS AXYS METHOD MLA-075	1.87-3.93 ng/L
		USGS RESEARCH METHOD 9017	4.62 ng/L
		USGS METHOD O-2440-14	4.62-80.0 ng/L
Fluvoxamine	54739-18-3	USGS RESEARCH METHOD 9017	53.8 ng/L
		USGS METHOD O-2440-14	53.8-200.0 ng/L
Furosemide	54-31-9	SGS AXYS METHOD MLA-075	37.5-134.0 ng/L
Gemfibrozil	25812-30-0	SGS AXYS METHOD MLA-075	1.41-1.62 ng/L
Glipizide	29094-61-9	SGS AXYS METHOD MLA-075	5.62-6.46 ng/L
		USGS RESEARCH METHOD 9017	34.6 ng/L
		USGS METHOD O-2440-14	148.0 ng/L
Glyburide	10238-21-8	SGS AXYS METHOD MLA-075	2.81-3.23 ng/L
		USGS RESEARCH METHOD 9017	3.95 ng/L
		USGS METHOD O-2440-14	3.95-4.0 ng/L
Hydrochlorothiazide	58-93-5	SGS AXYS METHOD MLA-075	11.7-66.8 ng/L
Hydrocodone	125-29-1	SGS AXYS METHOD MLA-075	1.48-3.03 ng/L
		USGS RESEARCH METHOD 9017	10.5 ng/L
		USGS METHOD O-2440-14	10.5-80.0 ng/L
Hydrocortisone	50-23-7	SGS AXYS METHOD MLA-075	56.2-118.0 ng/L
		USGS RESEARCH METHOD 9017	147.0 ng/L
		USGS METHOD O-2440-14	147.0 ng/L
10-hydroxy-amitriptyline	1159-82-6	SGS AXYS METHOD MLA-075	0.141-0.343 ng/L
		USGS RESEARCH METHOD 9017	8.3 ng/L
		USGS METHOD O-2440-14	8.3 ng/L
2-hydroxy-ibuprofen	51146-55-5	SGS AXYS METHOD MLA-075	75.0-193.0 ng/L
Hydroxyzine	68-88-2	USGS RESEARCH METHOD 9017	7.43 ng/L
		USGS METHOD O-2440-14	7.43 ng/L

Chemical name	CAS number	Analytical method	Reporting limit
Ibuprofen	15687-27-1	SGS AXYS METHOD MLA-075	14.1-41.1 ng/L
		USGS OGRL LCAB	0.05 µg/L
Iminostilbene	256-96-2	USGS RESEARCH METHOD 9017	145.0 ng/L
		USGS METHOD O-2440-14	145.0-200.0 ng/L
Indole	120-72-9	USGS METHOD O-1433-01	80 ng/L
Iopamidol	60166-93-0	SGS AXYS METHOD MLA-075	75.0-529.0 ng/L
Isoborneol	124-76-5	USGS METHOD O-1433-01	80 ng/L
Iso-chlorotetracycline	514-53-4	USGS OGRL LCAB	32 ng/L
Isophorone	78-59-1	USGS METHOD O-1433-01	32 ng/L
Isoquinoline	119-65-3	USGS METHOD O-1433-01	46-800 ng/L
Ketoconazole	65277-42-1	USGS RESEARCH METHOD 9017	113.0 ng/L
		USGS METHOD O-2440-14	113.0 ng/L
Lamivudine	134678-17-4	USGS RESEARCH METHOD 9017	16.1 ng/L
		USGS METHOD O-2440-14	16.1-80.0 ng/L
Lidocaine	137-58-6	USGS RESEARCH METHOD 9017	15.2 ng/L
		USGS METHOD O-2440-14	15.2 ng/L
Lincomycin	154-21-2	SGS AXYS METHOD MLA-075	2.9-6.0 ng/L
		USGS OGRL LCAB	5 ng/L
Lomefloxacin	98079-51-7	SGS AXYS METHOD MLA-075	2.9-30.5 ng/L
		USGS OGRL LCAB	5 ng/L
Loperamide	53179-11-6	USGS RESEARCH METHOD 9017	11.5 ng/L
		USGS METHOD O-2440-14	11.5 ng/L
Loratadine	79794-75-5	USGS RESEARCH METHOD 9017	6.95 ng/L
		USGS METHOD O-2440-14	6.95 ng/L
Lorazepam	846-49-1	USGS RESEARCH METHOD 9017	116 ng/L
		USGS METHOD O-2440-14	116.0-200.0 ng/L
Medroxyprogesterone acetate	71-58-9	SGS AXYS METHOD MLA-075	3.75-10.1 ng/L
Melphalan	148-82-3	SGS AXYS METHOD MLA-075	23.2-289.0 ng/L
Meprobamate	57-53-4	SGS AXYS METHOD MLA-075	3.75-7.85 ng/L
		USGS RESEARCH METHOD 9017	86.0 ng/L
		USGS METHOD O-2440-14	86.0 ng/L
Mestranol	72-33-3	USGS METHOD 2434	0.8-1.11 ng/L
Metalaxyl	57837-19-1	USGS METHOD O-1433-01	120 ng/L
Metaxalone	1665-48-1	USGS RESEARCH METHOD 9017	15.6 ng/L
		USGS METHOD O-2440-14	15.6-80.0 ng/L
Metformin	657-24-9	SGS AXYS METHOD MLA-075	2.98-29.5 ng/L
		USGS RESEARCH METHOD 9017	13.1-20.0 ng/L
		USGS METHOD O-2440-14	13.1 ng/L
Methadone	76-99-3	USGS RESEARCH METHOD 9017	7.61 ng/L
		USGS METHOD O-2440-14	7.61-80.0 ng/L

Chemical name	CAS number	Analytical method	Reporting limit
Methocarbamol	532-03-6	USGS RESEARCH METHOD 9017	8.72 ng/L
		USGS METHOD O-2440-14	8.72-10.0 ng/L
Methotrexate	59-05-2	USGS RESEARCH METHOD 9017	52.4 ng/L
		USGS METHOD O-2440-14	52.4-80.0 ng/L
Methyl salicylate	119-36-8	USGS METHOD O-1433-01	44 ng/L
Methylprednisolone	83-43-2	SGS AXYS METHOD MLA-075	3.75-24.2 ng/L
Metolachlor	51218-45-2	USGS METHOD O-1433-01	28 ng/L
Metoprolol	51384-51-1	SGS AXYS METHOD MLA-075	1.45-17.7 ng/L
		USGS RESEARCH METHOD 9017	27.5 ng/L
		USGS METHOD O-2440-14	27.5 ng/L
Metronidazole	443-48-1	SGS AXYS METHOD MLA-075	3.75-15.7 ng/L
Miconazole	22916-47-8	SGS AXYS METHOD MLA-075	1.45-3.0 ng/L
Morphine	57-27-2	USGS RESEARCH METHOD 9017	14.0 ng/L
		USGS METHOD O-2440-14	14.0-80.0 ng/L
Moxifloxacin	151096-09-2	SGS AXYS METHOD MLA-075	3.87-111.0 ng/L
Nadolol	42200-33-9	USGS RESEARCH METHOD 9017	80.8 ng/L
		USGS METHOD O-2440-14	80.8 ng/L
Naphthalene	91-20-3	USGS METHOD O-1433-01	40 ng/L
Naproxen	22204-53-1	SGS AXYS METHOD MLA-075	2.81-10.7 ng/L
Nevirapine	129618-40-2	USGS RESEARCH METHOD 9017	15.1 ng/L
		USGS METHOD O-2440-14	15.1-80.0 ng/L
Nicotine	54-11-5	USGS RESEARCH METHOD 9017	57.8 ng/L
		USGS METHOD O-2440-14	57.8-80.0 ng/L
Nizatidine	76963-41-2	USGS RESEARCH METHOD 9017	19.0 ng/L
		USGS METHOD O-2440-14	19.0-80.0 ng/L
Nonylphenol diethoxylate	NP2EO	AXYS METHOD MLA-004	0.697-101.0 ng/L
		USGS METHOD O-1433-01	5,000 ng/L
Nonylphenol monoethoxylate	NP1EO	AXYS METHOD MLA-004	0.796-30.3 ng/L
Nordiazepam	1088-11-5	USGS RESEARCH METHOD 9017	41.4 ng/L
		USGS METHOD O-2440-14	41.4-80.0 ng/L
Norethisterone	68-22-4	USGS RESEARCH METHOD 9017	10.8-44.3 ng/L
		USGS METHOD 2434	0.8-0.9 ng/L
		USGS METHOD O-2440-14	10.9-80.0 ng/L
Norfloxacin	70458-96-7	SGS AXYS METHOD MLA-075	14.5-277.0 ng/L
		USGS OGRL LCAB	5 ng/L
Norfluoxetine	83891-03-6	SGS AXYS METHOD MLA-075	1.41-2.95 ng/L
		USGS RESEARCH METHOD 9017	199.0 ng/L
		USGS METHOD O-2440-14	199.0 ng/L
Norgestimate	35189-28-7	SGS AXYS METHOD MLA-075	2.9-15.8 ng/L
Norsertraline	87857-41-8	USGS RESEARCH METHOD 9017	192.0 ng/L

Chemical name	CAS number	Analytical method	Reporting limit
		USGS METHOD O-2440-14	192.0-200.0 ng/L
Norverapamil	67018-85-3	SGS AXYS METHOD MLA-075	0.141-0.295 ng/L
		USGS RESEARCH METHOD 9017	8.58 ng/L
		USGS METHOD O-2440-14	8.58-80.0 ng/L
Ofloxacin	82419-36-1	SGS AXYS METHOD MLA-075	1.45-5.3 ng/L
		USGS OGRL LCAB	5 ng/L
Omeprazole/Esomeprazole mix	OMEPRAZOLE-MIX	USGS RESEARCH METHOD 9017	5.62 ng/L
		USGS METHOD O-2440-14	5.62-80.0 ng/L
Orlistat	96829-58-2	USGS RESEARCH METHOD 9017	52.0 ng/L
Ormetoprim	6981-18-6	SGS AXYS METHOD MLA-075	0.581-1.2 ng/L
		USGS OGRL LCAB	5 ng/L
Oseltamivir	196618-13-0	USGS RESEARCH METHOD 9017	14.6 ng/L
		USGS METHOD O-2440-14	14.6-20.0 ng/L
Oxacillin	66-79-5	SGS AXYS METHOD MLA-075	2.9-6.0 ng/L
Oxazepam	604-75-1	SGS AXYS METHOD MLA-075	3.75-7.96 ng/L
		USGS RESEARCH METHOD 9017	140.0 ng/L
		USGS METHOD O-2440-14	140.0-200.0 ng/L
Oxolinic acid	14698-29-4	SGS AXYS METHOD MLA-075	0.581-6.18 ng/L
Oxycodone	76-42-6	SGS AXYS METHOD MLA-075	0.593-3.78 ng/L
		USGS RESEARCH METHOD 9017	24.9 ng/L
		USGS METHOD O-2440-14	24.9-80.0 ng/L
Oxytetracycline	79-57-2	USGS OGRL LCAB	0.01 µg/L
Paroxetine	61869-08-7	SGS AXYS METHOD MLA-075	3.75-7.85 ng/L
		USGS RESEARCH METHOD 9017	20.6 ng/L
		USGS METHOD O-2440-14	20.6 ng/L
p-Cresol	106-44-5	USGS METHOD O-1433-01	0.08 µg/L
p-Cumylphenol	599-64-4	USGS METHOD O-1433-01	0.06 µg/L
p-Dichlorobenzene	106-46-7	USGS METHOD O-1433-01	0.04 µg/L
Penciclovir	39809-25-1	USGS RESEARCH METHOD 9017	40.2 ng/L
		USGS METHOD O-2440-14	40.2-80.0 ng/L
Penicillin G	61-33-6	SGS AXYS METHOD MLA-075	2.9-6.0 ng/L
Penicillin V	87-08-1	SGS AXYS METHOD MLA-075	2.9-6.0 ng/L
Pentoxifylline	6493-05-6	USGS RESEARCH METHOD 9017	9.35 ng/L
		USGS METHOD O-2440-14	9.35-10.0 ng/L
Phenanthrene	85-01-8	USGS METHOD O-1433-01	0.016 µg/L
Phenazopyridine	94-78-0	USGS RESEARCH METHOD 9017	13.3 ng/L
		USGS METHOD O-2440-14	13.3-40.0 ng/L
Phendimetrazine	634-03-7	USGS RESEARCH METHOD 9017	31.1 ng/L
		USGS METHOD O-2440-14	31.1-80.0 ng/L
Phenol	108-95-2	USGS METHOD O-1433-01	0.16 µg/L

Chemical name	CAS number	Analytical method	Reporting limit
Phenytoin	57-41-0	USGS RESEARCH METHOD 9017	188.0 ng/L
		USGS METHOD O-2440-14	188.0 ng/L
Piperonyl butoxide	51-03-6	USGS RESEARCH METHOD 9017	3.07 ng/L
		USGS METHOD O-2440-14	3.07-80.0 ng/L
p-Octylphenol	1806-26-4	AXYS METHOD MLA-004	0.117-5.54 ng/L
		USGS METHOD O-1433-01	0.06-0.08 µg/L
Prednisolone	50-24-8	SGS AXYS METHOD MLA-075	5.62-99.3 ng/L
		USGS RESEARCH METHOD 9017	150.0 ng/L
		USGS METHOD O-2440-14	150.0 ng/L
Prednisone	53-03-2	SGS AXYS METHOD MLA-075	18.7-325.0 ng/L
		USGS RESEARCH METHOD 9017	168.0 ng/L
		USGS METHOD O-2440-14	168.0-200.0 ng/L
Progesterone	57-83-0	USGS METHOD 2434	8.0 ng/L
Promethazine	60-87-7	SGS AXYS METHOD MLA-075	0.375-12.1 ng/L
		USGS RESEARCH METHOD 9017	50.0 ng/L
		USGS METHOD O-2440-14	50.0-80.0 ng/L
Prometon	1610-18-0	USGS METHOD O-1433-01	0.12 µg/L
Propoxyphene	469-62-5	SGS AXYS METHOD MLA-075	0.281-1.08 ng/L
		USGS RESEARCH METHOD 9017	17.2 ng/L
		USGS METHOD O-2440-14	17.2-80.0 ng/L
Propranolol	525-66-6	SGS AXYS METHOD MLA-075	1.87-3.93 ng/L
		USGS RESEARCH METHOD 9017	26.3 ng/L
		USGS METHOD O-2440-14	26.3 ng/L
Pseudoephedrine/Ephedrine mix	EPHED_PSEUDOEPH	USGS RESEARCH METHOD 9017	11.1 ng/L
		USGS METHOD O-2440-14	11.1 ng/L
Pyrene	129-00-0	USGS METHOD O-1433-01	0.042 µg/L
Quinine	130-95-0	USGS RESEARCH METHOD 9017	79.9 ng/L
		USGS METHOD O-2440-14	79.9-80.0 ng/L
Raloxifene	84449-90-1	USGS RESEARCH METHOD 9017	9.72 ng/L
		USGS METHOD O-2440-14	9.72-80.0 ng/L
Ranitidine	66357-35-5	SGS AXYS METHOD MLA-075	0.586-6.57 ng/L
		USGS RESEARCH METHOD 9017	192.0 ng/L
		USGS METHOD O-2440-14	192.0 ng/L
Rosuvastatin	287714-41-4	SGS AXYS METHOD MLA-075	3.75-8.32 ng/L
Roxithromycin	80214-83-1	SGS AXYS METHOD MLA-075	0.29-1.19 ng/L
		USGS OGRL LCAB	0.005 µg/L
Sarafloxacin	98105-99-8	SGS AXYS METHOD MLA-075	14.5-33.9 ng/L
		USGS OGRL LCAB	0.005 µg/L
Sertraline	79617-96-2	SGS AXYS METHOD MLA-075	0.375-0.907 ng/L
		USGS RESEARCH METHOD 9017	16.2 ng/L

Chemical name	CAS number	Analytical method	Reporting limit
		USGS METHOD O-2440-14	16.2-80.0 ng/L
Simvastatin	79902-63-9	SGS AXYS METHOD MLA-075	18.7-208.0 ng/L
Sitagliptin	486460-32-6	USGS RESEARCH METHOD 9017	97.3 ng/L
		USGS METHOD O-2440-14	97.3 ng/L
Stigmastanol	19466-47-8	USGS METHOD O-1433-01	2.6 µg/L
Sulfachloropyridazine	80-32-0	SGS AXYS METHOD MLA-075	1.45-9.46 ng/L
		USGS OGRL LCAB	0.005 µg/L
Sulfadiazine	68-35-9	SGS AXYS METHOD MLA-075	1.45-3.0 ng/L
		USGS OGRL LCAB	0.005 µg/L
Sulfadimethoxine	122-11-2	SGS AXYS METHOD MLA-075	0.29-5.98 ng/L
		USGS RESEARCH METHOD 9017	65.5 ng/L
		USGS OGRL LCAB	0.005 µg/L
		USGS METHOD O-2440-14	65.5 ng/L
Sulfamerazine	127-79-7	SGS AXYS METHOD MLA-075	0.581-3.24 ng/L
Sulfamethazine	57-68-1	SGS AXYS METHOD MLA-075	0.586-9.05 ng/L
		USGS OGRL LCAB	0.005 µg/L
Sulfamethizole	144-82-1	SGS AXYS METHOD MLA-075	0.581-5.46 ng/L
		USGS RESEARCH METHOD 9017	104.0 ng/L
		USGS METHOD O-2440-14	104.0 ng/L
Sulfamethoxazole	723-46-6	SGS AXYS METHOD MLA-075	0.591-1.96 ng/L
		USGS RESEARCH METHOD 9017	26.1 ng/L
		USGS OGRL LCAB	0.005 µg/L
		USGS METHOD O-2080-08	0.091 µg/L
		USGS METHOD O-2440-14	26.1-80.0 ng/L
Sulfanilamide	63-74-1	SGS AXYS METHOD MLA-075	14.5-52.8 ng/L
Sulfathiazole	72-14-0	SGS AXYS METHOD MLA-075	1.45-5.07 ng/L
		USGS OGRL LCAB	0.005 µg/L
Tamoxifen	10540-29-1	SGS AXYS METHOD MLA-075	0.375-0.796 ng/L
		USGS RESEARCH METHOD 9017	52.4 ng/L
		USGS METHOD O-2440-14	80.0-181.0 ng/L
Temazepam	846-50-4	USGS RESEARCH METHOD 9017	18.4 ng/L
		USGS METHOD O-2440-14	18.4-80.0 ng/L
Teniposide	29767-20-2	SGS AXYS METHOD MLA-075	3.75-7.96 ng/L
Testosterone	58-22-0	USGS METHOD 2434	1.6 ng/L
Tetrachloroethylene	127-18-4	USGS METHOD O-1433-01	0.12 µg/L
Tetracycline	60-54-8	USGS OGRL LCAB	0.01 µg/L
Theophylline	58-55-9	SGS AXYS METHOD MLA-075	56.2-118.0 ng/L
		USGS RESEARCH METHOD 9017	41.5 ng/L
		USGS METHOD O-2440-14	41.5-200.0 ng/L
Thiabendazole	148-79-8	SGS AXYS METHOD MLA-075	1.45-15.9 ng/L

Chemical name	CAS number	Analytical method	Reporting limit
		USGS RESEARCH METHOD 9017	4.1 ng/L
		USGS METHOD O-2080-08	0.06 µg/L
		USGS METHOD O-2440-14	4.1 ng/L
Tiotropium	186691-13-4	USGS RESEARCH METHOD 9017	43.1 ng/L
		USGS METHOD O-2440-14	43.1-200.0 ng/L
Tolyl triazole	29385-43-1	USGS RESEARCH METHOD 9017	141.0 ng/L
		USGS METHOD O-2440-14	141.0 ng/L
Tramadol	27203-92-5	USGS RESEARCH METHOD 9017	15.1 ng/L
		USGS METHOD O-2440-14	15.1 ng/L
Trenbolone	10161-33-8	SGS AXYS METHOD MLA-075	3.75-7.85 ng/L
Trenbolone acetate	10161-34-9	SGS AXYS METHOD MLA-075	0.281-2.48 ng/L
Triamterene	396-01-0	SGS AXYS METHOD MLA-075	0.293-1.04 ng/L
		USGS RESEARCH METHOD 9017	5.25 ng/L
		USGS METHOD O-2440-14	5.25-80.0 ng/L
Tribromomethane	75-25-2	USGS METHOD O-1433-01	0.1 µg/L
Tributyl phosphate	126-73-8	USGS METHOD O-1433-01	0.16 µg/L
Triclocarban	101-20-2	SGS AXYS METHOD MLA-075	2.81-3.23 ng/L
Triclosan	3380-34-5	SGS AXYS METHOD MLA-075	56.2-64.6 ng/L
		AXYS_MLA-083	4.69-11.0 ng/L
		USGS METHOD O-1433-01	0.2-1.28 µg/L
Triethyl citrate	77-93-0	USGS METHOD O-1433-01	0.16 µg/L
Trimethoprim	738-70-5	SGS AXYS METHOD MLA-075	1.45-3.0 ng/L
		USGS RESEARCH METHOD 9017	19.0 ng/L
		USGS OGRL LCAB	0.005 µg/L
		USGS METHOD O-2080-08	0.034 µg/L
		USGS METHOD O-2440-14	19.0-80.0 ng/L
Triphenyl phosphate	115-86-6	USGS METHOD O-1433-01	0.12 µg/L
Tris(1,3-dichloro-2-propyl)phosphate	13674-87-8	USGS METHOD O-1433-01	0.16 µg/L
Tris(2-butoxyethyl) phosphate	78-51-3	USGS METHOD O-1433-01	0.8-2.6 µg/L
Tris(2-chloroethyl) phosphate	115-96-8	USGS METHOD O-1433-01	0.1 µg/L
Tylosin	1401-69-0	SGS AXYS METHOD MLA-075	5.81-12.0 ng/L
		USGS OGRL LCAB	0.01 µg/L
Valacyclovir	124832-26-4	USGS RESEARCH METHOD 9017	163 ng/L
		USGS METHOD O-2440-14	163 ng/L
Valsartan	137862-53-4	SGS AXYS METHOD MLA-075	3.75-14.1 ng/L
Venlafaxine	93413-69-5	SGS AXYS METHOD MLA-075	0.387-6.37 ng/L
		USGS RESEARCH METHOD 9017	4.48 ng/L
		USGS METHOD O-2440-14	4.48 ng/L
Verapamil	52-53-9	SGS AXYS METHOD MLA-075	0.141-0.295 ng/L

Chemical name	CAS number	Analytical method	Reporting limit
		USGS RESEARCH METHOD 9017	15.5 ng/L
		USGS METHOD O-2440-14	15.5-80.0 ng/L
Virginiamycin M1	21411-53-0	SGS AXYS METHOD MLA-075	2.9-11.0 ng/L
		USGS OGRL LCAB	0.005 µg/L
Warfarin	81-81-2	SGS AXYS METHOD MLA-075	1.41-1.62 ng/L
		USGS RESEARCH METHOD 9017	6.03 ng/L
		USGS METHOD O-2080-08	0.08 µg/L
		USGS METHOD O-2440-14	6.03
Zidovudine	30516-87-1	SGS AXYS METHOD MLA-075	22.5 - 173.0

References

Adams, R. 2016. Pollution Sensitivity of Near-Surface Materials. In *Minnesota Hydrogeology Atlas Series HG-02*. St. Paul, Minnesota: Minnesota Department of Natural Resources.

Adolphson, D.G., J.F. Ruhl, and R.J. Wolf. 1981. Designation of Principal Water-Supply Aquifers in Minnesota. In *Water-Resources Investigations Report 81-51*. St. Paul, Minnesota: U.S. Geological Survey.

Anderson, H.W., Jr. 1993. Effects of Agriculture and Residential Land Use on Ground-Water Quality, Anoka Sand Plain Aquifer, East-Central Minnesota. In *Water-Resources Investigations Report 93-4074*. Mounds View, Minnesota: U.S. Geological Survey.

Austin Utilities. *2016 Water Quality Report* 2016 [cited August 29th, 2018. Available from http://www.austinutilities.com/files/pdf/2016WaterQualityReport.pdf.

Berg, J.A. 2018. Geologic atlas of Clay County, Minnesota [Part B]. In *County Atlas Series C-29*. St. Paul, Minnesota: Minnesota Department of Natural Resources.

Cassanelli, J.P., and G.A. Robbins. 2013. "Effects of road salt on Connecticut's Groundwater: A statewide centennial perspective." *Journal of Environmental Quality* no. 42:737-748.

City of Baxter. *2017 Drinking Water Report* 2019 [cited February 27th, 2019. Available from http://www.baxtermn.gov/2017-drinking-water-report/.

City of Brooklyn Center. *2017 Drinking Water Report* 2018 [cited August 29th, 2018. Available from http://www.ci.brooklyn-center.mn.us/DocumentCenter/View/6434.

City of Cloquet. *Cloquet's Drinking Water Supply* [cited July 25th, 2019. Available from https://www.cloquetmn.gov/departments/public-works/water-utility.

City of Saint Paul. *Water Treatment Process* 2018 [cited August 28th, 2018. Available from https://www.stpaul.gov/departments/water-services/water-quality/water-quality-control/water-treatment-process.

City of St. Cloud. *Water Treatment Process* 2018 [cited August 29th, 2018. Available from https://www.ci.stcloud.mn.us/345/Water-Treatment-Process.

City of Sturgeon Lake. 2011. Wellhead Protection Plan for the City of Sturgeon Lake, MN. Sturgeon Lake, Minnesota.

Cook, Peter G., and Andrew Leslie Herczeg. 2000. *Environmental tracers in subsurface hydrology*. Boston: Kluwer Academic Publishers.

Cordy, Gail E., Norma L. Duran, Herman Bouwer, Robert C. Rice, Edward T. Furlong, Steven D. Zaugg, Michael T. Meyer, Larry B. Barber, and Dana W. Kolpin. 2004. "Do Pharmaceuticals, Pathogens, and Other Organic Waste Water Compounds Persist When Waste Water Is Used for Recharge?" *Ground Water Monitor Remediation Ground Water Monitoring & Remediation* no. 24 (2):58-69.

Cowdery, T.K. 1998. Ground-water quality in the Red River of the North Basin, Minnesota and North Dakota, 1991-95. In *Water-Resources Investigations Report*. Mounds View, Minnesota.

Davis, Stanley N., Donald O. Whittemore, and June Fabryka-Martin. 1998. "Uses of Chloride/Bromide Ratios in Studies of Potable Water." *Ground Water* no. 36 (2):338-350. doi: 10.1111/j.1745-6584.1998.tb01099.x.

Dubrovsky, N.M., K.R. Burow, G.M. Clark, J.M. Gronberg, P.A. Hamilton, K.J. Hitt, D.R. Mueller, M.D. Munn, B.T. Nolan, L.J. Puckett, M.G. Rupert, T.M. Short, N.E. Spahr, L.A. Sprague, and W.G. Wilber. 2010. The Quality of Our Nation's Water-- Nutrients in Streams and Groundwater, 1992-2004. In *Circular 1350*. Reston, Virginia: U.S. Geological Survey.

Edwards, M., S. Jacobs, and D. Dodrill. 1999. "Desktop guidance for mitigating Pb and Cu corrosion by-products." *Journal AWWA* no. 91:12.

Erickson, Melinda L., and Randal J. Barnes. 2005a. "Glacial Sediment Causing Regional-Scale Elevated Arsenic in Drinking Water." *Ground Water* no. 43 (6):796-805. doi: 10.1111/j.1745-6584.2005.00053.x.

Erickson, Melinda L., and Randal J. Barnes. 2005b. "Well characteristics influencing arsenic concentrations in ground water." *Water Research* no. 39 (16):4029-4039. doi: http://dx.doi.org/10.1016/j.watres.2005.07.026.

Falteisek, Jan. 1997. Geologic atlas Rice County, Minnesota Part B, plate 7-9. Part B, plate 7-9. St. Paul: Univ. of Minnesota.

Falteisek, Jan, Minnesota, Waters Division of, and Survey Minnesota Geological. 1996. Geologic atlas, Fillmore County, Minnesota. St. Paul [Minn.]: Dept., Division of Waters.

Fong, A.L. 2000. Water-quality assessment of part of the Upper Mississippi River Basin, Minnesota and Wisconsin-Ground-water quality in three different land-use areas, 1996-98. In *Water-Resources Investigations Report 00-4131*. Mounds View: U.S. Geological Survey.

Groschen, G.E., T.L. Arnold, W.S. Morrow, and K.L. Warner. 2008. Occurrence and distribution of iron, manganese, and selected trace elements in groundwater in the glacial aquifer system of the Northern United States. In *U.S. Geological Survey Scientific Investigations Report 2009-5006*. Reston, Virginia: U.S. Geological Survey.

Helsel, D.R., and L.M. Frans. 2006. "Regional Kendall Test for Trend." *Environmental Science & Technology* no. 40:4066-4073.

Helsel, Dennis R. 2005. "More Than Obvious: Better Methods for Interpreting Nondetect Data." *Environ. Sci. Technol. Environmental Science & Technology* no. 39 (20):419A-423A.

Houde, M., A. O. De Silva, D. C. Muir, and R. J. Letcher. 2011. "Monitoring of perfluorinated compounds in aquatic biota: an updated review." *Environmental science & technology* no. 45 (19):7962-7973.

Howard, K.W.F., and L.C. Taylor. 1998. Hydrogeochemistry of Springs in Urban Toronto, Canada. Paper read at Gambling with groundwater: physical, chemical, and biological aspects of aquifer-stream relations: Proceedings of the Joint Meeting of the XXVIII Congress of the International Assocation of Hydrogeologists and the Annual meeting of the American Institute of Hydrologists, 28 September-2 October 1998, at Las Vegas, Nevada.

Huang, C-C. 2007. "Parkinsonism Induced by Chronic Manganese Intoxication: An Experience in Taiwan." *Chang Gung Medical Journal* no. 30 (5):385-395.

Kaiser, Kim, Brennon Schaefer, and Bill VanRysWyk. 2017. Nitrate Trends in Private Well Networks. St. Paul, Minnesota: Minnesota Department of Agriculture.

Kelly, W.R. 2008. "Long-term trends in chloride concentrations in shallow aquifers near Chicago." *Ground Water* no. 46:772-781.

Kies, Constance. 1987. "Manganese Bioavailability Overview." In *Nutritional Bioavailability of Manganese*, 1-8. American Chemical Society.

Kinny, C.A., E.T. Furlong, S.D. Zaugg, M.R. Burkhardt, S.L. Werner, J.D. Cahill, and G.R. Jorgensen. 2006. "Survey of organic wastewater contaminants in biosolids destined for land application. Environmental Science and Technology " *Environmental Science and Technology* no. 40:1202-1211.

Kroening, S.E., and M. Ferrey. 2013. The Condition of Minnesota's Groundwater, 2007-2013. In *Report Number wq-am1-06*. St. Paul, Minnesota: Minnesota Pollution Control Agency.

Kroening, Sharon E. 2017. Perfluorinated Chemicals in Minnesota's Ambient Groundwater. St. Paul, Minnesota: Minnesota Pollution Control Agency.

Lincoln-Pipestone Rural Water. 2017. Wellhead Protection Plan for Lincoln-Pipestone Rural Water System, Lake Benton, Minnesota.

Llopis, José L. 1991. *The effects of well casing material on ground water-quality*. [Washington, D.C.]: U.S. Environmental Protection Agency, Office of Research and Development, Office of Solid Waste and Emergency Response.

Mao, Z., X. Zheng, Y. Zhang, X. Tao, Y. Li, and W. Wang. 2012. "Occurrence and biodegradation of nonylphenol in the environmental: International Journal of Molecular Sciences." *International Journal of Molecular Sciences* no. 13:15. doi: 10.3390/ijms13010491.

Masoner, Jason R., Dana W. Kolpin, Edward T. Furlong, Isabelle M. Cozzarelli, and James L. Gray. 2016. "Landfill leachate as a mirror of today's disposable society: Pharmaceuticals and other contaminants of emerging concern in final leachate from landfills in the conterminous United States." *ETC Environmental Toxicology and Chemistry* no. 35 (4):906-918.

McDonald, B. C., J. A. de Gouw, J. B. Gilman, S. H. Jathar, A. Akherati, C. D. Cappa, J. L. Jimenez, J. Lee-Taylor, P. L. Hayes, S. A. McKeen, Y. Y. Cui, S. W. Kim, D. R. Gentner, G. Isaacman-VanWertz, A. H. Goldstein, R. A. Harley, G. J. Frost, J. M. Roberts, T. B. Ryerson, and M. Trainer. 2018. "Volatile chemical products emerging as largest petrochemical source of urban organic emissions." *Science (New York, N.Y.)* no. 359 (6377):760-764.

Meyer, G.N., and A.R. Knaeble. 1996. "Quaternary Geology of Stearns County, Minnesota." In *Text Supplement to the Geologic Atlas of Stearns County, Minnesota*, edited by G.N. Meyer and L. Swanson. St. Paul, Minnesota: Minnesota Geological Survey.

Meyer, M.T., J.E. Bumgarner, J.L. Varns, J.V. Daughtridge, E.M. Thurman, and K.A. Hostetler. 2000. "Use of radioimmunoassay as a screen for antibiotics in confined animal feeding operations and confirmation by liquid chromatography/mass spectrometry." *Science of the Total Environment* no. 248:181-188.

Minnesota Department of Agriculture. 2015. Minnesota Nitrogen Fertilizer Management Plan. St. Paul, Minnesota.

Minnesota Department of Agriculture. 2017. Southeast Minnesota Volunteer Nitrate Monitoring Network 2017 Results. St. Paul, Minnesota.

Minnesota Department of Agriculture. 2018. 2017 Water Quality Monitoring Report. St. Paul, Minnesota.

Minnesota Department of Health. 2008. Arsenic in Drinking Water. St. Paul, Minnesota.

Minnesota Department of Health. 2012. Memo: Initial Assessment of Manganese in Groundwater. St. Paul, Minnesota.

Minnesota Department of Health. 2013. Trichloroethylene (TCE) and Drinking Water. St. Paul, Minnesota.

Minnesota Department of Health. *Arsenic in Private Wells* 2019a [cited February 2nd, 2019. Available from https://data.web.health.state.mn.us/arsenic_wells.

Minnesota Department of Health. *Manganese in Drinking Water* 2019b [cited February 27th, 2019. Available from https://www.health.state.mn.us/communities/environment/water/contaminants/manganese.html.

Minnesota Department of Health. *Volatile Organic Compounds in Your Home* 2019c [cited February 28th, 2019. Available from https://www.health.state.mn.us/communities/environment/air/toxins/voc.htm.

Minnesota Department of Health, and United States Agency for Toxic Substances Disease Registry. 2001. *The Minnesota Arsenic Study (MARS) : phase I, arsenic occurrence in drinking water : phase II, biomarkers of arsenic exposure and effect*. Atlanta, Ga.: ATSDR.

Minnesota Department of Natural, Resources. 2002. Geologic atlas of Mower County, Minnesota. Part B. St. Paul, Minn.: Minnesota Dept. of Natural Resources.

Minnesota Department of Natural Resources. 2001. Geologic atlas of Wabasha County, Minnesota. Part A and B. [St. Paul, Minn.]: Minnesota Dept. of Natural Resources : Minnesota Geological Survey.

Minnesota Department of Natural Resources. 2003. Geologic atlas of Goodhue County, Minnesota. St. Paul, MN: Minnesota Dept. of Natural Resources.

Minnesota Ground Water Association. 2015. Manganese in Minnesota's Groundwaters: Emphasizing the Health Risks of Manganese in Drinking Water. St. Paul, Minnesota.

Minnesota Pollution Control Agency. 2007. Baytown Ground Water Contamination Superfund Site. St. Paul, Minnesota.

Minnesota Pollution Control Agency. 2013. Nitrogen in Minnesota Surface WAters. St. Paul, Minnesota.

Minnesota Pollution Control Agency. *What is Vapor Intrusion?* 2019 [cited February 20th, 2019. Available from https://www.pca.state.mn.us/waste/what-vapor-intrusion.

Mulla, D.J., J. Galzki, K. Fabrizzi, K. Kim, and Wall. D. 2013. "Nonpoint Source Nitrogen Loading, Sources, and Pathways for Minnesota Surface Waters." In *Nitrogen in Minnesota Surface Waters*, edited by D. Wall. St. Paul, Minnesota: Minnesota Pollution Control Agency.

Mullvaney, J.R., D.L. Lorenz, and A.D. Arntson. 2009. Chloride in Groundwater and Surface Water in Areas Underlain by the Glacial Aquifer System, Northern United States. In *Scientific Investigations Report 2009-5086*. Reston, Virginia: U.S. Geological Survey.

Nazaroff, W.W., and C.J. Weschler. 2004. "Cleaning products and air fresheners: exposure to primary and secondary air pollutants." *Atmospheric Environment* no. 38:2841-2865. doi: 10.1016/j.atmosenv.2004.02.040.

Nguyen, C.K., D.R. Stone, A. Dudi, and M.A. Edwards. 2010. "Corrosive microenvironments at lead solder surfaces arising from galvanic corrosion with copper pipe." *Environmental Science & Technology* no. 44:7076-7083.

Nguyen, C.K., D.R. Stone, and M.A. Edwards. 2011. "Chloride-to-sulfate mass ratio—Practical studies in galvanic corrosion of lead solder." *Journal AWWA* no. 103:81-91.

Nicholas, S. L., M. L. Erickson, L. G. Woodruff, A. R. Knaeble, M. A. Marcus, J. K. Lynch, and B. M Toner. 2017. "Solid-phase arsenic speciation in aquifer sediments: a micro-X-ray absorption spectroscopy approach for quantifying trace-level speciation." *Geochimica Cosmochimica Acta* no. 211:228-255.

Olcott, Perry G. 1992. Ground water atlas of the United States. Segment 9. Reston, Va.: U.S. Geological Survey.

Overbo, A., and S. Heger. *Estimating Annual Chloride Use in Minnesota* 2018 [cited September 14th, 2018. Available from https://www.wrc.umn.edu/chloride.

Pankow, James F., Neil R. Thomson, Richard L. Johnson, Arthur L. Baehr, and John S. Zogorski. 1997. "The Urban Atmosphere as a Non-Point Source for the Transport of MTBE and Other Volatile Organic Compounds (VOCs) to Shallow Groundwater." *Environ. Sci. Technol. Environmental Science & Technology* no. 31 (10):2821-2828.

Pionke, H.B., and J.B. Urban. 1985. "Effect of Agricultural Land use on Ground-Water Quality in a Small Pennsylvania Watershed." *Ground Water* no. 23:68-80.

Research Triangle Institute, and United States Agency for Toxic Substances Disease Registry. 1997. Toxicological profile for chloroform. Washington, D.C.: ATSDR.

Revitt, D. Michael, Lian Lundy, Frederic Coulon, and Marin Fairley. 2014. "The sources, impact and management of car park runoff pollution: a review." *Journal of Environmental Management* no. 146:552-567. doi: 10.1016/j.envman.2014.05.041.

Ritter, S.K. 2010. "Fluorochemicals Go Short—Shorter Perfluoroalkyl Chain Lengths Improve Environmental Profile of Versatile Stain-, Grease-, and Water-Repelling Chemicals." *Chemical and Engineering News Archive* no. 88 (5):12-17.

Rochester Public Utilities. 2017. 2017 Water Quality Report. Rochester, Minnesota: Rochester Public Utilities.

Runkel, A.C., J.R. Steenberg, R.G. Tipping, and A.J. Retzler. 2013. Geologic controls on groundwater and surface water flow in southeastern Minnesota and its impact on nitrate concentrations in streams. In *Open-File Report 14-02*. St. Paul, Minnesota: Minnesota Geological Survey.

Saint-Hilaire, D., and U. Jans. 2013. "Reactions of three halogenated organophosphorus flame retardants with reduced sulfur species." *Chemosphere* no. 93:2033-2039.

Salminen, R., S. Reeder, B. De Vivo, A. Demetriades, S. Pirc, M.J. Batista, K. Marsina, R.-T. Ottesen, P.J. O'Connor, M. Bidovec, A. Lima, U. Siewers, B. Smith, H Taylor, R. Shaw, I. Salpeteur, V. Gregorauskiene, J. Halamic, I. Slaninka, K. Lax, P. Gravesen, M. Birke, N. Breward, E.L. Ander, G. Jordan, M. Duris, P. Klein, J. Locutura, A. Bel-lan, A. Pasieczna, J. Lis, A. Mazreku, A. Gilucis, P. Heitzmann, G. Klaver, and V. Petersell. 2006. Geochemical Atlas of Europe Part 2. In *Interpretation of Geochemical Maps, Additional Tables, Figures, Maps, and Related Publications*, edited by W. De Vos and T. Tarvainen.

Scheringer, M., X. Trier, I.T. Cousins, P. de Voogt, T. Fletcher, Z. Wang, and T.F. Webster. 2014. "Helsingor Statement of Poly- and Perfluorinated Alkyl Substances (PFASs)." *Chemosphere* no. 114:337-340.

Schoenberg, M.E. 1984. Water levels and water-level changes in the Prairie du Chien-Jordan and Mount Simon-Hinckley aquifers, Twin Cities Metropolitan Area, Minnesota, 1971-90. In *Water-Resources Investigations Report 83-4237*. St. Paul, Minnesota: U.S. Geological Survey.

Seaber, P.R., F.P. Kapinos, and Knapp. G.L. 1987. Hydrologic Unit Maps. In *Water-Supply Paper 2294*. Reston, Virginia: U.S. Geological Survey.

Slinn, W. G. N., L. Hasse, B. B. Hicks, A. W. Hogan, D. Lal, P. S. Liss, K. O. Munnich, G. A. Sehmel, and O. Vittori. 1978. "Some aspects of the transfer of atmospheric trace constituents past the air-sea interface." *Atmospheric Environment* no. 12 (11):2055-2087.

Smedley, P. L., and D. G. Kinniburgh. 2002. "A review of the source, behaviour and distribution of arsenic in natural waters." *Applied Geochemistry* no. 17 (5):517-568. doi: 10.1016/S0883-2927(02)00018-5.

Smith, D.B., W.F. Cannon, L.G. Woodruff, Federico Solano, and K.J. Ellefsen. 2014. Geochemical and mineralogical maps for soils of the conterminous United States. In *Open-File Report 2014-1082*. Reston, Virginia: U.S. Geological Survey.

Ternes, T.A., and R. Hirsch. 2000. "Occurrence and behavior of x-ray contrast media in sewage facilities and the aquatic environment." *Environmental Science and Technology* no. 34:2741-2748.

Toner, B.M., S.L. Nicholas, L.J. Briscoe, A.R. Knaeble, J.A. Berg, and M.L. Erickson. 2011. Natural Sources of Arsenic in Minnesota Groundwater. In *CURA Reporter*, edited by Michael D. Greco. Minneapolis, Minnesota: University Printing Services.

Trojan, M.D., J.S. Maloney, J.M. Stockinger, E.P. Eid, and M.J. Lahtinen. 2003. "Effects of land use on ground water quality in the Anoka Sand Plain aquifer of Minnesota." *Ground Water* no. 41:482-492.

U.S. Environmental Protection Agency. 2004. Drinking Water Health Advisory for Manganese. In *USEPA Report EPA-822-R-04-003*. Washington D.C.

U.S. Environmental Protection Agency. 2010. Nonylphenol (NP) and Nonylphenol Ethoxylates (NPEs) Action Plan. Washington D.C.

U.S. Environmental Protection Agency. 2011. Reactive Nitrogen in the United States: An Analysis of Inputs, Flows, Consequences, and Management Options. In *U.S. EPA Report*. Washington D.C.: U.S. Environmental Protection Agency,.

U.S. Environmental Protection Agency. 2012. Petroleum Hydrocarbons and Chlorinated Solvents Differ in Their Potential for Vapor Intrusion. Washington D.C.

U.S. Environmental Protection Agency. *PFAS Laws and Regulations*. U.S. Environmental Protection Agency, 2019 [cited February 28th, 2019. Available from https://www.epa.gov/pfas/pfas-laws-and-regulations.

United States Agency for Toxic Substances Disease Registry. 1997. ToxFAQs for 1,2-dichloroethene. Atlanta, Georgia: Department of Health and Human Services.

United States Agency for Toxic Substances Disease Registry. *Draft toxicological profile for manganese*. U.S. Department of Health and Human Services 2008. Available from http://books.google.com/books?id=9J0B58RVjE8C.

Warner, K.L., and J.D. Ayotte. 2014. The Quality of Our Nation's Waters-- Water Quality in the Glacial Aquifer System, Northern United States, 1993-2009. In *Circular 1352*. Reston, Virginia: U.S. Geological Survey.

Wendel, F.M., C.L. Eversloh, E.J. Machek, S.E. Duirk, M.J. Plewa, S.D. Richardson, and T.A. Ternes. 2014. "Transformation of iopamidol during chlorination." *Environmental Science & Technology* no. 48:12689-12697.

Williams, D.D., N.E. Williams, and Y. Cao. 2000. "Road Salt contamination of groundwater in a major metropolitan area and development of a biological index to monitor its impact." *Water Research* no. 34:127-138.

World Health Organization. 2006. Tetrachloroethene. In *Concise International Chemical Assessment Document 58*, edited by Maria Sheffer. Geneva, Switzerland.

Yu, Soonyoung, Pyeong-Koo Lee, Seong-Taek Yun, Sang-Il Hwang, and Gitak Chae. 2017. "Comparison of volatile organic compounds in stormwater and groundwater in Seoul metropolitan city, South Korea." *Environ Earth Sci Environmental Earth Sciences* no. 76 (9):1-17.

Zogorski, John S., Janet M. Carter, Tamara Ivahnenko, Wayne W. Lapham, Michael J. Moran, Barbara L. Rowe, Paul J. Squillace, and Patricia L. Toccalino. 2006. *The quality of our nation's waters : volatile organic compounds in the nation's ground water and drinking-water supply wells, Circular 1292*. Reston, Va.: U.S. Dept. of the Interior, U.S. Geological Survey.

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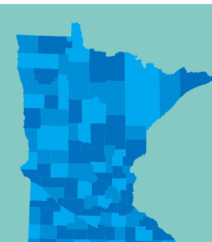
Nutrients in water

August 2020

5-year Progress Report on Minnesota’s Nutrient Reduction Strategy

MINNESOTA POLLUTION CONTROL AGENCY



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This report is available in alternative formats upon request, and online at www.pca.state.mn.us.

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Tables

Acronyms and abbreviations

%	percent
1W1P	One Watershed One Plan
AA	Anhydrous ammonia
ac	acre
ACPF	Agricultural Conservation Planning Framework
BMP	best management practices
BWSR	Board of Water and Soil Resources
CFO	concentrated feeding operation
CREP	Conservation Reserve Enhancement Program
CRP	Conservation Reserve Program
CSP	Conservation Stewardship Program
CTIC	Conservation Technology Information Center
DAP	diammonium phosphate
DEP	Daily Erosion Project
DNR	Minnesota Department of Natural Resources
EPA	U.S. Environmental Protection Agency
EQB	Environmental Quality Board
EQIP	Environmental Quality Incentive Program
EWG	Environmental Work Group
GRAPS	groundwater restoration and protection strategies
HSPF	Hydrological Simulation Program – FORTRAN
HSPF-SAM	Hydrological Simulation Program – FORTRAN Scenario Application Manager
HUC	hydrologic unit code
IPNI	International Plant Nutrition Institute
ITPHS	imminent threats to public health and safety
L	liter
lb N	pounds of nitrogen
LiDAR	Light Detection and Ranging
MAP	mono-ammonium phosphate
MDA	Minnesota Department of Agriculture
MDH	Minnesota Department of Health
Met Council	Metropolitan Council
mg	milligram
MG	million gallon
Minn. R. Ch.	Minnesota Rule Chapter
MPCA	Minnesota Pollution Control Agency
MRBI	Mississippi River Basin Healthy Watersheds Initiative
MRTN	Maximum return on total nitrogen
MS4	municipal separate storm sewer system
MT	metric ton
NASS	National Agricultural Statistics Service
NPDES	National pollutant discharge elimination system
NRCS	Natural Resources Conservation Service

NRS	Nutrient Reduction Strategy
NWQI	National Water Quality Initiative
OpTIS	Operational Tillage Information System
ppm	parts per million
PTMApp	Prioritize, Target, and Measure Application
RIM	Re-Invest in Minnesota
SDS	State Discharge System
SPARROW	SPAtially Referenced Regression on Watershed Attributes
SSTS	Subsurface Sewage Treatment Systems
TMDL	total maximum daily load
UAN	Nitrogen solutions
U of MN	University of Minnesota
USDA	United State Department of Agriculture
USGS	U.S. Geological Survey
WLA	wasteload allocation
WLSSD	Western Lake Superior Sanitation District
WRAPS	Watershed Restoration and Protection Strategies
yr	year

1 Introduction

Nutrients are important for all living things. However, too many nutrients in water can produce problems like algae growth, low levels of dissolved oxygen, toxicity to aquatic life, and unhealthy drinking water. Excessive nutrients can diminish water quality, both within Minnesota and in downstream waters, including Lake Winnipeg, the Gulf of Mexico, and Lake Superior.

To address the issue of excessive nutrients, 11 Minnesota organizations finalized a state-level Nutrient Reduction Strategy (NRS) in 2014. Minnesota is one of 12 states on the Gulf of Mexico Hypoxia Task Force that developed such a strategy to reduce nutrients entering in-state waters and to achieve fair-share nutrient reductions for the Gulf of Mexico and other downstream waters. Minnesota's NRS set specific goals for reducing nitrogen and phosphorus and outlined scenarios of changes needed in Minnesota's rural and urban areas to meet those goals. The 2014 NRS is available at https://www.pca.state.mn.us/water/nutrient-reduction-strategy.

Figure 1. Major drainage basins in Minnesota.

1.1 Overview of 2014 NRS goals and milestones

The 2014 NRS set milestones, or interim goals, to assist in tracking Minnesota's statewide nutrient reduction progress. Each major basin has numeric reduction milestones for phosphorus and nitrogen. For example, the nitrogen milestone for the Mississippi River is a 20% reduction by 2025, with a 2040 target date for reaching a 45% final reduction goal. Nitrogen and phosphorus milestones and final goals vary in the three major drainages in Minnesota (Table 1).

Table 1. Timeline for reaching goals and milestones.

Major basin	Milestone 2014 to 2025	Final Goal 2025 to 2040
1. Mississippi River (Also includes Cedar, Des Moines, and Missouri Rivers)	**12%** reduction in phosphorus (33% reduced prior to 2014)	Achieve **45%** total reduction from 1980-96 baseline and meet in-state lake and river water quality standards
	20% reduction in nitrogen	Achieve **45%** total reduction from 1980-96 baseline
2. Red River (Lake Winnipeg Basin)	**10%** reduction in phosphorus	Achieve final reductions identified through joint efforts with Manitoba (about 50% from 1998 to 2001) [a]
	13% reduction in nitrogen	
3. Lake Superior	Maintain protection goals, no net increase from 1970s	
Groundwater/Source Water	Meet the goals of the 1989 Groundwater Protection Act	

a. The 2014 NRS noted that the International Red River Basin Water Quality Committee had suggested revised Red River nutrient reduction goals as high as 50% reductions from baselines. In September 2019, the International Red River Board agreed to pass along the proposed loading targets for the Red River at the US/Canada Boundary onto the International Joint Commission. The new load targets on the Red River at the Minnesota/Canadian Border are 1,400 MT of total phosphorus and 9,525 MT of total nitrogen. These load targets represent 48% and 52% of phosphorus and nitrogen 5-year rolling average loads during the 1998 to 2001 baseline timeframe, respectively. 5-year rolling average loads during recent years have averaged about 2,200 MT for phosphorus and 13,000 MT for nitrogen.

1.2 Tracking progress toward NRS goals and milestones

Tracking progress toward these nutrient reduction goals and making necessary adjustments is a key component of the 2014 NRS. In the 2014 strategy, Minnesota partner agencies committed to progress reports: a 5-year progress report and a 10-year update and NRS re-publishing.

The 5-year progress report was supposed to include progress on the following:

- Implementation activities and strategies
- Best management practice (BMP) adoption assessment
- Water quality outcomes
- Next steps for the 2020 to 2024 period

The 2024 NRS update will examine progress after 10 years of implementation prior to the 2025 milestone. Depending on the progress found at that time, Minnesota partner agencies could potentially make additional adjustments to NRS implementation efforts.

Overarching goals that the Minnesota NRS and this 5-year progress report address include the following:

- **Ensure nitrogen reductions to water are achieved** in the large parts of Minnesota where specific local drivers do not exist for nitrogen reduction, but where local nitrogen delivery incrementally impacts downstream waters.
- **Ensure local phosphorus reductions are collectively adding up** to address eutrophication in downstream large rivers, regional lakes/reservoirs, and waters further downstream, such as Lake Winnipeg and the Gulf of Mexico.
- **Ensure Minnesota adapts to remain well-positioned for long-term nutrient reduction success**, modifying as necessary the state-level programs, partnerships, priorities, provision to local watersheds, and technical practices to achieve large-scale BMP adoption.
- **Maintain commitments to evaluate and communicate** Minnesota's implementation approaches and progress to both in-state and out-of-state national and international audiences.

1.3 What's in the NRS 5-year progress report

This document is the 5-year progress report intended to fulfill the reporting objectives set forth in the 2014 NRS. This report evaluates and documents Minnesota's progress toward reaching NRS goals and benchmarks at the mid-point of NRS implementation to achieve the 2025 milestones, presented above. This 5-year progress report takes the pulse of water quality trends and provides insights into the implementation activities cited in the 2014 NRS as integral to achieving the 2025 milestones. Evaluation of state-level program advancements, BMP scales of adoption, and nutrient trends in waters provide the needed assessment information to gage progress thus far and recommend next steps.

Key questions that are explored as part of this 5-year progress report include:

Programs – Are the NRS strategies progressing? This section discusses progress on new or expanded programmatic initiatives identified in the 2014 NRS, in addition to continuation and expansion of existing efforts and programs, to achieve nutrient reduction milestones. This section is not intended to be a full accounting of all nutrient reduction programs and activities, but is a comparison of NRS recommended strategies with associated programmatic advancements made since 2014.

In the water – What can we tell so far? This section presents water quality information on nitrogen and phosphorus changes and trends identified from key data sources.

On our cropland – Are we on track for the needed scale of BMP adoption? This section provides information on cropland BMP adoption progress implemented through new and existing programs intended to achieve the NRS milestones.

Wastewater and other sources – Is progress consistent with NRS direction? A summary of progress from wastewater, feedlots, urban stormwater, and septic system sources is provided.

What are the next steps for the NRS (2020 to 2024)? This section outlines high priority steps to
a) increase the potential for successful nutrient reductions prior to the 2025 NRS milestones, and
b) develop the information needed to strengthen the republished NRS in 2024.

Together, answers to these questions help to tell the story of NRS implementation in Minnesota over the past five years and help set the course for successful NRS implementation for the next five years.

This progress report represents a collective effort by the Minnesota partner agencies who developed the 2014 NRS. Each agency contributed readily available data and information to generate this 5-year progress report, minimizing the resources required to assess the NRS progress to date.

2 Programs – Are the NRS strategies progressing?

To make substantial progress in reducing Minnesota's nutrient loads into waters, Minnesota's 2014 NRS Chapter 6 recommended many strategies necessary to achieve NRS reduction goals. These recommended strategies included the creation of new programs and continuation of existing programs for agricultural lands, wastewater, septic systems, feedlots, stormwater, and other overarching activities. These programs and initiatives were intended to help achieve the increased level of effort (implementation of agricultural BMPs, wastewater reductions, etc.) necessary to meet the goals and milestones of the 2014 NRS. In addition, Chapter 7 of the NRS identifies the needed information and tools to track implementation, expected nutrient reductions, and changes in water quality from NRS activities.

The following sections summarize the progress made since 2014 towards NRS recommended strategies and the needed information and tools to track NRS implementation. Sections 4 and 5 in this 5-year progress report provide an update on the adoption levels of the specific activities recommended in the NRS.

Climate change resiliency

While not a specific recommended strategy in the 2014 NRS, climate change resiliency and planning has become a major focus of state agency action in recent years. Several reports and committees have been created to advance programs related to understanding and mitigating the potential effects of climate change. Many NRS practices not only reduce nutrients but help to mitigate the effects of climate change. Reports related to climate change resiliency and planning since 2014 include but are not limited to:

Climate Change Trends and Action Plan (BWSR 2019): https://bwsr.state.mn.us/sites/default/files/2019-09/ClimateChangeTrends%2BActionPlan_Sept2019.pdf

Adapting to Climate Change in Minnesota (Interagency Climate Adaption Team 2017): https://www.pca.state.mn.us/sites/default/files/p-gen4-07c.pdf

Greenhouse gas reduction potential of agricultural BMPs (MPCA 2019): https://www.pca.state.mn.us/air/agriculture-and-climate-change-minnesota

2.1 Progress towards NRS strategies

Minnesota has made substantial progress towards implementation of most of the strategies found in Chapter 6 of the 2014 NRS. Sections 2.1.1 through 2.1.5 summarize the progress made since 2014 towards the NRS recommended strategies by category: overarching, agricultural, wastewater, miscellaneous sources of nutrients, and protection strategies. Some programs created or expanded since 2014 support multiple strategies and are therefore listed multiple times. Major advances for each strategy are further described in Appendix A which includes associated program web links when available.

The programs highlighted in Appendix A and in the tables below are in various stages of development and implementation. Where quantification of program impacts is known for the 2014 to 2018 period, they are provided in the tables and/or Appendix A. However, quantified existing and projected outcomes are not available for each program at this time.

2.1.1 Implementation of overarching recommended strategies

Progressing toward the goals and milestones of the NRS requires a significant amount of coordination and communication at a statewide level. Programmatic infrastructure is necessary to support coordination and communication among the various local, state, and federal partners. The first set of 2014 NRS recommended strategies focus on developing and sustaining the necessary infrastructure to support coordinated implementation and communication on progress over time. Minnesota partner agencies have made substantial progress in implementing these recommendations. Major advances towards the 2014 overarching NRS recommendations are summarized in Table 2. These advances are expanded upon in Appendix A.

Table 2. Progress made towards implementation of overarching strategies.

Strategy	Major Advances since 2014
Develop a Statewide NRS Education/ Outreach Campaign	• Governor's 25% by 2025 initiative resulted in over 3,500 public suggestions from over 2,000 attendees • Interaction between shrimpers and Minnesota farmers • Technical Training and Certification Program established in 2015 • Nitrogen Smart Training Program held 36 educational events from 2016 to 2018 • Annual Statewide Nitrogen and Nutrient Management Conferences reaches approximately 400 attendees each year • Annual Conservation Tillage Conference • Agricultural BMP Guidance, Handbook and updates • Minnesota's Public Drainage Manual updates • Minnesota Department of Natural Resource (DNR) workshops and training to lake associations and local government regarding BMPs to reduce phosphorus inputs to waters • Continued updates to the Minnesota Water Research Digital Library. Over 2,800 articles and reports at the end of 2018
Integrate Basin Reduction Needs with Watershed Planning Goals and Efforts	• Advances in Total Maximum Daily Load (TMDL), Watershed Restoration and Protection Strategies (WRAPS), Groundwater Restoration and Protection Strategies (GRAPS), and One Watershed One Plan (1W1P) development o Over 60% of nutrient impaired waters have approved TMDL plans o 53 WRAPS completed in the state o 14 GRAPS completed by the Minnesota Department of Health (MDH) o Comprehensive watershed plans developed through 1W1P for 12 watersheds, 20 under development • Developed lake and stream protection prioritization guidance for use in WRAPS and 1W1Ps. DNR refined its lake phosphorus sensitivity index and associated cost-benefit analysis. • Watershed Conservation Planning Initiative to increase landowner and producer readiness to implement conservation practices in seven major watersheds • Small watershed activities through Section 319, small watersheds focus program, Mississippi River Basin Healthy Watershed Initiative (MRBI), and National Water Quality Initiative (NWQI) programs • 20 watersheds selected as part of the Section 319 Watersheds Focus Program

2.1.2 Agricultural BMPs

To achieve the goals and milestones of the NRS, strategies were identified to support the increased adoption of the agricultural BMPs identified in Chapter 5 of the NRS. These strategies fall into the following categories: Stepping Up Agricultural BMP Implementation in Key Categories; Support for

Advancing BMP Delivery programs; Economic Strategy Options; Education and Involvement Strategies; Research Strategies; and Demonstration Strategies. Major advances towards the 2014 agricultural BMP NRS recommendations are summarized in Table 3. These advances are expanded upon in Appendix A.

Table 3. Progress made towards agricultural BMP strategies.

Strategy	Major Advances since 2014
Stepping Up Agricultural BMP Implementation in Key Categories	
Work with Private Industry to Support Nutrient Reduction to Water	• Minnesota Agricultural Water Quality Certification Program initiated in 2015 and thus far certified 900+ farmers and over 600,000 acres of land • Nitrogen Smart Training Program held 36 educational events from 2016 to 2018 • Annual Statewide Nutrient Management Conference • Minnesota Corn Growers collaborative efforts • Forever Green Initiative • Discovery Farms efforts • Watershed Partnerships, such as the Cedar River Partnership
Increase and Target Cover Crops and Perennial Vegetation	• Forever Green Initiative • A new Minnesota Conservation Reserve Enhancement Program (CREP) began in 2017 • 12,186 acres received funding during the 2017 to 2018 CREP sign-up period • Working Lands Watershed Restoration Feasibility Study and Program Plan • Red River Conservation Easement Program • Nearly 7,000 easements over the lifetime of the Re-Invest in Minnesota Program
Soil Health	• Minnesota Office for Soil Health initiated in 2018 by University of Minnesota and the Board of Water and Soil Resources (BWSR) • Soil Health Specialist position created and filled
Riparian Buffers	• Minnesota's Buffer Law passed in 2015 • Over 99% compliance with Buffer Law along lakes, rivers and streams, and over 90% for public ditches • DNR developed "Innovative Shoreland Standards Showcase" that emphasizes riparian vegetative management standards
Fertilizer Use Efficiencies	• Nitrogen Smart Training Program held 36 educational events from 2016 to 2018 reaching over 500 farmers and over 100 agronomists • 466 trials covering over 32,000 acres of cropland completed since 2015 through the Nutrient Management Initiative • Nitrogen Fertilizer Management Plan completed in 2015; associated Groundwater Protection Rule passed in 2019
Reduced Tillage and Soil Conservation	• Annual Conservation Tillage Conference • Development of Soil Erosion Prediction Tool
Drainage Water Retention and Treatment	• Minnesota's Public Drainage Manual updated in 2016 • Multi-purpose Drainage Management Grant Program developed by BWSR • Several state-led drainage demonstration sites

Support for Advancing BMP Delivery Programs	
Coordinated Federal/State/Local/ Planning to Increase BMP Implementation for Key Categories of BMPs	• Watershed Based Funding Implementation Program pilot began in 2017 and anticipated program finalization in 2021. • Watershed Conservation Planning Initiative's contribution agreement with the BWSR to increase landowner and producer readiness for implementing BMPs in seven major watersheds • USDA programs including the MRBI and NWQI, RCPP, Conservation Stewardship Program (CSP), EQIP, and Agricultural Conservation Easement Program • Source Water Protection Program for surface waters developed by the MDH in 2017
Increase Delivery of Industry-Led BMP Implementation	• Minnesota Agricultural Water Quality Certification Program • 4R Certification Program for Minnesota led by agricultural industry expected to be launched in 2020
Study Social and Economic Factors Influencing BMP Adoption	• Social science research at the University of Minnesota's Center for Changing Landscapes
Create a Stable Funding Source to Increase Local Capacity to Deliver Agricultural BMPs	• Clean Water Fund provided between $50 and $74 million implementation funding per year over the last 5 years • Watershed Based Funding Implementation Program • Federal 319 Nonpoint Source Pollution Program continuation • A new Minnesota CREP began in 2017
Economic Strategy Options	
Nutrient BMP Crop Insurance Program	• Environmental Initiative is evaluating how cover crops reduce risk to producers and therefore should require less cost for crop insurance
Develop Markets and Technologies for Use of Perennials	• High value commodity crops for conservation being developed through the Forever Green Initiative with the University of Minnesota • The Forever Green Initiative hired a Supply Chain Development Specialist and Market Development Opportunity Specialist in 2019
Quantify Public Environmental Benefits of Reducing Nutrient Levels in Water	• Social science research at the University of Minnesota's Center for Changing Landscapes • 2018 Nitrate Report: Community Public Water Systems by the MDH • New academic research papers including: o The social costs of nitrogen (Keeler et al. 2016) Land-use changes and costs to rural households: a case study in groundwater nitrate contamination (Keeler et al. 2014)
Education and Involvement Strategies	
Targeted Outreach and Education Campaign with Expanded Public-Private Partnerships	• Nitrogen Smart Training Program • (see also Table 2)
Encourage Participation in the Agricultural Water Quality Certification Program	• Minnesota Agricultural Water Quality Certification Program initiated in 2015 and certified 900+ farmers representing over 600,000 acres of land

Focus Education and Technical Assistance to Co-Op Agronomists and Certified Crop Advisors	• Nitrogen Fertilizer and Education Promotion Team led by the Minnesota Department of Agriculture (MDA) • Annual statewide Nitrogen and Nutrient Management Conferences • Nutrient Management Initiative https://www.pca.state.mn.us/sites/default/files/wq-ws1-29.pdf • 4R Certification Program under development in Minnesota by private industry
Involve Agricultural Producers in Identifying Feasible Strategies	• Formation of the Agricultural Water Quality Solutions Workgroup by the MDA and Environmental Initiative • Final recommended framework to establish and fund voluntary Farmer-Led Councils presented to Governor in 2017 • Governor's 25% by 2025 initiative resulted in over 3,500 public suggestions from over 2,000 attendees
Watershed Hero Awards	• Agricultural Water Quality Certification awards 10-year certification to farmers for achieving defined standards of water quality protection
Work with SWCDs, MDA, and University of Minnesota Extension to Increase Education and Involvement	• Annual Statewide Nitrogen and Nutrient Management Conferences • (see also Table 2)
Promote Youth-Based Nutrient Reduction Education	• While this may have advanced, the authors of this report are not aware of major advancements
Research Strategies	
Consolidate and Prioritize Research Objectives **Conduct Research Activities**	• Minnesota Water Research Digital Library • Minnesota's Agricultural BMP Handbook updated with new research in 2017 • University of Minnesota research progress on drainage water management, in-field nitrogen management, benefits of reduced tillage, and living cover practices • Forever Green Initiative • MDA Clean Water Research Program • Met Council/University of Minnesota evaluation of sludge incinerator ash as a phosphorus source for crop production
Demonstration Strategies	
Watershed Scale Nutrient Reduction Demonstration Projects	• Several watershed projects in state including the Root River Field to Stream Partnership
Field Scale BMP Demonstration Projects	• Field and farm scale monitoring of BMP demonstration projects through Minnesota's Discovery Farms Program, Root River Field to Stream Partnership, Red River Valley Drainage Water Management Project, and Clay County Drainage Site • BWSR grant and cover crop demonstration program launched in 2019 • Demonstration practices in public water supply recharge areas

2.1.3 Wastewater

The Phosphorus Strategy and Rule discussed in the NRS has and will continue to address phosphorus reductions in wastewater. To address nitrogen in wastewater, the NRS provided a series of steps. The steps are intended to build the knowledge base and generate the data necessary to support informed decisions and investments and were intended to be completed in order. Major advances towards the 2014 wastewater NRS recommendations are summarized in Table 4. These advances are expanded upon in Appendix A.

Table 4. Progress made towards implementing wastewater strategies.

Strategy	Major Advances since 2014
Continued Implementation of the Current Phosphorus Strategy and Rule	• Phosphorus effluent limit reviews for half of the watersheds in the state • Total phosphorus effluent limits set for 271 facilities • Reductions in phosphorus discharges to all major basins • Regulatory Certainty legislation (for wastewater)
Influent and Effluent Nitrogen Monitoring at Wastewater Treatment Plants (Step 1)	• Minnesota's Nitrogen Monitoring Implementation Plan approved in 2014 • Wastewater nitrogen monitoring required at more than 450 facilities
Nitrogen Management Plans for Wastewater Treatment Facilities (Step 2)	• MPCA identifying steps to provide more direction for implementing Step 2 of the NRS Wastewater Nitrogen Reduction Strategy
Nitrogen Effluent Limits as Necessary (Step 3)	• Regulatory Certainty legislation (for wastewater) • MPCA is in the process of evaluating recently completed national scientific studies of nitrate effects on aquatic life toxicity for furthering nitrate standards development. When completed, these limits will inform wastewater permits, but the process is independent of the National Pollutant Discharge Elimination System (NPDES) program. • Currently nine surface water discharge permits with total nitrogen or nitrate limits
Add Nitrogen Removal Capacity with Facility Upgrades (Step 4)	• This step is contingent on the previous steps
Point Source to Nonpoint Source Trading (Step 5)	• New trading opportunities being considered throughout state, as interest in water quality trading is expressed

2.1.4 Miscellaneous sources

The NRS did not recommend significant new strategies to reduce loads from subsurface sewage treatment systems (SSTS), urban/suburban stormwater, feedlots, and sediment; however, continuation of existing programs was identified as a strategy. Major advances towards the 2014 NRS recommendations for miscellaneous sources are summarized in Table 5. These advances are expanded upon in Appendix A.

Table 5. Progress made towards implementation of strategies to address miscellaneous sources.

Strategy	Major Advances since 2014
SSTS Strategies	• Continued implementation of SSTS inspections • SSTSs with direct outlets to land surface estimated at less than 5% of all systems in the state. Several small community systems also fixed • Education and outreach efforts led by the University of Minnesota Onsite Sewage Treatment Program
Feedlot Strategies	• Continued implementation of feedlot inspection program through state and delegated counties • Increased inspection of land application of manure practices • Improved Feedlot Program inspection checklist and tracking of inspection results • Manure and Water Quality Specialist position created and filled by the University of Minnesota in 2017 • Manure and fertilizer Nutrient use evaluation tool developed by EWG
Nutrient Reduction Associated with Regulated Stormwater Sources	• Minnesota's municipal separate storm sewer system (MS4) general permit to be reissued in 2020 – currently 251 MS4s with stormwater permits • Minnesota's construction general permit reissued in 2018 • Minnesota's industrial stormwater multi-sector general permit reissuance in 2020
Stormwater Technical Assistance	• Continued updates to the Minnesota Stormwater Manual
Stormwater Research and Demonstration	• Minnesota Stormwater Research Council was formed in 2016 • 2018 Stormwater Research Road Map and Framework • Various research activities being conducted by the MPCA and University of Minnesota
Sediment Reduction Strategies	• Minnesota Sediment Reduction Strategy completed in 2015 • DNR standardizing approaches to targeting and prioritizing watershed upland sediment reduction and channel restoration and advancing floodplain culvert technologies at road/river crossings • Multiple TMDLs and sediment modeling efforts completed in the past five years, along with research and monitoring advancements

2.1.5 Protection strategies

The NRS states that protection strategies are needed in watersheds with anticipated changes in agriculture and land use practices, as well as vulnerable groundwater drinking water supplies. In addition, protection strategies for new nitrogen sources, soil phosphorus increases, and the need to be more protective from increasing precipitation are important elements that WRAPS and local water planning (e.g., 1W1P) should address. Major advances towards the 2014 protection NRS recommendations are summarized in Tqable 6. These advances are expanded upon in Appendix A.

Table 6. Progress made towards implementation of protection strategies.

Strategy	Major Advances since 2014
Protecting the Red River from Nitrate Increases	• Flood control and water retention efforts by the Red River Watershed Management Board • Red River Valley Drainage Water Management Project
Lake Superior Nutrient Load	• While this may have advanced, the authors of this report are not aware of major advancements apart from what has been previously noted about progress with misc. sources.
Groundwater Protection Strategies	• Nitrogen Fertilizer Management Plan completed in 2015; associated Groundwater Protection Rule adopted by MDA in 2019 o Fall fertilizer and frozen soil application restrictions set to start Fall 2020 o Development of a vulnerable groundwater area map • Agricultural BMP Practices Booklet for Groundwater

Summary of Progress Made Towards NRS Strategies

Why important

- The NRS identified needs for numerous state, local, private industry, and federal program advances, recognizing that a multi-pronged approach was going to be needed to achieve large-scale progress toward milestones.
- To understand progress with NRS implementation, state-level program advances need to be assessed, in addition to evaluating the actual changes on the land and in the water.

Findings

- Minnesota has advanced almost every major program area identified in the NRS for implementing nutrient reductions. Considerable progress has been made in establishing and/or advancing over 30 programs; described in more detail in Appendix A.
- Some of the programs have documented nutrient progress on hundreds of thousands of acres. The effects of other programs are more difficult to quantify and/or need much more time to reach their full potential to reduce nutrients in water.
- The sufficiency of program advancements to ultimately achieve the large-scale changes needed to meet milestones was not quantified. While program advancements are making a difference, the magnitude of needed change is so high that current program implementation approaches alone may not be enough to reach NRS goals.

Follow-up

- Ongoing improvement and continued implementation of state-level programs is needed for long-term success:
  - The Agricultural Water Quality Certification Program has grown considerably (now with more than a half million acres) and shows much more potential.
  - The Forever Green program has recently received increased funding to further develop marketable cover crops and perennials.
  - Public/private partnerships have recently been initiated and need time to expand and multiply.
  - Private industry 4R certification has been designed for Minnesota but will not begin until later in 2020.
  - WRAPS have now been completed for 53 watersheds and comprehensive local watershed plans completed in multiple watersheds. Time is needed to implement these plans and complete others, with an increasing emphasis on achieving multiple benefits and protecting both local and downstream waters.
- Greater state investment in program implementation is necessary for success with key strategies such as:
  - Building soil health with cover crops, reduced tillage, and perennial crops;
  - Municipal wastewater treatment for total nitrogen reduction; and
  - Programs to promote construction of wetlands and other water storage for tile-drainage water retention and treatment.

2.2 Information needed to track progress

Minnesota has also made significant progress in developing tracking mechanisms that help to account for progress made towards NRS goals and milestones, as provided in Chapter 7 of the NRS. Additional information on advances made in tracking mechanisms is provided in Section 4.2.1.

BMP implementation and evaluation

- Minnesota's Clean Water Legacy Act requires that MPCA report actions taken in Minnesota's watersheds to meet water-quality goals and milestones (Minn. Stat. §114D.26, subd. 2). To meet this requirement the MPCA developed the "Healthier watersheds: Tracking the actions taken" webpage on the MPCA website. Water quality protection and restoration BMP adoption levels implemented through government support programs can be found at the HUC-8 and HUC-12 watershed scales at: https://www.pca.state.mn.us/water/best-management-practices-implemented-watershed. This information is also aggregated and graphed for major river basins and statewide so that it can be used to evaluate progress toward the 2014 NRS goals. The statewide and major drainage basin BMP numbers and graphs can be found at Nutrient Reduction Strategy BMPs - adoption through government programs.
- Satellite aerial imagery analysis projects initiated through a partnership between BWSR and the University of Minnesota within the past five years are beginning to provide a more comprehensive view of soil conservation practices. This project is moving from prototype development into production mode in 2020 and 2021. Information from these projects, integrated with information from other sources such as the U.S. Census of Agriculture, can provide insights into the cumulative progress of living cover and field erosion control adopted through government programs and private adoption.
- Various other sources of information are available to help track activities occurring on private lands, including the U.S. Census of Agriculture and nitrogen fertilizer use farmer surveys, along with fertilizer sales records.

Improved watershed and BMP targeting planning tools

Multiple advancements have been made to aid watershed and conservation planners with identifying priority practices, scales of needed adoption, priority geographic areas and expected effects on nutrient and sediment load reductions to waters. Hydrological Simulation Program – FORTRAN (HSPF) models have been developed for most of the major watersheds in the state. Prioritize, Target, and Measure Application (PTMApp), HSPF Scenario Application Manager (HSPF-SAM), and Agricultural Conservation Planning Framework (ACPF) are three examples of new modeling tools that simulate nutrient and sediment reductions associated with BMP implementation. HSPF-SAM now includes updated BMP nutrient reduction efficiencies, using new information that was not available for the 2014 NRS. These tools and several other watershed planning tools and models are described at https://bwsr.state.mn.us/water-quality-tools-and-models.

Water quality monitoring evaluation

Minnesota dramatically increased its river and stream monitoring programs beginning in 2007. Ongoing nutrient load monitoring through the Watershed Pollutant Load Monitoring Network occurs on every major river throughout the state. The Minnesota Pollution Control Agency (MPCA) began a new monitoring program for large rivers in 2013, starting with the Mississippi River from its headwaters to St. Anthony Falls. Another river was started in each of the following years. The MPCA is working with the other border states to develop uniform monitoring and assessment processes. Trends in river nutrients are discussed in Section 3 of this progress report. More information on MPCA's monitoring programs is available at: https://www.pca.state.mn.us/water/water-monitoring-and-assessment.

Summary of Progress Made on Information Tracking

Why important

- Tracking and gauging progress on the land and in the water is needed so that adjustments can be made over time to improve NRS implementation.
- Time lags exist between program development, watershed planning, BMP adoption and outcomes in water. Tracking each step allows estimation of the potential for success well before observing outcomes in the water.
- Tracking NRS implementation increases Minnesota's accountability to in-state and downstream stakeholders.

Findings

- Significant progress has been made on ways to evaluate BMP adoption, including the development of the Healthier Watersheds tracking system, advances in satellite imagery to map BMPs, along with previously established tracking via surveys, regulatory reports, sales records, and other records.
- Improved watershed BMP targeting and planning tools, including HSPF-SAM and PTMApp, are increasingly used throughout Minnesota.
- Watershed Pollutant Load Monitoring occurs on every major river in Minnesota.

Follow-up

- Continued monitoring and tracking efforts are needed, including continuation and improvement of:
    - Long-term water monitoring programs to assess and re-assess long-term trends.
    - Government program BMP acreages shown in the "Healthier Watersheds" website.
    - Research and expansion of satellite imagery and other techniques to track the combination of BMPs adopted privately and through government programs.

3 In the water – What can we tell so far?

Nutrient water quality trends over time in Minnesota's waters are important metrics used to assess outcomes related to NRS efforts. While nutrient water quality trends provide useful indications of progress toward final outcomes, for a variety of reasons these types of trends are often challenging and complex when trying to associate results with NRS activities. This section presents an analysis of nutrient water quality trends and an overview of other water nutrient monitoring efforts in Minnesota.

3.1 External factors affecting nutrient water quality trends

Many factors affect nutrient water quality trends. External factors, such as land use changes, climate, drainage, and human and livestock population trends can influence nutrient delivery in a watershed or basin. As new BMPs are adopted, these other influences can either increase or decrease the expected nutrient reductions in waters. As a result, these factors might overshadow the effects of adopted BMPs in reducing nutrients.

Understanding external influences on water nutrient trends provides important context for comprehensively and objectively evaluating overall progress toward NRS milestones and goals. A summary of recent changes for key external factors is provided below. Additional information on each factor is provided in Appendix B.

- **Population.** Increases in human population influence domestic wastewater generation, as well as the amount of impervious surface cover and associated surface runoff. Minnesota's population increased 6.1% from 2010 to 2018, totaling 5,629,416 people. Livestock and poultry populations can influence the amount of manure generated. These populations changed slightly between 2012 and 2017, with hogs and pigs seeing the highest increase of 11% (NASS).
- **Precipitation.** The amount and timing of precipitation influences how much water soaks into the ground or runs off directly into lakes, rivers, and wetlands. Annual precipitation has increased at an especially high rate since 2007 in southern Minnesota. In addition, Minnesota experiences more frequent mega rains (over 6 inches of rain across 1,000 or more square miles) in recent years compared to decades past.
- **River flow.** Increases in river flow can cause increased streambank and bluff erosion, which is the largest source of sediment in many rivers. Since soil phosphorus is attached to the eroded sediment, the flow increases can also result in total phosphorus increases. During the past 20 years, streamflow in the Minnesota River increased by 68% at Jordan and 75% near the river's mouth at Fort Snelling. It is particularly challenging to achieve nonpoint source river nutrient load decreases during periods of river flow increases.
- **Land use.** Changes in urban, agricultural, and wetland acreages affect both runoff water quantity and quality. Developed lands, often characterized by an increase in impervious surfaces, increased by 14.3% from 2010 to 2017 (Blann 2019). Total acres of agricultural land use in Minnesota has remained relatively constant over time; however, the type of crops have changed in past decades to fewer acres of small grains and alfalfa and correspondingly more corn and soybean acres.
- **Irrigation and drainage.** Minnesota's irrigated acres increased by 16.7% from 2012 to 2017 and is up 20.8% since 2007; yet the total amount of irrigated lands remains less than 3% of the total cropland in Minnesota. Minnesota gained 6,550 wetland acres (an increase of 0.060%) from 2009 to 2014. Artificial drainage changes the ways that water and nutrients move through the soil and into surface waters, affecting the amount of nitrate and phosphorus delivered to

waters. According to the 2017 U.S. Census of Agriculture, tile-drained lands increased in Minnesota by 25% between 2012 and 2017, with over 8 million acres of Minnesota land tile-drained, equivalent to approximately half of the total statewide corn and soybean lands.

3.2 River nutrient trends

River nitrate and phosphorus trends analysis is one of several ways that Minnesota tracks long-term progress toward the NRS nutrient reduction goals. Measuring ambient nutrient levels in rivers over long periods of time provides information on the combined effects of changing land uses, management practices, and other factors. Improvements made on the land can sometimes take a significant amount of time—in some instances, decades or more—before these changes become observable water quality changes in rivers. This is especially true where dissolved nutrients such as nitrate flow downward through the soil and into groundwater before slowly flowing underground toward streams.

Understanding flow-adjusted versus non-flow-adjusted approaches

Looking at multiple parameters and using more than one statistical approach results in more complex findings, but the results tell a more complete story about river nutrient trends.

Flow-adjusted approaches use statistical analysis techniques to separate the water quality effects caused by human changes on the land and in cities from those caused by short-term variability in precipitation and river flow.

Non flow-adjusted approaches use statistical analysis techniques that do not try to take flow variability into account. Instead, it shows the actual trends which reflect a combination of human changes in urban and rural areas along with variations in precipitation and river flow.

To gain a more complete understanding of river nutrient trends, Minnesota partner agencies compiled and assessed available water quality data at multiple sites, over different time periods, using both flow-adjusted and non-flow-adjusted statistical analyses. The river nutrient water quality trend analysis primarily focuses on approximate 10-year (recent) and 20-year (mid-range) timeframes. The analysis includes a 40-year (long-term) time frame for certain major rivers with longer monitoring records. Mid-range trends indicate changes since the end of baseline periods established for the Mississippi and Red Rivers. Recent trends provide an indication of short-term changes that follow Minnesota's Clean Water Fund establishment. A 5-year trend (since completing the 2014 NRS) would not necessarily yield meaningful results due to limitations in accurately assessing such short periods of time with water trend statistical methods. Therefore, this analysis did not attempt to assess 5-year statistical trends, but instead includes 5-year rolling average nutrient loads.

To make best use of previous and ongoing efforts to statistically assess river nutrient trends, the analysis incorporates trends generated through the work of three partner organizations as follows:

- **U.S. Geological Survey (USGS)**: Red River Basin (mid-range trends).
- **Metropolitan Council (Met Council)**: Major rivers entering and leaving the Twin Cities Metropolitan area (mid-range and long-term trends), based on recent updates to the work reported by Met Council (Met Council 2018). Met Council updated their work reported in www.metrocouncil.org/river-assessment to also include the years 2016 to 2018 and new river nutrient load trend analyses.
- **MPCA**: In-depth analysis of a few major rivers with associated long-term monitoring results, along with a more simplified analysis of all other rivers monitored by the MPCA for the past 10, 20 and 40 years.

Trends from the past 10, 20 and 40 years show that statewide phosphorus concentrations have generally been decreasing and nitrate concentrations have generally been increasing. However, regional differences exist and many of the sites and timeframes have too much variability to show statistically significant trends.

The discussion below summarizes the mid-range (~20-year) trends conducted by all three organizations and the short-term (~10-year) trend work conducted by the MPCA. Appendix C includes a complete discussion of the river nutrient trend analysis results and methods from the USGS, Met Council, and the MPCA.

3.2.1 Mid-range (20-year) river nutrient concentration trend results

This section presents river trend analysis results for phosphorus and nitrate concentrations.

3.2.1.1 *Phosphorus*

Mid-range flow-adjusted phosphorus concentration trends were determined at major river sites and near the outlets of certain tributaries (Figure 2). A majority of the sites (21 of 28) show decreasing trends ranging from 15% to 55%. Six of the 28 sites had no significant trend detected. The only increase (27%) occurred at Emerson, Canada, at a point on the Red River that is immediately downstream of where the Pembina River (North Dakota and Manitoba watershed) enters the Red River. The Pembina River was found to have increasing phosphorus concentrations during this same period of time (Nustad and Vecchia 2020).

Figure 2. River monitoring site locations at sites with enough information to determine mid-range (approximately 20-year) flow-adjusted phosphorus concentration trends. QWTREND was used to assess trends at mapped sites above, except that the flow-adjusted bootstrapped Seasonal Kendall test was used at tributaries to the Minnesota River, the Sauk River and Kettle River.

Phosphorus concentrations in the Red River have decreased since 2000 in the upstream reaches of the River.

The Mississippi River sites near the Twin Cities had flow-adjusted phosphorus concentration decreases of 21% to 26% over the past two decades, with decreases by as much as 50% detected further downstream at Winona, upstream from the state border with Iowa.

The Minnesota River, a high nutrient-loading tributary to the Mississippi River, has had 20-year phosphorus decreases of about 17%. However, at Jordan, Minnesota, this decrease shifted since about 2009 and appears to be increasing, as described in further detail in Appendix C.

Decreasing phosphorus concentrations do not always translate into statistically significant decreasing loads. This is the case in southern Minnesota where increased precipitation and river flows during the past two decades have increased nonpoint source phosphorus runoff amounts, thereby somewhat offsetting the great progress Minnesota has made through changes in urban and rural areas. At most of the Mississippi River sites in Minnesota a statistically significant downward trend in the phosphorus loads during the past 20 years was not found, except when flow-adjusted statistical techniques were used. Near the state border at Winona, the actual phosphorus loads appear to have decreased, but just not enough to be statistically significant.

3.2.1.2 *Nitrogen*

The predominant form of nitrogen added to waters from human activities is nitrate-N, which is typically measured in laboratories in combination with nitrite-N (e.g. nitrite+nitrate-N). Therefore, this report focuses on nitrite+nitrate trend results, typically referred to as “nitrate.” Total nitrogen trend analyses generally showed similar patterns and trend directions as nitrate, although less statistically significant in some instances. Total nitrogen includes all of the nitrite+nitrate-N, organic nitrogen, and ammonium.

Mid-range flow-adjusted nitrate concentration trend determinations showed increasing trends at half of the sites (14 out of 28) and only 3 of 28 sites showed a decreasing trend (Figure 3). Eleven of the 28 sites had too much variability to confidently determine a significant change. Nitrate concentration increases in the major rivers ranged from 21% to 55%, with nitrate concentrations more than doubling in some tributaries. The only decrease in southern Minnesota over the 20-year period was in the Minnesota River at Fort Snelling. A more in-depth analysis of this site showed a 15% nitrate concentration decrease from 2005 to 2018, but with an increase between 1979 and 2004 that caused an overall long term increase of 21% (1979 to 2018).

The Mississippi River sites near the Twin Cities showed 20-year nitrate concentration increases in the range of 25% to 34%. Just downstream of the Twin Cities, at the Mississippi River in Red Wing, nitrate *loads* increased by 62%, which is a much greater increase than the 25% flow-adjusted nitrate *concentration* increase. Increases in both nitrate concentrations and increases in river flow explain the larger load increase as compared to the flow-adjusted concentration increase. Further downstream at Winona, there is too much variability in river flow and nitrate levels for the 20-year nitrate load trends to be statistically significant.

The Minnesota River, a major tributary to the Mississippi and the largest contributor of nitrate, has had mixed 20-year nitrate trends. Nitrate concentration trends (flow-adjusted) at Jordan, Minnesota have shown increases since 2012. The Minnesota River at Fort Snelling has decreasing nitrate concentrations since 2005. The Minnesota River is heavily tile-drained with shorter lag times between practice changes and observed effects in the river. Other tributaries to the Mississippi River are more heavily influenced by groundwater baseflow, which can have a much longer lag time than tile flow. The Minnesota River also has much higher nitrate concentrations than the Mississippi River, therefore requiring much more nitrate additions to the river to cause an increase as compared to the Mississippi River.

With a few exceptions, the Red River Basin has had increasing nitrate trends during the past 20 years in both the Red River main stem and Minnesota tributaries to the Red River. At the state border with Canada, the Red River nitrate trend was not considered statistically significant.

Figure 3. River monitoring site locations at sites with enough information to determine mid-range (20-year) flow-adjusted nitrate concentration trends. QWTREND was used to assess trends at these sites, except that the flow-adjusted bootstrapped Seasonal Kendall test was used at tributaries to the Minnesota River, the Sauk River and Kettle River.

3.2.2 Recent (10-year) nutrient concentration trend results

The MPCA conducted trends analyses from 2008 to 2017 to evaluate trends occurring during more recent years. This period of time is more closely associated with potential NRS effects as compared to the 20-year trend analyses. Another reason to separately focus on the recent, 10-year, timeframe is because many more sites are available for trend analysis. The MPCA greatly increased river monitoring beginning in 2007 to 2008. One drawback of the shorter-term timeframe is that the fewer years of data tends to reduce the likelihood of observing statistically significant trends.

3.2.2.1 *Phosphorus*

Using flow-adjusted approaches, 10-year phosphorus concentrations were found to be decreasing at 48% (24 of 50) of river sites, with all other sites showing no detectable trend (Figure 4). No sites had an increasing phosphorus concentration trend for this 2008 to 2017 period. The majority of the 10-year decreases were found in the eastern part of the state, with the western and northwestern parts of the state showing mostly non-significant trends. Results were similar when the 10-year phosphorus concentration trends were assessed without using a flow-adjusted approach. When not using flow-adjusted techniques, a few decreasing trends shifted to no-trend, and one site showed an increase. In-depth analysis of recent phosphorus trends for major rivers is available in Appendix C.

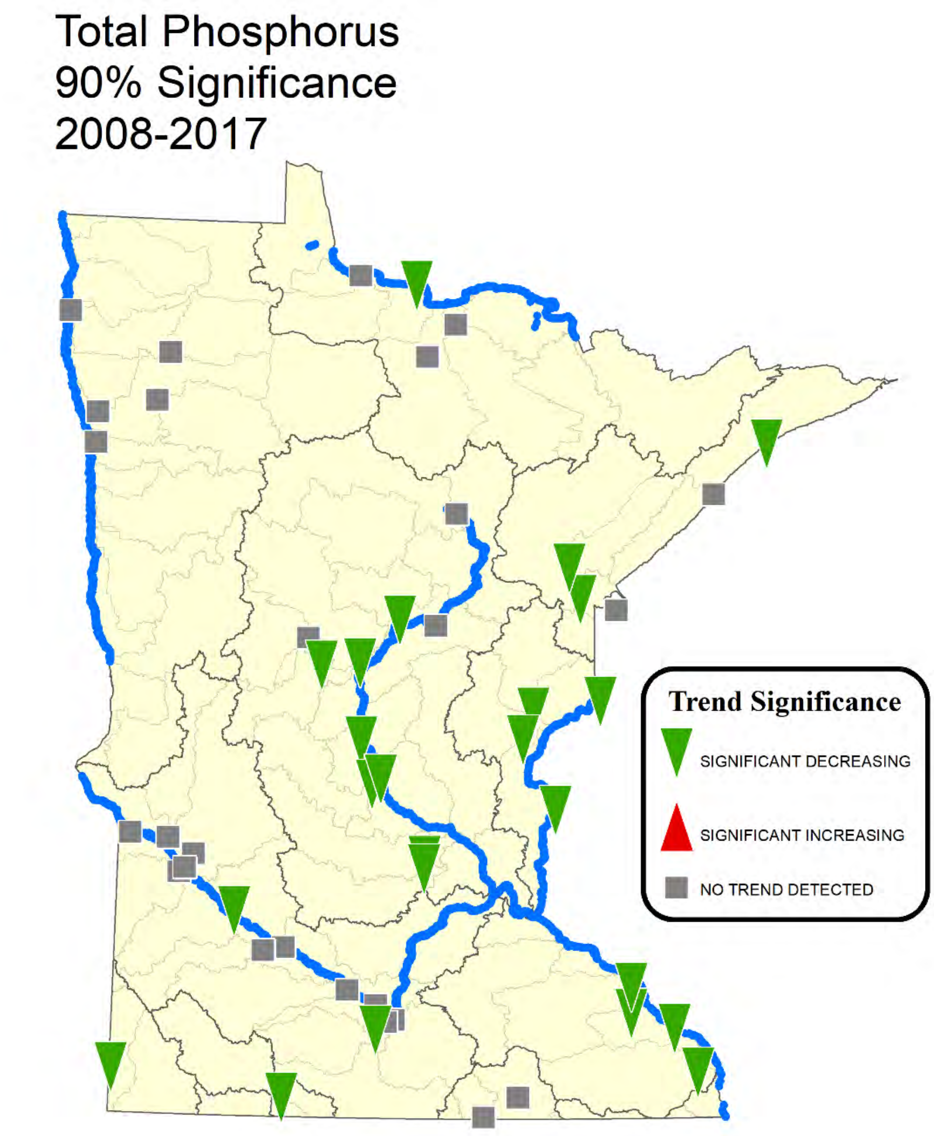


Figure 4. Phosphorus 10-year flow-adjusted concentration trends.

3.2.2.2 *Nitrogen*

Using flow-adjusted techniques for the 10-year period, 37% of sites (14 of 38) that had detectable nitrate levels showed increasing nitrate concentration trends, with the others showing no detectable trend. When using trend analysis techniques that do not adjust for the variability in flow, a higher fraction of sites showed increasing trends (50%), with the others showing non-significant trends. None of the 10-year nitrate trends showed a decrease. The majority of 10-year nitrate concentration trend increases were found in the central and southwestern parts of the state (Figure 5).

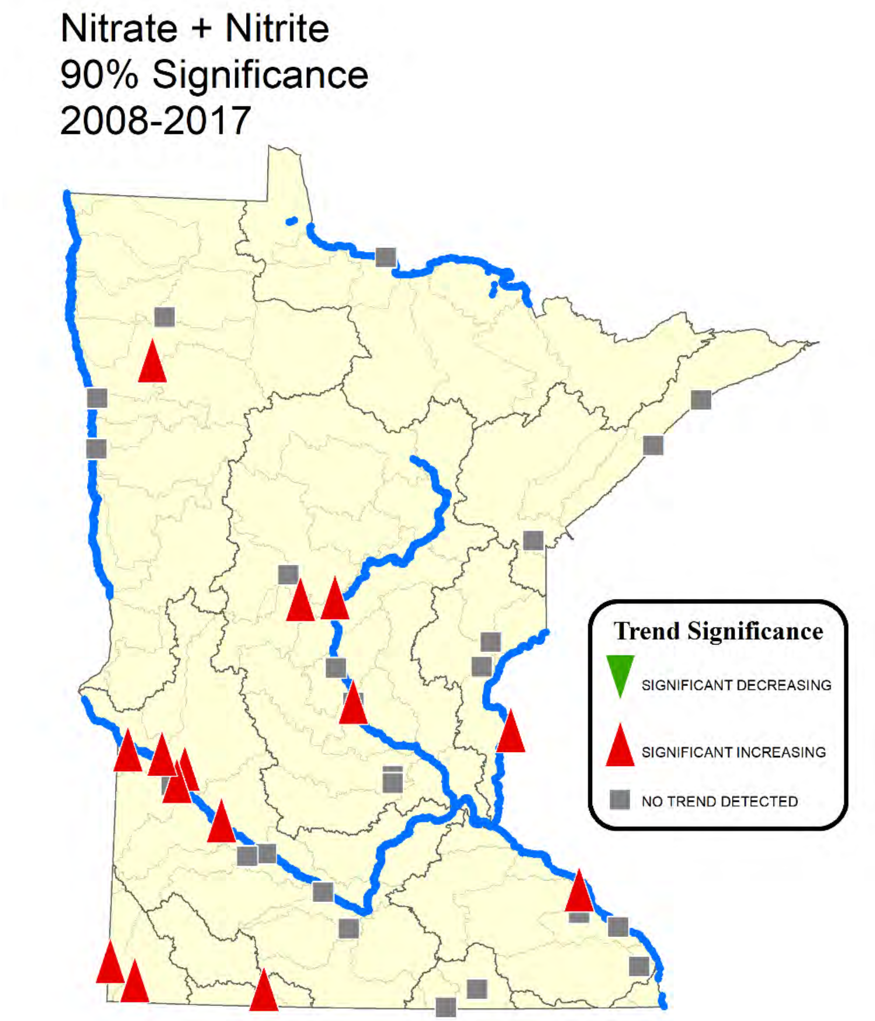


Figure 5. Nitrate plus nitrite 10-year flow-adjusted concentration trends.

3.2.3 Differences between river phosphorus and nitrogen trends

The differences between generally decreasing phosphorus concentration trends and generally increasing nitrogen concentration trends can be explained by differences between nutrient sources, pathways from sources to waters, and Minnesota's progress made toward reductions.

Wastewater discharges, one of the most influential sources of phosphorus in the state (Barr 2004), have decreased by over 70% in the past 20 years. While wastewater nitrogen discharges contribute less than 10% of the nitrogen load to waters, they have increased slightly over the same 20-year timeframe due to both increased population and a limited number of cities that remove total nitrogen from their wastewater.

Row crop agriculture has been the largest source of nitrogen over time. The documented progress in reducing cropland nitrogen losses is not as evident as progress made to reduce cropland phosphorus losses. The substantial adoption of cropland soil and water conservation practices over the years has had a much greater impact on reducing cropland phosphorus than nitrogen. Phosphorus is transported in overland runoff, which can be easier to control, as compared to nitrogen losses that occur largely through subsurface drainage tile lines and groundwater pathways. Since the number of acres that are tile-drained and planted to row-crops in Minnesota has increased over time, those changes may have offset some gains made in improved nitrogen fertilizer and manure management.

Another nutrient source, urban stormwater runoff, is a higher contributor of phosphorus than nitrogen. Minnesota has made significant progress in managing urban stormwater during the past two decades through the state's stormwater permitting program implemented at the municipal level. Additionally, phosphorus fertilizer restrictions have been enacted for lawns and turf.

Lag times are another possible contributing factor for differences in the phosphorus and nitrogen trends. In places where nitrogen is transported to streams and rivers predominantly via groundwater, the lag time between cropland BMP adoption and river improvement can be considerably longer for nitrogen as compared to overland runoff of phosphorus.

Nutrient trends at Mississippi River at Red Wing (Lock and Dam #3)

Minnesota's long-term monitoring site on the Mississippi River at Red Wing (also known as Lock and Dam #3) is important for evaluating nutrient reduction progress throughout much of the state. The location is downstream of the Upper Mississippi River Basin, the Minnesota River Basin, the St. Croix River Basin and the Twin Cities Metropolitan area (Figure 6). This site represents an integrated sample of much of the nutrient pollution that ultimately leaves the state in the Mississippi River. Therefore, nutrient trends at the Red Wing site are key to tracking changes resulting from NRS implementation. It is important to note that not all nutrients reaching this location end up leaving the state; the Red Wing site is upstream of Lake Pepin and other Mississippi River backwaters where some of the nutrients are either temporarily or permanently lost from the river.

Figure 6. Drainage area to Lock and Dam #3.

Met Council results from a statistical analysis in Table 7 shows flow-adjusted phosphorus concentration reductions of 21% and 40% over the past 20 and 40 years, respectively.

Table 7. Statistical trend for total phosphorus concentration in the Mississippi River at Red Wing site (Lock and Dam #3)

Trend Period	Concentration (mg/L)	Change in Conc (%)	Change Rate (mg/L/yr)	*p*	Trend
1976 – 2018	0.17 – 0.10	-41%	-0.0016	< 0.0001	⬇
Overall Trends					
20 years (1999 – 2018)	0.12 – 0.10	-21%	-0.0013	–	⬇
40 years (1979 – 2018)	0.17 – 0.10	-40%	-0.0017	–	⬇

Phosphorus loads at Red Wing show high year-to-year variability (Figure 7). While the 5-year rolling average shows a phosphorus load decrease from 1994 to 2008, a non-flow adjusted analysis of load trends does not show a statistically significant change for either mid-range or long-term periods. This is likely a function of increased average and maximum flow in the river over the past 20 years. While the water has lower phosphorus concentrations, there is more water flow; therefore, the phosphorus load changes are not statistically significant.

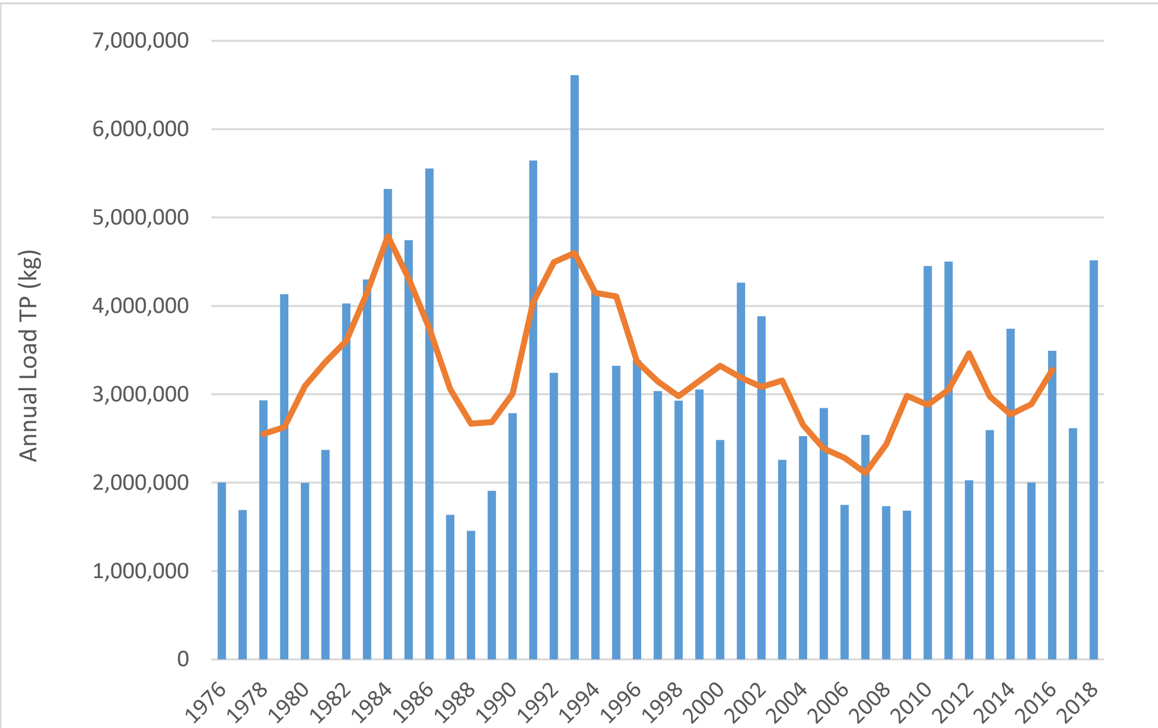


Figure 7. Annual phosphorus loads in the Mississippi River at Red Wing (Lock and Dam 3) and 5-year rolling average load (orange).

Results of the flow-adjusted statistical analysis for nitrate in Table 8 show that flow-adjusted nitrate concentrations in the Mississippi River at Red Wing increased by 25% and 154% over the past 20 and 40 years, respectively. Nitrate concentrations increased markedly from 1976 to 1982, followed by a more gradual increase between 1983 and 2018.

Table 8. Statistical trends for nitrate concentration in the Mississippi River at Red Wing site (Lock and Dam #3)

Trend Period	Concentration (mg/L)	Change in Conc (%)	Change Rate (mg/L/yr)	*p*	Trend
1976 – 1982	0.58 – 1.39	142%	0.12	< 0.0001	⬆
1983 – 2018	1.39 – 2.03	46%	0.018	< 0.0001	⬆
Overall Trends					
20 years (1999 – 2018)	1.62 – 2.03	25%	0.020	–	⬆
40 years (1979 – 2018)	0.80 – 2.02	154%	0.031	–	⬆

Non flow-adjusted loads very greatly from year to year, but overall show increases since 1976 (Figure 8). A statistical analysis of these non-flow-adjusted nitrate load trends showed 62% and 53% increases during the past 20 and 40 years, respectively (Figure 8). This is not surprising since loads reflect the combination of concentrations and river flow, and both have increased. Flows have especially increased during the past 20 years. Both nitrate and total nitrogen loads show a similar pattern over time. More details on the analysis for the Red Wing site, as well as other major river basins, is available in Appendix C.

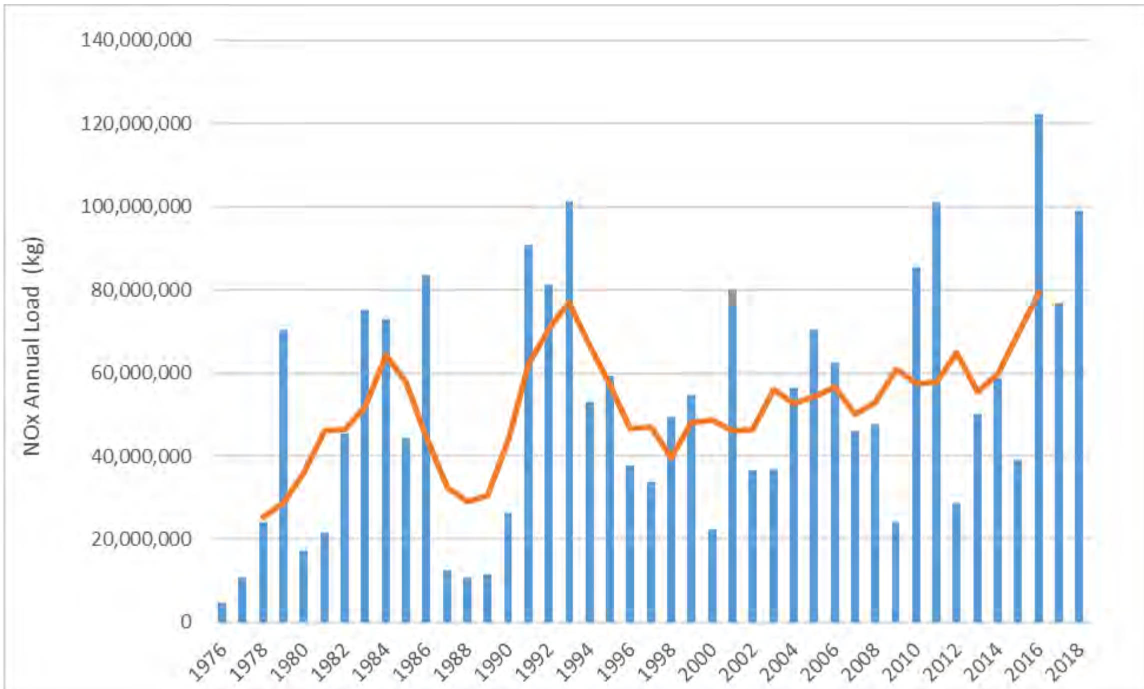


Figure 8. Annual NOx Loads in the Mississippi River at Red Wing (Lock and Dam 3) and 5-year rolling average load (orange).

Summary of Minnesota's Progress in Rivers

Why important

- The NRS aims to achieve measured water nutrient reductions and track our progress toward that outcome.
- Reducing nutrient *concentrations* is important for local water health and drinking water. Reducing nutrient *loads* (total amounts flowing down the river) is important for downstream lakes, reservoirs and the Gulf of Mexico.
- It is important to evaluate water nutrient trends over at least 10 to 20 years because nutrient concentrations and loads are highly variable from year-to-year with changing weather patterns, and because the changes across the landscape can take long periods of time to show observed effects in rivers.
- Changes during the past five years since completion of the NRS (2014-18) have a large effect on the outcomes of the 10 and 20-year trends evaluated for this progress report. However, trends over just a 5-year period is typically too short of time to draw meaningful conclusions about the effects of nutrient-reducing strategies.
- Changes in river nutrients are affected by many factors, in addition to newly adopted BMPs. Flow-adjusted methods are important for assessing trends independent of river flow variability, allowing a more direct evaluation of the effects of human activities.

Findings

- Phosphorus concentrations have generally decreased and nitrate-nitrogen and total nitrogen concentrations have generally increased over the past 10 and 20 years. However, river flow and nutrient concentration variability makes it difficult to confidently show trend directions at many of the monitoring locations.
- *Phosphorus concentration* trends over the past approximate 20 years show mostly decreases (improvements) around the state, with reductions ranging from 15% to 55%. Over the past 10 years, phosphorus concentrations have decreased at nearly half (42%) of 57 monitoring sites evaluated, with all other sites showing no significant trend. This shows that our efforts to reduce phosphorus in recent years have been making a difference.
- *Nitrate concentration* trends over the past approximate 20 years show increases of 20 to 60% in most major rivers. However several sites have no trend detected, and a couple sites showed decreases. Over the past 10 years, nitrate concentrations increased at over one-third of the sites and had no statistically significant trend at the rest. This suggests that efforts to reduce nitrate thus far are either insufficient and/or not enough time has elapsed for the full effects of our efforts to be seen in rivers.
- Increasing precipitation in southern Minnesota over the past two decades has been offsetting the benefits of our phosphorus-reducing activities. As a result, phosphorus load reductions are not statistically significant (i.e. no-trend) in most southern Minnesota rivers, unless statistical methods are used to adjust for river flow variability.

Follow-up

- Continued monitoring will be important to more confidently assess ongoing nutrient changes and the long-term effects of our collective state efforts to reduce river nutrients.
- Follow-up study is needed to help identify the factors contributing to nutrient increases in certain river stretches and decreases in others.

3.3 Small watershed monitoring

The use of small watershed implementation and monitoring programs are very important in Minnesota's NRS approach. The lessons learned from nearly 40 years of nonpoint source pollution management across the nation show the need for long-term, small-scale watershed efforts to increase the likelihood that changes in water quality will occur and be measured. Measured improvements from implementing BMPs in small watersheds can provide other watersheds with information about successful techniques to improve water quality.

While larger-scale (major river basin and hydrologic unit code [HUC-8] major watersheds) monitoring programs provide important overall assessments of water quality conditions and long-term trend analyses, they generally do not provide the data necessary to evaluate changes in water quality attributable to specific sets of management practices. As the watershed size increases, so does the amount of BMP implementation needed to detect changes, the likelihood of undocumented changes occurring, and the length of time required to achieve and measure changes in water quality. A small watershed framework with a strong monitoring component enables Minnesota partner agencies to more clearly connect implementation changes on the land to trends in water quality.

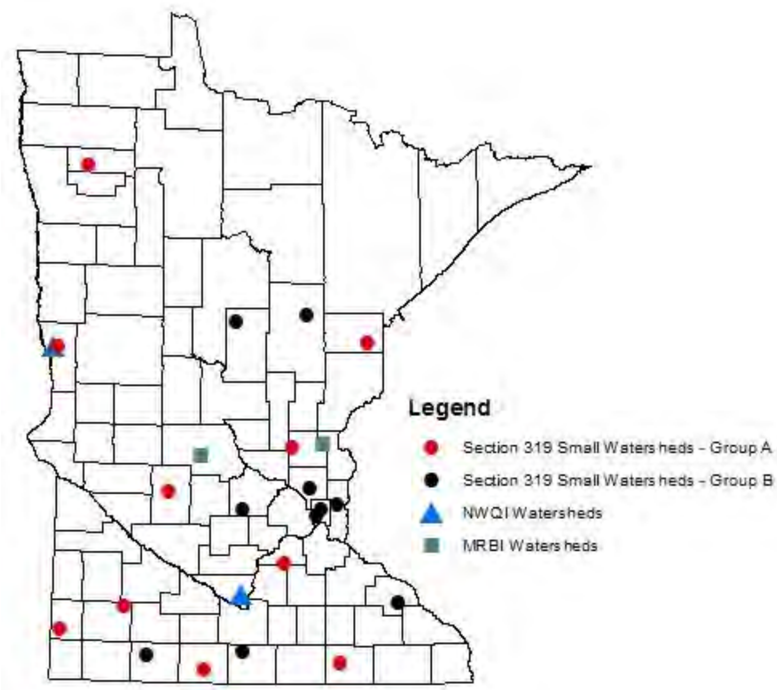


Figure 9. Small watershed monitoring.

The Natural Resources Conservation Service (NRCS) implements both the NWQI and the MRBI in Minnesota. These water quality efforts focus on priority HUC-12 and larger watersheds and have funded efforts such as recent work in the Seven Mile Creek watershed, including effectiveness monitoring. Monitoring and implementation in smaller watersheds are funded through the NWQI, MRBI, and Section 319 Small Watersheds Focus Program (Figure 9). These small watershed programs support small-scale, long-term efforts and provide measurable changes that can be replicated for larger watersheds. Information about these efforts and other small watershed monitoring efforts are described in Appendix A.

3.4 Edge of field monitoring

Edge-of-field monitoring allows us to better understand the factors influencing nutrient delivery to waters. Minnesota is fortunate to have many edge-of-field monitoring programs supported by the agricultural community. The MDA oversees many of these monitoring efforts, which include the Discovery Farms, Root River Field to Stream Partnership, and the Red River Valley Drainage Water Management Project, and others (Figure 10).

Data from on-farm, edge-of-field monitoring sites are used to assess nitrogen, phosphorus and sediment loss at the field scale and to evaluate the effectiveness of conservation practices. Data are also used to support farmer-to-farmer learning and encourage the adoption of conservation practices that protect water resources. In addition, data from edge-of-field projects on small acreages throughout the state are used to improve larger scale models which can show nutrient reduction scenario estimates throughout various watersheds. Example models that have been calibrated with edge-of-field monitoring include: HSPF, Soil and Water Assessment Tool, Agricultural Policy/Environmental eXtender Model, PTMApp, Adapt-N, and the Runoff Risk Advisory Forecast Tool. Without these data, the tools used in the impaired waters process would not be as accurate or refined for conditions in Minnesota.

Key lessons learned across the edge-of-field monitoring locations, as reported by MDA:

- On average, 40-47% of the total surface runoff volume occurs when the soil is frozen.
- Over 50% of the annual phosphorus and sediment losses often occur during 1-2 rain events each year.
- 70-78% of the sediment loss occurs during May and June on fields that lack established crop cover.
- Across the Discovery Farms Minnesota network, nitrogen losses are typically four times higher from subsurface drainage lines compared to surface runoff. Phosphorus losses are typically nine times higher from surface runoff compared to subsurface drainage.

More information on these efforts is provided in Appendix A and https://www.mda.state.mn.us/environment-sustainability/farm-projects.

Small watershed and edge-of-field work should continue during the next five years and results should be carefully studied before making NRS updates.

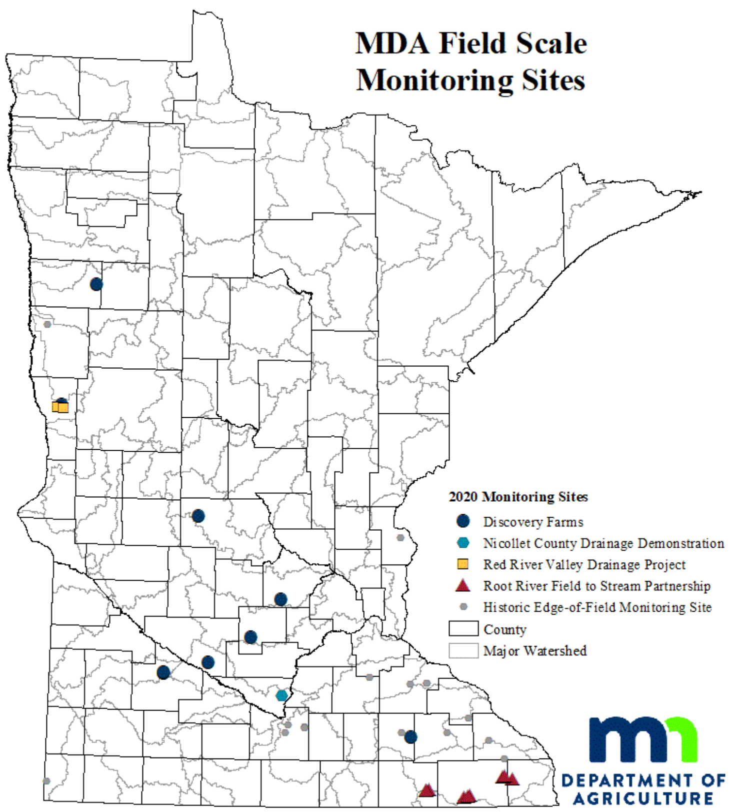


Figure 10. MDA field scale monitoring sites.

3.5 Lake clarity trends

In addition to river nutrient trends, MPCA analyzed lake water clarity trends as one indicator of changes in Minnesota lakes nutrient conditions. While phosphorus can affect lake clarity, it is important to keep in mind that other factors contribute to changes in lake clarity.

Timeframes for this lake clarity trends analysis varies, with the shortest length of monitoring being 2010 to 2018, and the longest 1973 to 2018. A total of 4,796 lakes statewide contained some monitoring data, 1,646 of which met the minimum data requirements and were included in this analysis. Minimum data requirements for lake trend analysis was at least eight years of data and 50 observations.

To be considered an *improving* or *degrading* water clarity trend, a lake must experience a Secchi disk change greater than ½ foot/decade. A lake demonstrating either an improvement or reduction in water clarity that is equal to or less than ½ foot/decade is classified as having *no change* in water clarity trend. A lake that meets the minimum data requirements, but has a non-significant statistical result (i.e., the p value is less than 0.05), is considered to have *no trend* detected at this time.

Of the 1,646 lakes analyzed for trends, 29% were observed to be improving, while 11% saw degrading water quality over the 2010 to 2018 period (Figure 11 and Figure 12). In other words, lakes are getting clearer in nearly three times as many lakes as those showing worsening water clarity. While the larger number of lakes with improving clarity is encouraging, this analysis did not confirm that the improved clarity is the direct result of decreasing phosphorus loads into those lakes. Determining the causes for the improved clarity requires additional study and will vary from one lake to another.

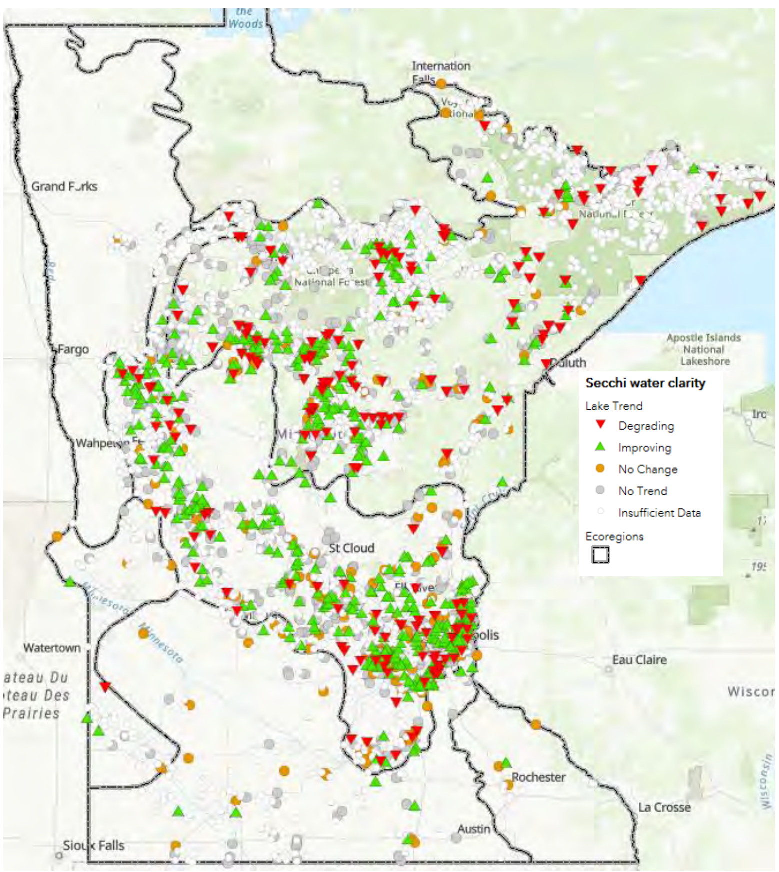


Figure 11. Map of lake clarity trends in Minnesota.
https://www.pca.state.mn.us/water/transparency-trends

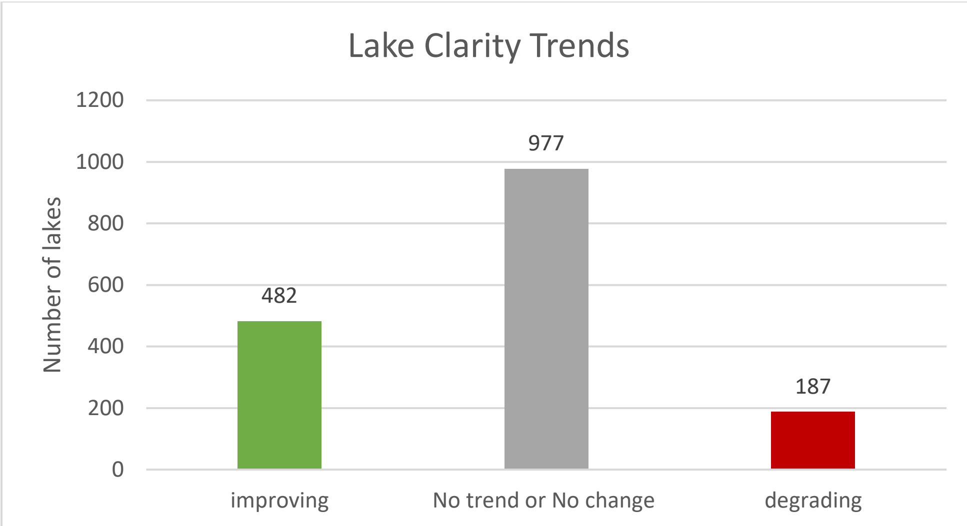


Figure 12. Lake clarity trends in Minnesota.

Lake Pepin phosphorus

Lake Pepin receives nutrients from most of the Mississippi River Basin drainage in Minnesota and has battled eutrophication for many years. Since the mid-1990s, the USGS Long-Term Resource Monitoring Program has served as the principal source of data for Lake Pepin. MPCA used water quality data collected at four USGS sampling stations to characterize average total phosphorus and chlorophyll-*a* concentrations for the most recent 10-year period (2008 to 2017). Chlorophyll-*a* is an indicator of algae growth driven partly by phosphorus. Over the most recent 10-year period, there is a decreasing trend in both phosphorus concentration and chlorophyll-*a* (Figure 13 and Figure 14). The improvement in Lake Pepin water quality coincides with Mississippi River decreases in total phosphorus concentrations.

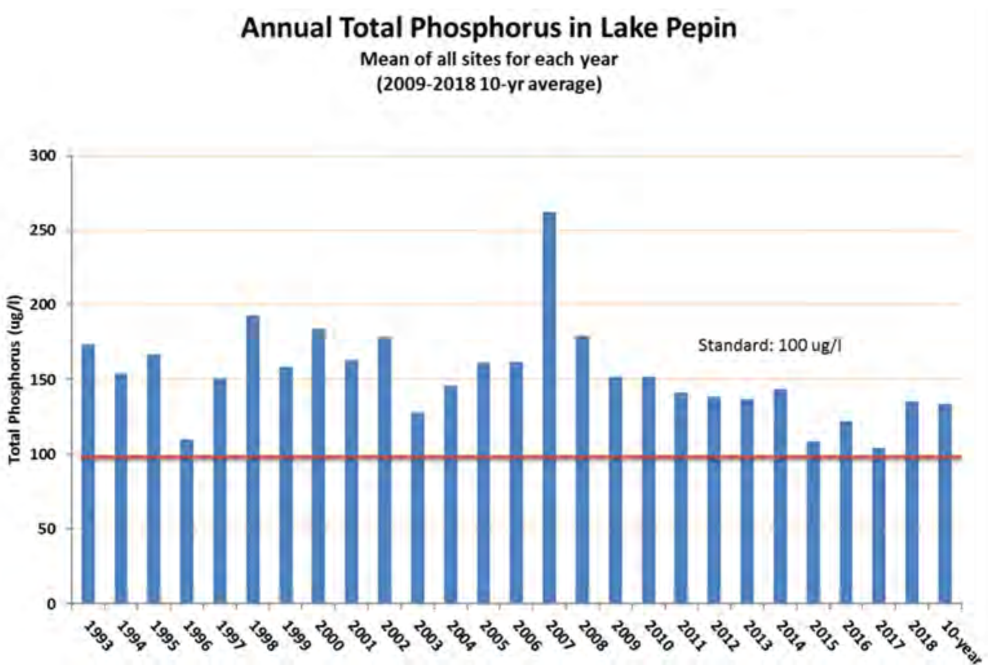


Figure 13. Mean annual total phosphorous in Lake Pepin summarized into a composite concentration from four monitoring stations.

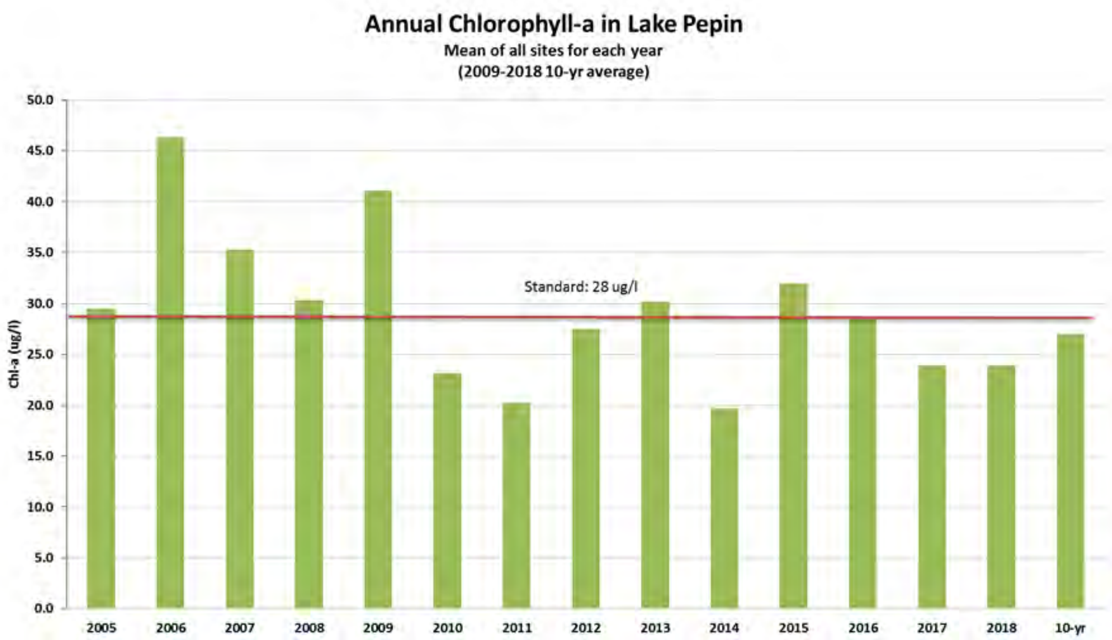


Figure 14. Mean annual chlorophyll-*a* in Lake Pepin summarized into composite concentration from the four monitoring stations (MPCA 2019a).

3.6 Groundwater nitrate trends

Groundwater nitrate is a concern for well water consumption in many parts of Minnesota and as a contributor of nitrate to surface waters. Groundwater baseflow nitrate contributions to rivers depends on the geology, groundwater flow pathways, and time of transport between groundwater recharge area and re-emergence into rivers. River nitrate concentrations and loads often represent a broad-scale mixing of multiple waters, including surface water runoff, groundwater baseflow, and agricultural and urban drainage waters. Some groundwater nitrate can reach surface waters before the nitrate is lost to the atmosphere (as nitrogen gas through denitrification processes). Therefore, studying trends in groundwater nitrate can help inform progress evaluation of river and stream nitrogen goals.

Wells constructed into an aquifer can provide an indication of nitrate concentrations at a discrete point and depth within the groundwater system. Since well water nitrate concentrations often vary greatly within short distances both horizontally and vertically, many wells are often needed to characterize groundwater nitrate concentrations and trends in a given area. The Minnesota Geological Survey recently reported on how greatly hydrogeologic controls affect groundwater nitrate load contributions to surface waters in southeastern Minnesota (https://conservancy.umn.edu/handle/11299/162612). It is important to recognize such limitations and complexities in well-water sampling when evaluating groundwater nitrate trends.

The MPCA and MDA each maintain their own ambient groundwater-monitoring network that, when combined, covers a variety of conditions across the state. The MPCA's ambient groundwater monitoring primarily targets aquifers in urban parts of the state, and most of the MDA's monitoring is performed in agricultural areas. A recently released *Condition of Minnesota's Groundwater Quality* report included a nitrate trend analysis from 117 wells monitored from 2005-2017 by MPCA and MDA (MPCA 2019b).

Statistical analysis of these 117 wells in the upper-most aquifers showed 74 (63%) of the individual wells with no statistically significant change in nitrate concentrations, 19 sites (16%) having significant increases, and 24 sites (21%) having significant decreases in nitrate concentrations (Figure 15**Error! Reference source not found.**). The sites with significant upward or downward trends were scattered throughout the state and generally did not appear to be located within any specific region or land use setting. The report provides some clues about changes in groundwater nitrate levels in recent years but is largely inconclusive about nitrate trends, overall.

Additionally, MDA recently reported on well water nitrate trends results from two Volunteer Nitrate Monitoring Networks in Minnesota (Kaiser et al. 2019). Southeastern Minnesota well water nitrate showed no statistically significant trend between 2008 and 2019 with 5778 samples taken. However, the Central Minnesota Sands private well network showed a slight downward trend between 2011 and 2019 with 3768 samples taken.

MDA also manages a broader domestic well monitoring program and tested 30,769 domestic wells in geologically vulnerable agricultural areas between 2013 and 2018.

4 On our cropland – Are we on track for the needed scale of BMP adoption?

This section examines agricultural BMP adoption from 2014 to 2018 in the same four general categories of practices outlined in the 2014 NRS scenarios. It addresses the example BMP adoption scenarios put forth in the 2014 NRS, the methods and assumptions for assessing BMP adoption, and discussion of BMP adoption for the following categories of practices:

- Crop nutrient management efficiency (fertilizer and manure)
- Living cover
- Field erosion control
- Drainage water treatment and storage

The ongoing township groundwater testing program has provided an increased understanding of the locations and magnitude of high nitrate wells in Minnesota (Figure 16). The results show that 9.2% of the wells in these vulnerable areas had nitrate-N exceeding the 10 mg/l Health Risk Limit. Well water nitrate concentrations are particularly high in southeastern, southwestern and central Minnesota. More info at https://www.mda.state.mn.us/township-testing-program.

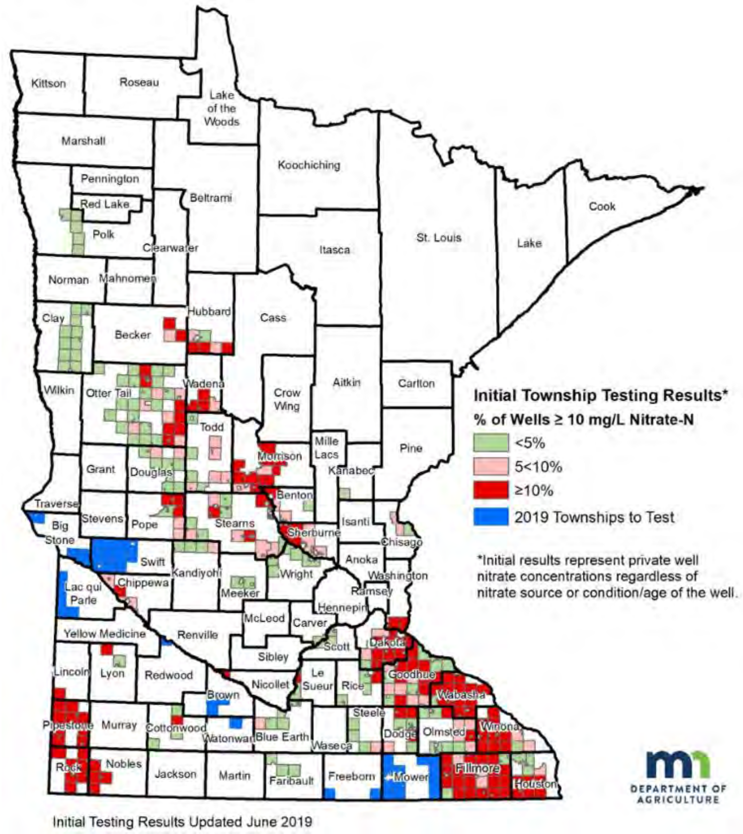


Figure 15. Private well nitrate testing - MDA Township Testing Program results.

5 On our cropland – Are we on track for the needed scale of BMP adoption?

This section examines agricultural BMP adoption from 2014 to 2018 in the same four general categories of practices outlined in the 2014 NRS scenarios. It addresses the example BMP adoption scenarios put forth in the 2014 NRS, the methods and assumptions for assessing BMP adoption, and discussion of BMP adoption for the following categories of practices:

- Crop nutrient management efficiency (fertilizer and manure)
- Living cover
- Field erosion control
- Drainage water treatment and storage

Several sources of data are used as indicators of the general scale of agricultural BMP adoption in the state of Minnesota through a) government supported programs and b) overall BMP adoption reflecting a combination of government-supported and private adoption. These BMPs are just one important factor affecting overall change on the land and in the water. Cropland changes over time (Figure 17, population trends, climate and land use changes, and river flow are additional factors that affect nutrients. Recent changes in these factors are described in Appendix B.

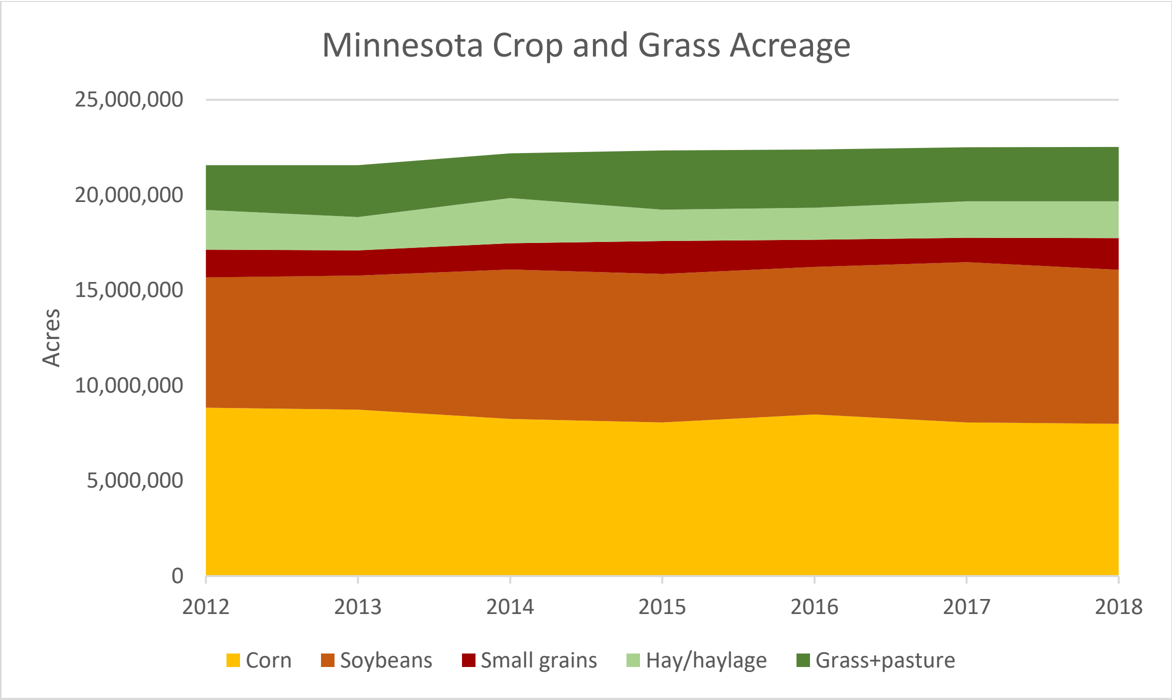


Figure 16. Statewide crop and grass/pasture acreage changes between 2012 and 2018 as identified from Crop Data Layer (CDL).

5.1 Agriculture BMP adoption scenario goals

To guide Minnesota's progress toward the 2014 NRS nutrient reduction goals, the 2014 NRS included example cropland BMP scenarios. These scenarios serve as examples of the level of BMP adoption needed to achieve the nutrient reduction goals and milestones in major river basins, when combined with point source nutrient reductions and other reductions. BMP scenarios included identification of BMPs and adoption rates which were intended to maximize the combination of BMP effectiveness, cost and practice acceptability.

Several million acres of needed BMP additions were identified in the Mississippi River and Red River Basins (Table 9 and Figure 14). For both basins, "total BMP acres" assumes that nitrogen and phosphorus reduction BMPs are on the same lands. For example, cover crop acres to achieve nitrogen reduction are the same cover crop acres that will achieve phosphorus reduction. However, when local watershed prioritization for phosphorus and nitrogen reduction are in different areas, the total needed acreages may be higher than shown in Table 9 and Figure 17. More acres of agricultural BMPs are needed to meet the milestones in the Mississippi River Basin than the Red River Basin (Table 10).

In general, the approach for nitrogen reduction from cropland includes increasing fertilizer and manure use efficiency by optimizing nutrient management, treating tile drainage waters, and implementing living cover BMPs such as cover crops and perennials. Phosphorus reductions from cropland are based largely on optimizing fertilizer and manure application, subsurface banding or injection of fertilizer/manure, reducing soil erosion, and adding riparian buffers and other living cover on the landscape.

Nutrient reduction milestones and final goals for downstream waters

Phosphorus

- 12% reduction for the Mississippi River Basin (thus meeting the overall 45% reduction needed to meet the goal)
- 10% milestone reduction in Minnesota's Red River portion of the Lake Winnipeg Basin on the way to a 50% reduction goal

Nitrogen

- 20% reduction as a milestone on the way to a final 45% reduction goal for the Mississippi River Basin
- 13% milestone reduction for the Red River Basin on the way to a 50% reduction goal

Table 9. Example combined basin scenario from 2014 NRS to achieve milestones.

Agricultural BMP categories	Combined Basin Total (Mississippi River and Red River Basin)		
	Nitrogen BMP acres	Phosphorus BMP acres	Total BMP acres [b]
Field Erosion Control	0	4,900,000	4,900,000
Increasing Fertilizer Use Efficiencies [a]	6,800,000	2,200,000	6,800,000+
Drainage Water Retention and Treatment	620,000	0	620,000
Increase and Target Living Cover			
Perennials	440,000	440,000	440,000
Cover crops	1,900,000	1,400,000	1,900,000

a. Table 5-15 in the 2014 NRS shows a statewide total acreage for nitrogen fertilizer management of 80% of corn acres, or 11,900,000 acres of the 14,875,000 statewide acres of corn/soybean rotations. The BMP used in the 2014 NRS scenario was to decrease the industry average fertilizer rate on those 11,900,000 acres. It is useful to translate the industry average acreages to the actual number of acres that could be more optimally managed for nitrogen fertilizer. A fertilizer use survey report published by the MDA around the time the NRS was finalized showed that 57% of corn following soybean lands could lower rates to align with University of Minnesota recommended economically optimum nitrogen rates (MDA 2014). Using these findings, the total number of acres that could achieve nitrogen fertilizer reductions based on the 2012-2014 timeframe would be 6,783,000 corn/soybean acres (57% of 11,900,000 acres). Note that 2016 and 2019 increases in University of Minnesota recommended nitrogen rates lower this fraction of cropland receiving excess nitrogen fertilizer compared to the 57% reported for 2012. These BMP acreages should be adjusted in future NRS revisions to account for both updated fertilizer use surveys and the changing University of Minnesota recommended rates.

b. The total BMP acres assumes that nitrogen and phosphorus reduction BMPs are on the same lands. In most cases, this is expected to provide a conservative estimate of total acreage. Where local watershed prioritization for phosphorus and nitrogen reducing BMPs are in different areas, the total needed acreages will be higher.

Table 10. Example scenarios from 2014 NRS to achieve milestones in Mississippi River and Red River basins.

BMP categories	Mississippi River			Red River		
	Additional BMP acres needed at the time of NRS (2014)					
	Nitrogen	Phosphorus	Total	Nitrogen	Phosphorus	Total
Field Erosion Control	0	4,500,000	4,500,000	0	400,000	400,000
Increasing Fertilizer Use Efficiencies [a]	6,100,000	2,200,000	6,100,000+	700,000	0	700,000
Drainage Water Retention and Treatment	600,000	--	600,000	20,000	--	20,000
Increase and Target Living Cover						
Perennials	400,000	400,000	400,000+	40,000	40,000	40,000+
Cover crops	1,200,000	800,000	1,200,000+	700,000	600,000	700,000+

a. See footnote "a" in Table 9. Note: The total acres in the Mississippi River Basin that are needed for Increased Fertilizer Use Efficiency BMPs is expected to exceed 6,100,000.

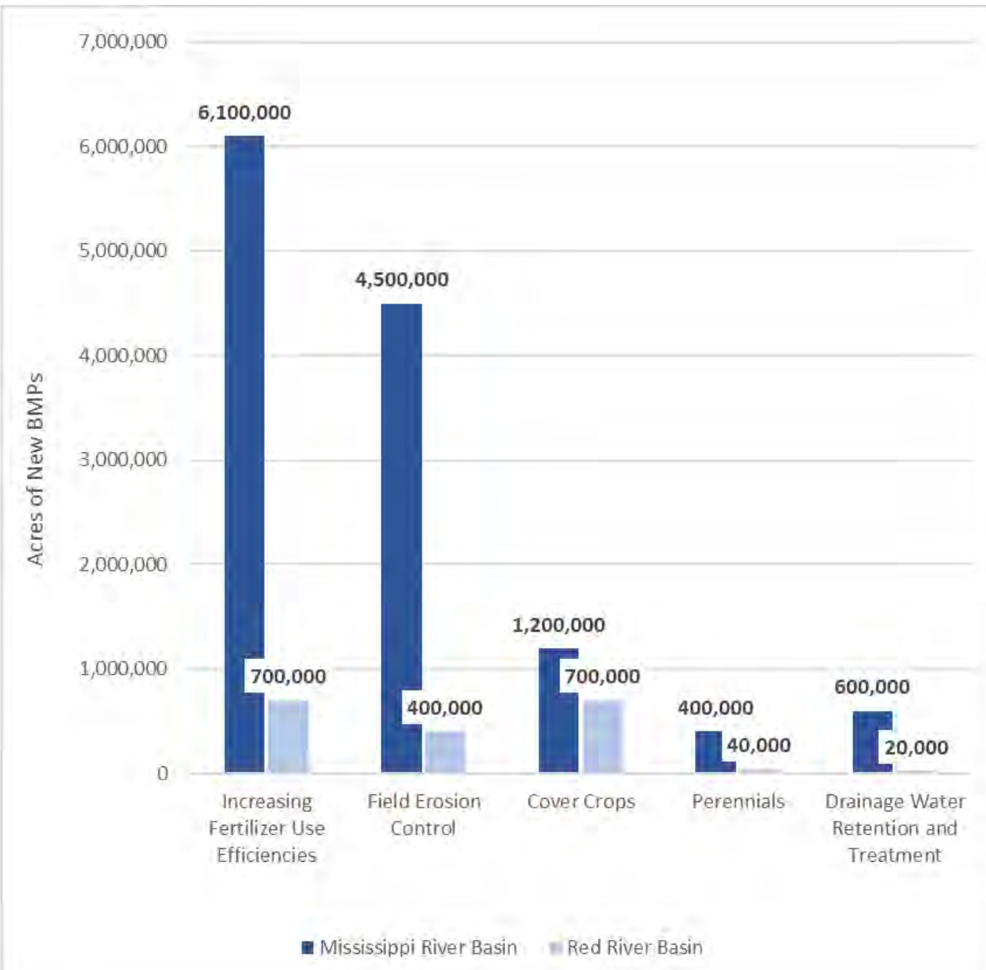


Figure 17. Example agricultural BMP scenario from 2014 NRS to achieve milestones, showing needs for additional acreages of new BMP additions.

The 2014 NRS focused on BMP scenarios to achieve the nitrogen milestones rather than the nitrogen final goals (e.g., 20% reduction in nitrogen in the Mississippi River Basin). The NRS acknowledged that Minnesota did not have a realistic way of showing how the 45% reduction could be achieved using the current state of scientific advancement. However, two hypothetical scenarios were described to indicate what it would potentially take in the future to achieve a 45% reduction in nitrogen from cropland sources in the Mississippi River Basin. Both scenarios assumed that research would advance the success of cover crops in Minnesota, enabling increases in cover crop establishment and success rates. The two hypothetical scenarios included:

Scenario 1 for final goals – Use same adoption rates as for the milestone except that cover crops are established on 80% of corn grain, soybean, dry bean, potato, and sorghum acres and improving the success rate on cover crop establishment from 40% to 80%.

Scenario 2 for final goals – Increase adoption rates of the BMPs used for the milestone to 100% of suitable acreages for those BMPs, and additionally increase cover crops from 10% to 60% of the corn grain, soybean, dry bean, potato, and sorghum acres and improve establishment success from 40% to 60%.

These 45% reduction scenarios indicate that the total amount of land with cover crops or perennials would ultimately need to increase by an estimated 10 to 12 million acres from the current living cover acreages (note: total row crop acres in Minnesota are approximately 16 million acres).

5.2 Agricultural BMP adoption since 2014

Progress toward these hypothetical 2014 NRS scenarios has been evaluated based on trends in the adoption of agricultural BMPs from 2014 to 2018. The following sections describe the data tracking process and provide summaries of key trends for four categories of agricultural BMPs: nutrient management efficiency practices, living cover practices, field erosion control practices, and tile drainage water treatment and storage practices.

5.2.1 Tracking agricultural BMP adoption in Minnesota

Minnesota partner agencies estimate statewide agricultural BMP adoption rates by examining a combination of BMPs adopted through government-supported programs and indicators of overall adoption rates based on satellite imagery, surveys, regulatory inspections, sales data and private industry data.

- **Government programs** that provide BMP-funding assistance have kept records of the new BMPs funded through these programs since approximately 2004. A tracking system managed by the MPCA, referred to as “Healthier Watersheds BMP tracking system,” includes the BMPs tracked by each of the major government programs. In addition, the United States Department of Agriculture (USDA) Farm Service Agency tracks Conservation Reserve Program (CRP) acreages and reports the data annually on a statewide basis.
- **Satellite imagery** provides snapshots in time of certain BMPs used at the time the photos were taken. These images can be used to estimate cover crops, reduced tillage, terraces, water and sediment control basins, grassed waterways, strip-cropping and other structural practices. Satellite imagery can also be used to estimate various land-covers and crops in place, such as hay and grasses.
- **Surveys** by the National Agricultural Statistics Service (NASS) have been used to gauge Minnesota fertilizer use periodically since 2010. Additionally, the U.S. Census of Agriculture surveys taken every five years provide information about cover crops and conservation tillage starting in 2012.

- **Regulatory inspections** of manure spreading practices regulated by the MPCA and delegated counties provide some clues about the adoption of various manure spreading BMPs, but do not provide a statistical representation of statewide manure spreading practices.
- **Sales and private industry records** for fertilizer statewide, when combined with crop harvest data, provide an indication about nutrient use efficiencies at a state scale. Soil phosphorus test results can also be used to inform nutrient management progress but are not currently collected in a manner that provides statistical representation of soil phosphorus trends.

5.2.1.1 *Government programs*

Minnesota's Clean Water Legacy Act requires that MPCA report actions taken in Minnesota's watersheds to meet water-quality goals and milestones (Minn. Stat. § 114D.26, subd. 2). To meet this requirement the MPCA developed the "Healthier watersheds: Tracking the actions taken" webpage. Water quality protection and restoration BMP adoption levels can be found at the HUC-8 and HUC-12 watershed scales at: https://www.pca.state.mn.us/water/best-management-practices-implemented-watershed. For use in evaluating progress toward the 2014 NRS, the Healthier Watersheds information is aggregated into major river drainage basins and four categories of BMPs consistent with the NRS, and can be found at: https://public.tableau.com/profile/mpca.data.services#!/vizhome/MinnesotaNutrientReductionStrategyBMPSummary/MinnesotaNutrientReductionStrategyBMPSummary .

The programs providing BMP information for the Healthier Watersheds tracking system include:

- USDA– NRCS
  - Environmental Quality Incentives Program (EQIP)
  - CSP
  - Agricultural Conservation Easement Program – Wetland Reserve Easement
  - Emergency Watershed Protection Program – Floodplain Easement
  - Emergency Wetlands Reserve Program
  - Farm and Ranch Lands Protection Program
  - Grassland Reserve Program
  - Wetlands Reserve Program
- Minnesota BWSR
  - Easement Programs
    - CREP
    - RIM
    - Wetland Reserve Program
    - Army Compatible Use Buffer Program
    - Riparian Buffer Conservation Easements
  - Grant Programs
    - Disaster Recovery Assistance Program
    - Clean Water Fund (CWF) Grants
    - State Conservation Cost-Share
    - Native Buffer Grant Program
    - Natural Resources Block Grant
  - Other programs as reported in the eLINK tracking system

Conservation Reserve Enhancement Program (CREP)

The Minnesota CREP began in 2017 with a goal of creating 60,000 acres of buffers, restored wetlands, and protected wellheads for drinking water. CREP is funded through USDA and State of Minnesota funds. Landowner sign-ups began in May 2017 and continued until August 2018. During the landowner sign-up period, a total of 290 applications received funding, representing 12,186 acres. Over 90% of the CREP practice acreages were for wetlands. Due to new federal Farm Bill negotiations and the federal government shutdown, no further sign-ups occurred for the remainder of 2018. More information is available in Appendix A and at: http://www.bwsr.state.mn.us/crep/

MINNESOTA CREP

- MDA
    - Agriculture BMP Loan Program
    - Minnesota Agricultural Water Quality Certification Program
- MPCA
    - Federal Clean Water Act Section 319 Program
    - Clean Water Partnership Program

Specific information provided on the “Healthier watersheds: Tracking the actions taken webpage” is provided below.

Reporting period: The BMP data in this analysis covers the period 2004-2018, except for CSP which goes back to only 2010 and only separates out enhancement BMPs during the past couple years.

Year of BMP: Represents the best available date for BMP installation. When installation dates are not available, the funding year is used.

Joint state/federal cost-share: All BMPs in the BWSR grant tracking system (eLINK) that report federal match (except for the 319 Program) are categorized only with federal program acreages. These practices are not reported under state-funded categories to prevent potential double counting. The majority of the joint state/federal practices are accounted for by the NRCS - EQIP Program. Less than 5% of the eLINK BMPs are associated with federal allocations.

Location of BMP (HUC-12): BMPs that do not have HUC-12 location data associated could not be attributed to a specific drainage area. These BMPs are included in statewide BMP aggregations but are not included with basin or watershed-specific information.

New BMPs: 5-year tallying of acres for this report assumes that once a BMP is installed that it will continue to operate within this 5-year reporting period. In practice, some of the BMPs that are initially funded through government programs will not continue to be implemented after government funding ceases. Therefore, the cumulative BMP elements in this report represent a high-end or overestimate of actual ongoing cumulative practices through government assistance programs.

Multi-year contracts: The EQIP Program funds many BMPs such as reduced tillage, cover crops, and nutrient management under three-year contracts. For such cases, the BMP is attributed to the first year under contract and is assumed to be in operation for the remainder of the reporting period.

Agricultural BMP Loan Program: Acres under this program are assigned to individual loans and may overlap if a borrower has multiple loans for the same BMP within the reporting period. In addition, loan-funded equipment could be used on the same acres that receive federal cost-share under a program like EQIP.

Acres assumptions: When specific adoption acreages were not listed by the government program, estimates of treated acres were derived from statewide averages and literature review related to the practice or closely related practice.

The methods to refine specific acreage estimates of newly adopted practices during any given year may be modified in the future to best meet both state and federal program purposes. While this may result in differences between the acres in this report and future website reported acreages, the general magnitude of government program supported practice adoption acreages over a multi-year period described in this report is not expected to change in a way that would significantly affect this report’s conclusions.

Data from the Healthier Watersheds website (NRS version), in addition to federal tracking of CRP acreage, are used to track BMP adoption categories (Table 11). The government program BMP tracking system developed in Minnesota generally aligns with the Nonpoint Source Workgroup recommendations stemming from the Gulf of Mexico Hypoxia Task Force at: https://www.epa.gov/sites/production/files/2018-05/documents/nps_measures_progress_report_1-_may_2018.pdf.

Table 11. BMPs included in Healthier Watersheds website, reported in the following sections.

Nutrient Management Efficiency	Living Cover	Field Erosion Control	Tile Drainage Water Treatment and Storage
Nutrient management	Conservation Cover Conservation Crop Rotation Conservation Easement Cover Crop Critical Area Planting Filter Strip Forage and Biomass Planting Riparian Forest Buffer Riparian Herbaceous Cover Windbreak/Shelterbelt Establishment	Alternative Tile Intake Contour Buffer Strips Field Border Grassed Waterway Mulching Residue and Tillage Management, No-Till/Strip Till Residue and Tillage Management, Reduced Till Residue and Tillage Management, Ridge Till Sediment Basin Stripcropping Terrace Water and Sediment Control Basins	Denitrifying Bioreactor Drainage Water Management Saturated Buffer Wetland Restoration

5.2.1.2 *Satellite imagery*

Satellite aerial imagery projects initiated by the BWSR within the past five years are beginning to provide a more comprehensive view of soil conservation practices, specifically crop residue and cover crops. The BWSR, the University of Minnesota, and Iowa State University have been working together since 2016 to develop a long-term program to systematically provide cover crop, crop residue, land cover and soil erosion data in Minnesota counties with at least 30% agricultural land use. The goal is to quantify and track this information on multiple scales and to calculate estimated average annual and daily soil loss due to wind and water erosion.

Reduced tillage and cover crop practices are often used without government assistance and are not always tracked through government assistance program databases. The BWSR contracted with the University of Minnesota to provide more comprehensive snapshots of crop residue cover levels and cover crop practices in Minnesota. Data from this project will be important for gauging the statewide NRS goals, as well as measuring changes at the local sub-watershed level. This project is moving from prototype development into production mode in 2020 and 2021.

For collection of spring crop residue levels and fall cover crop adoption, remote sensing techniques utilizing Sentinel 2 and Landsat 8 satellite imagery are used. Data has been collected and analyzed by the University of Minnesota from 2016 through 2019. To provide quality assurance and control of the data, ground truth data is collected in the field to verify and validate the remote sensing model. Digital images of residue are collected to provide precise residue measurements in a limited number of locations. This data is used to calibrate the model and thus improve the accuracy of the model outputs for Minnesota.

One of the major components of Minnesota's crop residue and cover crop satellite imagery project is to deploy the Daily Erosion Project (DEP) web application in Minnesota. The DEP application provides data on the following parameters in an easy to use geospatial interface at https://www.dailyerosion.org/: precipitation, runoff, soil erosion (detachment), soil erosion (hillslope soil loss), along with wind erosion to be added in the future. The DEP will be utilized to help track soil loss by water and wind erosion on an annual basis and Minnesota will have ability to look at trends in the data over time. Data from this project will be useful in looking at regional, county, and watershed scale comparisons. No direct link between erosion and nutrients are provided by this work, however, in the future these connections may be explored.

Similar to Minnesota's satellite imagery project, The Conservation Technology Information Center (CTIC) partnered with Applied GeoSolutions and The Nature Conservancy on the development, testing and application of the Operational Tillage Information System (OpTIS). OpTIS is an automated system to map tillage, residue cover, winter cover, and soil health practices using remote sensing data. OpTIS-based data are currently available for the years 2005 through 2018 for the U.S. Corn Belt, and results can be found at: https://www.ctic.org/optis.

Satellite data can also be used to identify and map the locations of structural practices. Structural BMPs (sediment basins, terraces, waterways, etc.) are being mapped throughout Iowa using Light Detection and Ranging (LiDAR) digital elevation model data and aerial imagery interpretation. Using similar methods to Iowa, the BWSR undertook a pilot project in 2018 to assess the workload that would be needed to conduct such an inventory in Minnesota. A total of 23 HUC-12 watersheds were mapped in this project: 18 in the Blue Earth River Watershed, 2 in the Yellow Medicine Watershed, and 3 in the Buffalo Red Watershed. The Blue Earth Watershed was chosen because of the proximity to Iowa and the ability to compare Minnesota and Iowa information using Iowa's mapping protocol. The Yellow Medicine and Buffalo Red watersheds were selected because of their proximity to glacial ridges and a high density of structural BMPs.

Structural agricultural practices identified from satellite images included:

- Water and sediment control basins
- Grade stabilization structures
- Grassed waterways
- Terraces
- Ponds and dam structures

Figure 18 from the pilot project clearly shows the diversity of adopted structural BMPs. Collecting BMP data from LiDAR provides a more accurate picture of the structural BMPs on the landscape. In the pilot area, the LiDAR BMP mapping project identified 1,420 structural practices, while the BWSR eLINK database identified 226 structural practices. The eLINK data includes practices that have state funding and does not include many practices funded under Federal programs or by landowners directly. In the future, mapping structural practices statewide would allow better tracking of structural BMP adoption. However, the mapping of these practices does not indicate how well the practices are being maintained or their ability to continue providing the intended soil and water protection.

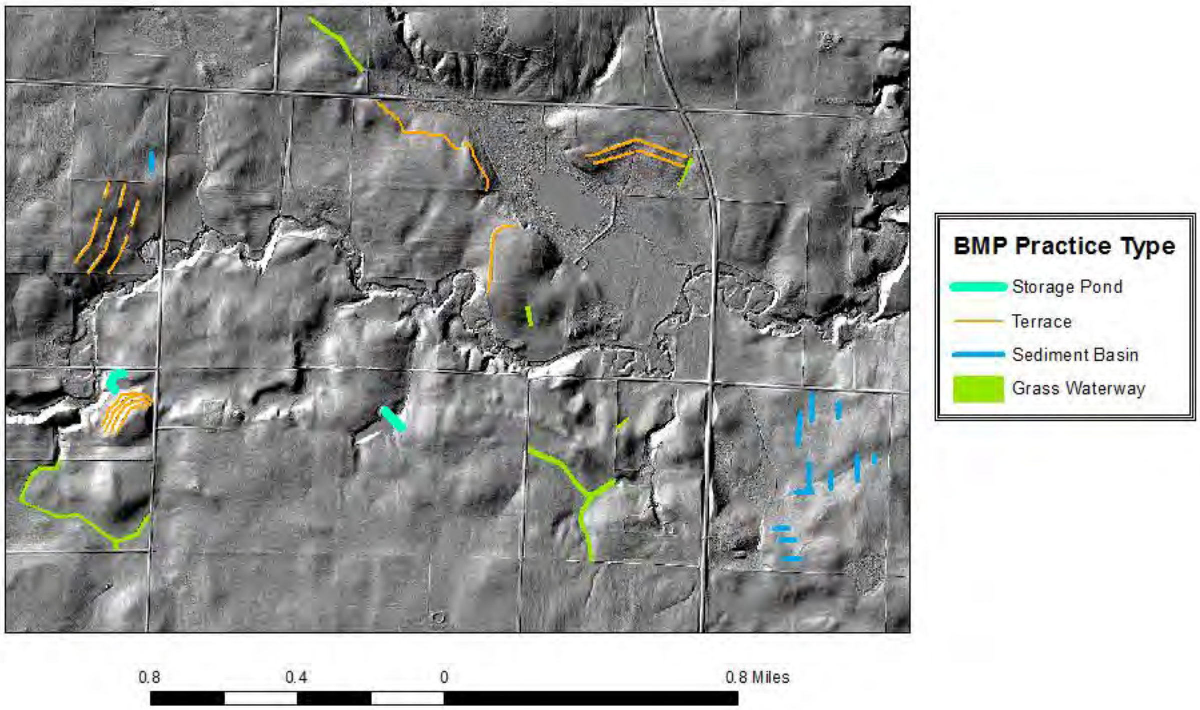


Figure 18. Example image from LiDAR mapping pilot project. (Source: BWSR)

5.2.1.3 *Surveys, regulatory reports and inspections, and sales and private industry records*

In April 2019, the USDA NASS released the 2017 U.S. Census of Agriculture: https://www.nass.usda.gov/Publications/AgCensus/2017/index.php. This Census is taken every five years to look at trends in all aspects of agriculture production for both animal and cropland agriculture. The results most relevant to this assessment of BMP adoption include the 2012 and 2017 census findings on conservation tillage and cover crops in Minnesota.

Nitrogen fertilizer-use farmer surveys are periodically conducted across Minnesota, with findings summarized in reports by the MDA. A survey instrument was developed specifically for the surveys which were conducted over the phone by enumerators from NASS. Reports from the surveys are available at: www.mda.state.mn.us/nutrient-management-surveys.

5.2.2 Nutrient management efficiency (fertilizer and manure) practices

As discussed in the 2014 NRS, increasing the efficient use of fertilizers and manure is a fundamental strategy for reducing nutrient movement to waters.

Nutrient management efficiency practices selected for phosphorus and nitrogen reduction analysis in the 2014 NRS include applying recommended fertilizer rates, proper placement and timing of application, nitrification inhibitors, reducing soil phosphorus levels, and livestock feed management. Adoption levels of fertilizer and manure use-efficiency practices implemented from 2014 to 2018 were assessed using data from government tracking systems as well as overall indicators of adoption derived from fertilizer sales, nitrogen fertilizer use efficiency indices, and farmer fertilizer use survey data. While government programs can help to foster good nutrient management, the NRS suggests that private industry has the largest role to ensure the most efficient fertilizer and manure management practices.

5.2.2.1 *Progress of nutrient management efficiency practice adoption through government programs*

Nutrient management practices under NRCS's conservation practice 590-standard focus on managing the amount (rate), source, placement (method of application), and timing of nutrients and soil amendments; 59,550 new acres of 590-standard nutrient management were newly enrolled through federal and state programs between 2014 and 2018 (Figure 18 and Table 12). Since 2014, annual new acres affected by government-support programs shows a marked decrease when compared to the preceding five years, and has not risen above 15,000 acres since 2013 (Figure 21). Existing data sources do not indicate how many acres continue with nutrient management BMPs after the contracts end (typically after three years). Additionally, the average acreage added annually under contract per year dropped substantially to 13,569 from 2014 to 2018 (compared to 107,640 acres per year during the previous 5-year period), due largely to NRCS EQIP enrollment reductions for this practice (Figure 21).

2014 NRS recommended agricultural BMPs

Increase fertilizer use efficiencies, emphasizing:

a. Nutrient management through reduction of nitrogen losses on corn following soybeans
b. Switch from fall to spring fertilizer applications (or use nitrification inhibitors)
c. Application of phosphorus in accordance with precision fertilizer and manure application techniques, including applications based on soil test results and University of Minnesota recommendations

Manure management on feedlots

When manure is part of the added nutrients to cropland, total manure and fertilizer additions are regulated by the MPCA and delegated county authorities through the Minnesota Feedlot Rules Chapter 7020. State and county inspections of manure spreading practices and records provide some insight into manure spreading BMP use. More information on feedlots and manure management on feedlots is provided in Section 6.

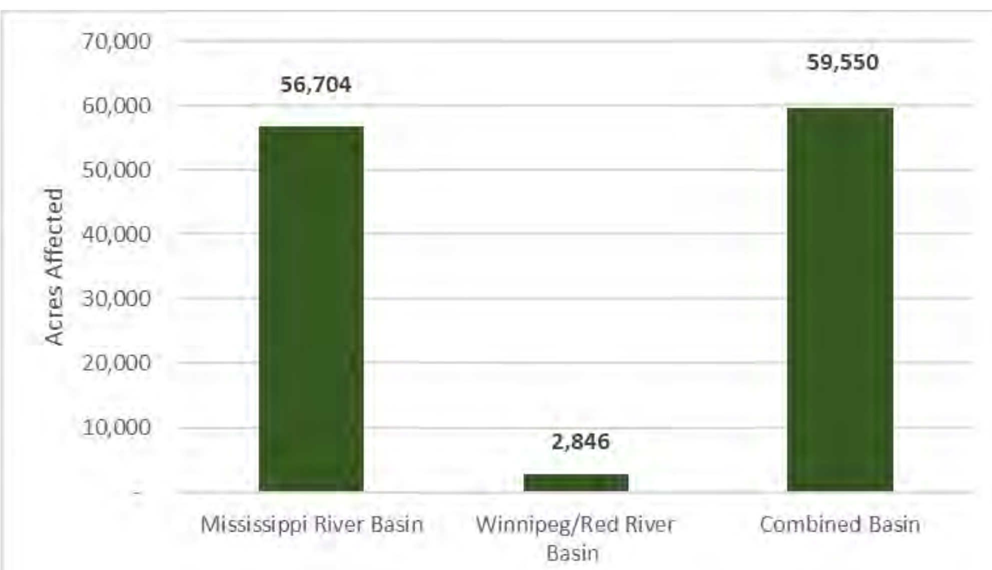


Figure 19. Total new acres for 590 nutrient management efficiency practices enrolled through government support programs from 2014 to 2018 (MPCA's Healthier Watersheds BMP tracking system).

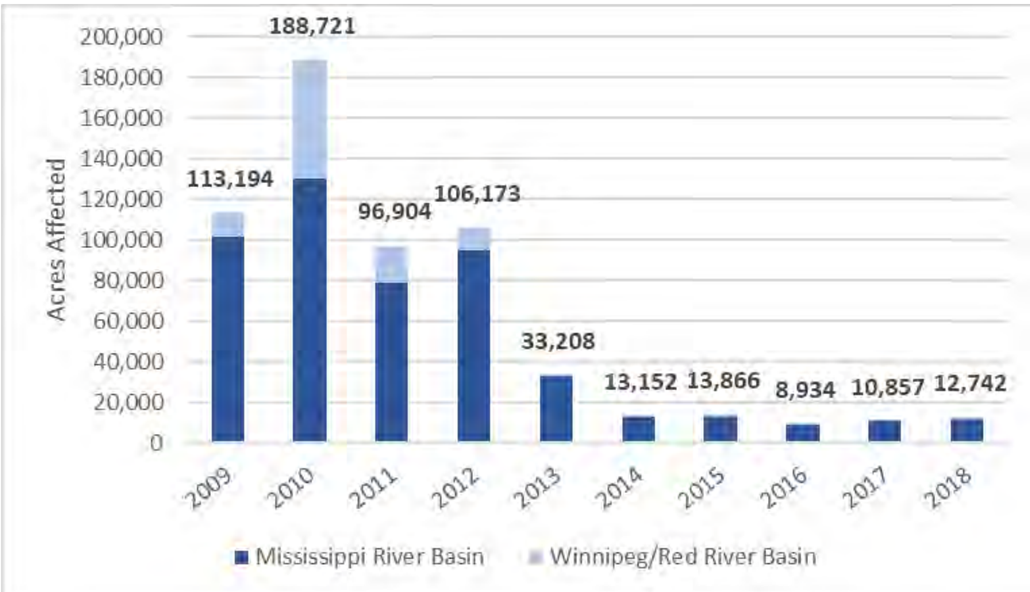


Figure 20. Annual new acres of 590 nutrient management efficiency practices added through government support programs, 2009 to 2018 (MPCA's Healthier Watersheds BMP tracking system - NRS version).

Table 12. Acres of nutrient management efficiency practices enrolled through government support programs, 2014 to 2018 (MPCA's Healthier Watersheds BMP tracking system)

	Nutrient management (CP 590)	Other nutrient management efficiency practices (CP 102 and 104 plans)	Nutrient management efficiency practices – total acreage
Mississippi Basin	56,704	10,300	67,004
Red River Basin	2,846	936	3,782

5.2.2.2 *Additional progress indicators of nitrogen management*

Indicators that help describe nitrogen management on cropland include fertilizer sales, application rates, timing of fertilizer application, and use of nitrification inhibitors. These indicators are described below. Additional detail on changes to University of Minnesota recommended nitrogen fertilizer rates for corn, or the Maximum Return to Nitrogen (MRTN), since 2014 is provided in Appendix D.

Fertilizer sales

Fertilizer sales are tracked by the MDA. The sales data are not tracked in such a way to precisely know the sales in specific watersheds but are more useful at a statewide level. Grain production information when combined with fertilizer sales can provide indications of state-level fertilizer use efficiencies. Statewide, nitrogen fertilizer sales reached a peak in 2012, when grain prices were high and corn acres were elevated. Since 2012, fertilizer sales have trended downward slightly (approximately 1.3% per year) (Figure 21).

The nitrogen sales since 2014 are about 15% higher than the 25-year average. The average decadal sales in the 1990s were 593,000 tons per year, which was comparable to the 2000s at 588,000 tons per year. During the 2010s, sales have hovered near 700,000 tons per year. Fertilizer tonnage reporting prior to 2010 may have underrepresented actual sales during some years and the inter-annual variation may be due to reporting inaccuracies rather than actual variation in sales.

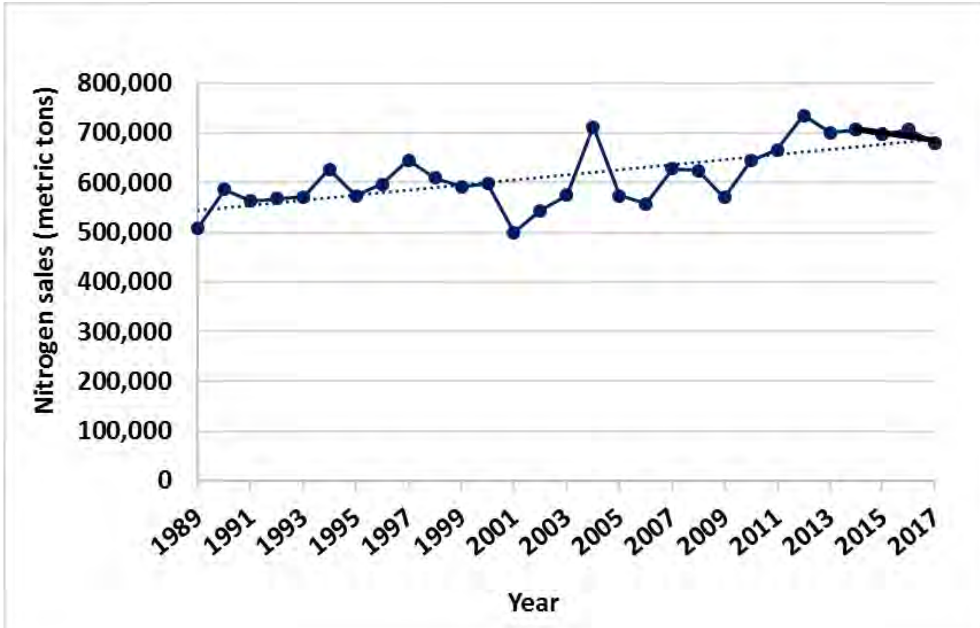


Figure 21. Annual nitrogen sales in fertilizer 1989 – 2017.

An index of nitrogen use efficiency is calculated by dividing total crop harvest yields by fertilizer sales. This index increased from 1992 to 2010, suggesting increased efficiency in nitrogen use, but has recently been lower or equivalent to the 2010 index (Figure 22). Nitrogen use on corn is used in the following example because approximately 75% of the fertilizer tonnage is used on corn acres. Corn yield gains have increased faster than the increase in nitrogen fertilizer application.

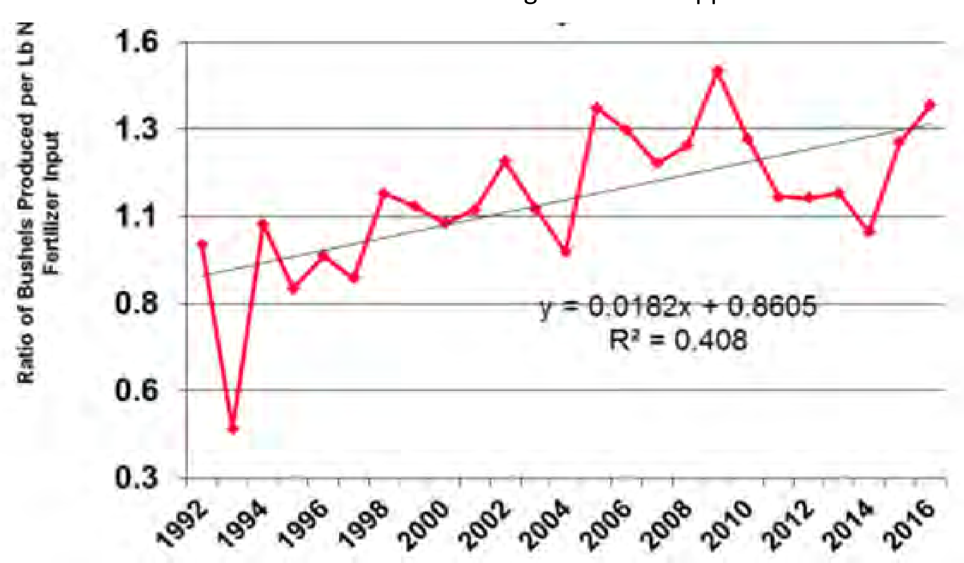


Figure 22. Nitrogen fertilizer use efficiency for corn 1992 – 2016 estimated based on statewide fertilizer sales and corn grain yield.

Application rates

Adherence to University of Minnesota guidelines on nitrogen rates for corn depends on the preceding crop. For example, on corn following corn, approximately 9% of the fields had application rates greater than 25 pounds nitrogen/acre (lb. N/ac) above the MRTN. For corn following soybean, that number is 25%. Excess nitrogen applications above the MRTN are higher yet when corn follows alfalfa in the rotation, or when manure is being applied. The fertilizer use rate information in this section is based on survey data collected by NASS and reported by MDA: https://www.mda.state.mn.us/nutrient-management-surveys.

Corn following corn

The statewide average nitrogen fertilizer application rate for corn following corn was 161, 160 and 153 lb. N/ac based on the 2010, 2012 and 2014 surveys, suggesting a possible slight decreasing trend in application rates. The data are based on 665, 589 and 414 fields for 2010, 2012 and 2014, respectively. A summary of fertilizer rates for corn following corn from the surveys is shown in Figure 23. None of the fields were reported to have received manure for two years or more prior to the cropping year represented by the survey. Also shown in Figure 23 are the approximate University of Minnesota nitrogen fertilizer rate ranges for 2006, 2016 and 2019 (for the 0.10 ratio of fertilizer cost to corn value). Across the three surveys, 55%, 63% and 77% of the fields were at or below the University of Minnesota's recommended rates from 2006, 2016 and 2019, respectively.

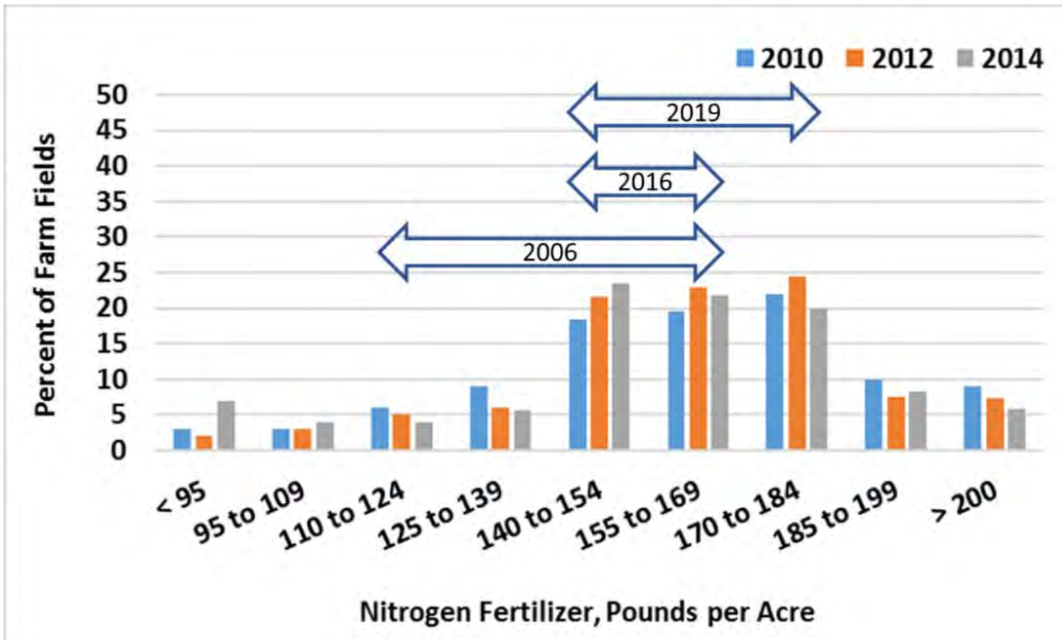


Figure 23. Distribution of nitrogen fertilizer rates from the 2010, 2012 and 2014 surveys for corn after corn. The nitrogen fertilizer rate ranges suggested by the University of Minnesota in 2006, 2016 and 2019 are approximated with the double-arrows.

Corn following soybean

The statewide average nitrogen fertilizer application rate for corn following soybean was 148, 144 and 144 lb. N/ac based on the 2010, 2012 and 2014 surveys (Figure 24). None of the fields were reported to have received manure for two years or more. Across the three surveys, 19%, 22% and 42% of the fields were at or below the University of Minnesota's recommended rates from 2006, 2016 and 2019, respectively. Across the three surveys, 48%, 37% and 15% of the fields had more than 25 lb. N/ac applied in excess of the University of Minnesota's recommended rates from 2006, 2016 and 2019, respectively.

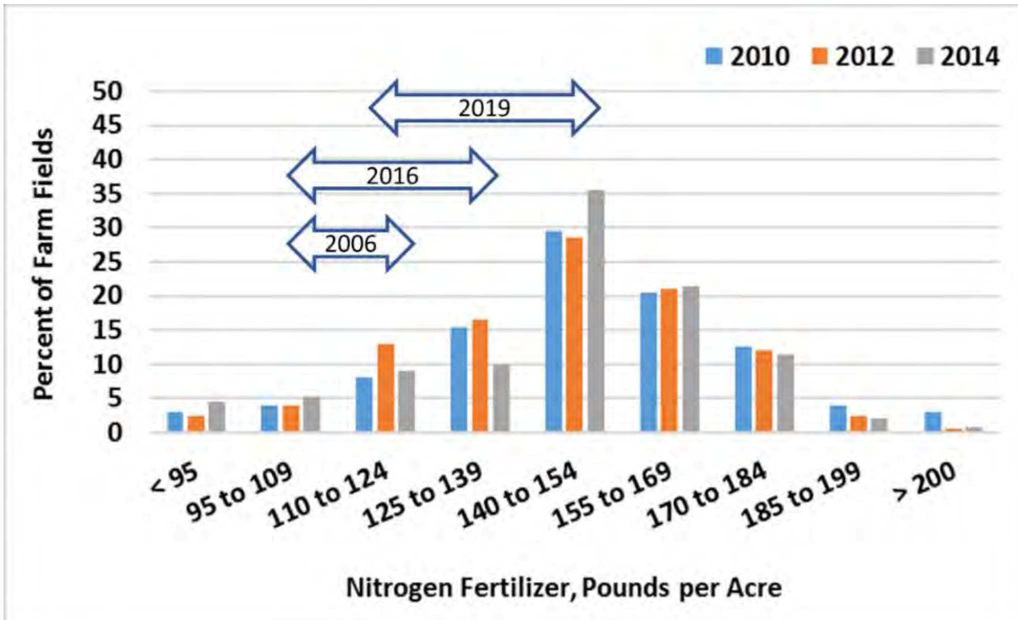


Figure 24. Distribution of nitrogen fertilizer rates from the 2010, 2012 and 2014 surveys for corn after soybean. The nitrogen fertilizer rates suggested by the University of Minnesota in 2006, 2016 and 2019 are approximated with the double-arrows.

Corn following small grain

The statewide average nitrogen fertilizer application rate for corn after small grains (wheat, barley, and rye) was 122, 127 and 119 lb. N/ac based on the 2010, 2012 and 2014 surveys. Across the three surveys, over 90% of the fields were at or below the University of Minnesota's recommended MRTN of 155 lb. N/ac.

Corn following manure

The statewide average nitrogen application rates for corn receiving manure were 173, 196 and 184 lb. N/ac based on the 2010, 2012 and 2014 surveys. This includes nitrogen sources from both manure and commercial fertilizer. The manure was field-applied either the previous fall, in the spring or within the growing season. The distribution of total nitrogen application rates on corn receiving manure from the 2014 survey is shown in Figure 25. The nitrogen inputs include manure and inorganic fertilizer. The average nitrogen inputs were 120 and 67 lb. N/ac from manure and fertilizer, respectively. Nearly half of the fields with manure received total nitrogen additions exceeding 200 lb./ac. The maximum of the range recommended for manured fields with corn following corn is 215 lb./ac (0.05 ratio U of MN published rates in 2019), and the maximum of the recommended range for corn following soybeans is 165 lb./ac. The survey did not determine how the manured-field nitrogen rates were different for these rotations.

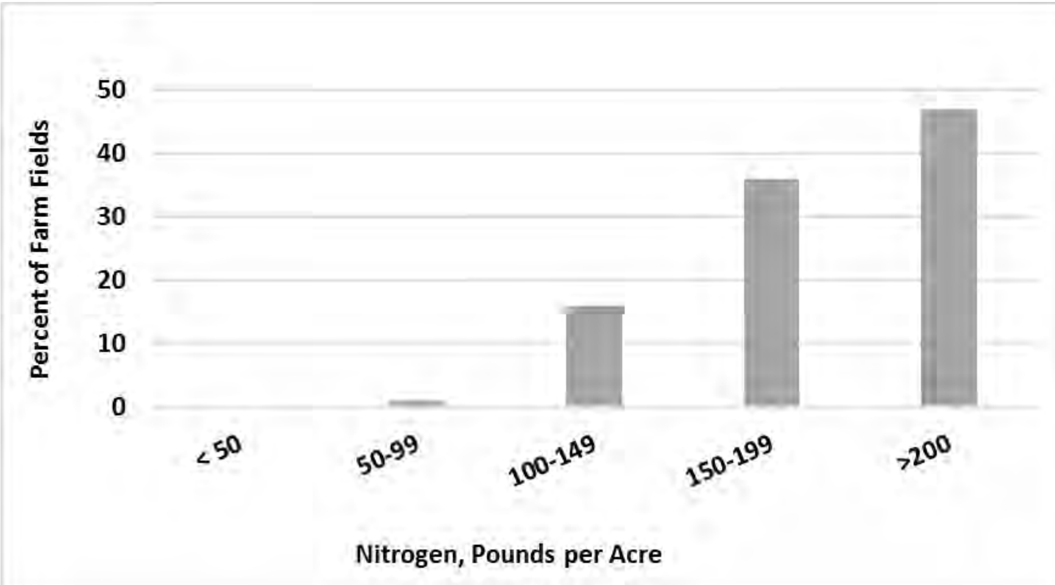


Figure 25. Distribution of total nitrogen application on corn fields receiving manure from 2014. Nitrogen inputs include manure and supplemental nitrogen.

Timing of fertilizer application

The risk of inorganic nitrogen loss typically increases as the time from application to crop uptake increases. For this reason, it is common to use higher nitrogen rates (additional 10-30 lb./ac) for fall application compared to spring applications in the same region. Even under optimal weather conditions, some fall-applied nitrogen will usually be lost either through leaching or denitrification by the time the crop starts uptake.

According to the 2014 survey, approximately 27%, 63% and 10% of nitrogen is applied in the fall, spring (either pre-plant or at planting), or in a split or side-dress application, respectively. The vast majority of the fall-applied acres are in the western and the south-central BMP Regions (Bierman 2011), where fall application of nitrogen fertilizer is a recommended BMP.

Anhydrous ammonia (AA) is considered a good nitrogen source for crop production and is generally the best option for fall application of nitrogen fertilizer. It is less likely to be lost compared to other nitrogen sources since AA immediately after injection converts to ammonium which is retained on the soil cation exchange sites. The injection of AA also causes a temporary inhibition of soil microbes (IPNI 2012). This delays the conversion of ammonium to nitrate which further reduces the risk of leaching losses. Urea is another good nitrogen fertilizer source. In the soil, urea is converted to ammonium, but lacks the nitrification inhibition properties of AA and is more prone to volatilization and leaching losses if not managed properly. Nitrogen solutions (UAN) contain nitrogen in the urea, ammonium and nitrate forms. Because these forms of nitrogen can be readily lost to volatilization or leaching if not managed properly, UAN is frequently banded or injected at planting, used for in-season nitrogen applications or added to irrigation water.

Anhydrous ammonia sales have dropped substantially over the past 25 years (Figure 26). Reasons for the decrease are safety concerns, increasing regulations, and cost. Additionally, it is a difficult product to manage within precision type applications and in no-till systems. Urea sales have steadily increased and have taken up much of the marketplace sales reductions in AA.

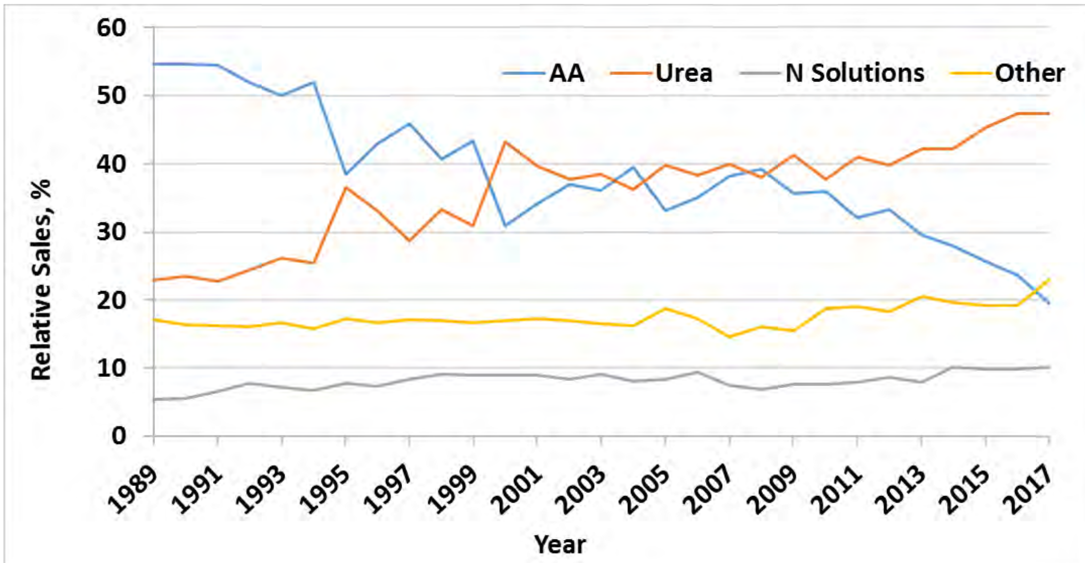


Figure 26. Sales trends for the three major nitrogen fertilizer sources. AA is anhydrous ammonia. Other sources include custom dry blends of fertilizer.

A complicating factor for timing of nitrogen fertilizer application is secondary nitrogen sources. Secondary nitrogen sources typically include ammonium-containing products for phosphorus and sulfur application, such as MAP (mono-ammonium phosphate), DAP (diammonium phosphate) or ammonium sulfate. In 2014 (most recent data), MAP and DAP account for 13% of the nitrogen applied from fertilizer. An additional 7% comes from other sources including sulfur fertilizer products. Approximately one-third of these products are typically applied in the fall, which is consistent with University of Minnesota BMPs. For areas with high loss potential, including areas with coarse textured soils or high rainfall, the University of Minnesota BMPs does not recommend fall nitrogen applications, regardless of source (including MAP and DAP).

Use of nitrification inhibitors

In areas of the state with high nitrogen fertilizer loss potential, it is a University of Minnesota recommended BMP to use nitrification inhibitors to help minimize nitrate losses. Nitrification inhibitors delay the conversion of ammonium to nitrate thereby minimizing the risk of nitrogen leaching losses. There are several nitrification inhibitors available with different modes of action. While many of these products have been rigorously tested and their performance has been verified through independent research, other products lack this testing under neutral research conditions. It continues to be a challenge, therefore, to accurately assess the benefit of some of the products that claim to be nitrification inhibitors.

Currently the state does not have a sales tracking program to collect information about the use of nitrogen enhancement or inhibitor type products in Minnesota. However, because the organic compound nitrapyrin, a commonly used nitrification inhibitor sold under such trade names as “N-Serve” and “Instinct” is considered a restricted use pesticide, its sales numbers are reported (Figure 27). When corn prices were peaking around 2010 to 2012, nitrapyrin sales (statewide) increased dramatically, but have leveled off at around 550,000 pounds per year since 2014. Using the labeled application rate of approximately 0.5 lb. of active ingredient per acre, the MDA estimates around 1,100,000 acres are treated each year with nitrapyrin alone, corresponding to approximately one-eighth of all corn acres.

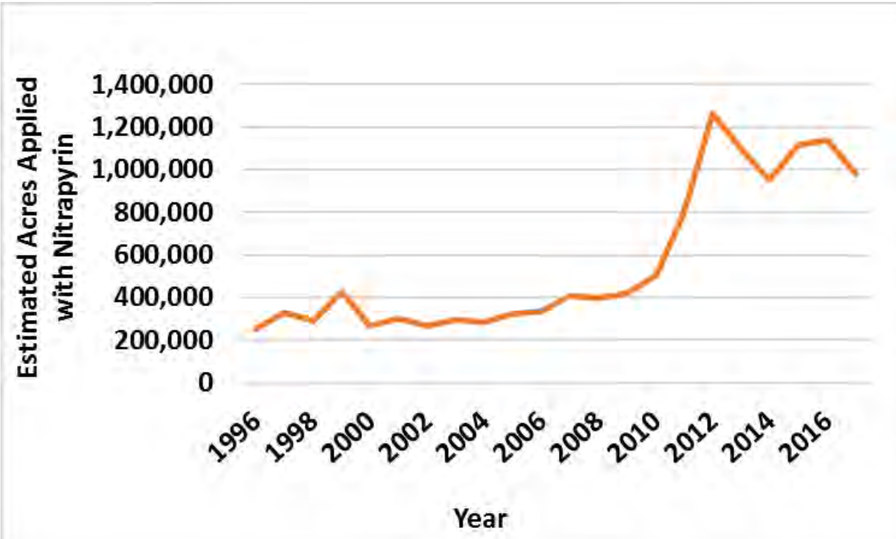


Figure 27. Estimated number of acres treated with the nitrification inhibitor nitrapyrin each year 1996 – 2017. Estimates are based on annual sale reports and the label application rate of one-half pound of active ingredient per acre.

There are regional differences in the use of nitrogen inhibitors. In regions of the state with higher leaching potential such as coarse textured soils or high rainfall amounts, fall application of nitrogen fertilizer is not a recommended BMP. For the southcentral BMP region of the state, which is a transition between the wetter eastern region and the drier western regions, the recommended practice for fall application is using anhydrous ammonia with N-Serve (nitrapyrin). The loss potential in the northwest, southwest and west-central regions is lower compared to the other BMP regions further to the east. For this reason, the BMPs do not suggest nitrification inhibitor use in western Minnesota. For fall applied anhydrous ammonia in 2012 for the 2013 corn crop, 60% and 12% of survey respondents in the south central region indicated all and some of fall-applied AA included nitrapyrin, respectively. Corn acres treated with nitrapyrin were low in the northwest and southwest/west-central regions (Figure 29).

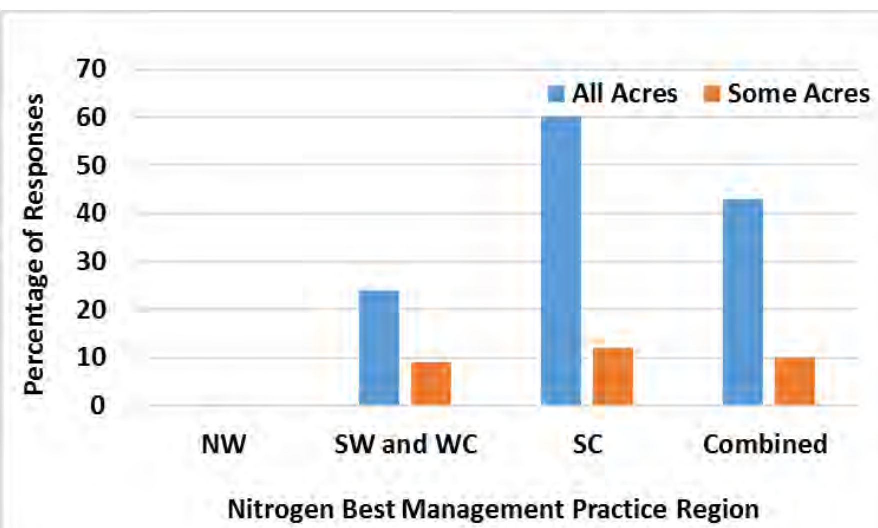


Figure 28. Percent of respondents that used nitrapyrin with fall applied anhydrous ammonia in 2012 for the 2013 corn crop. NW = northwestern MN; SW = southwestern MN; WC = west central; SC = south central MN; Combined = all regions.

5.2.2.3 *Additional progress indicators of phosphorus management*

Phosphorus fertilizer sales and soil phosphorus tests provide indicators of changes in phosphorus management. Phosphorus sales have remained nearly flat since 2014. Sales decreased in 2014 and 2015 and have slowly been rebounding since then (Figure 29). The average annual sale of phosphorus fertilizer increased by approximately 25% between 1989 and 2010.

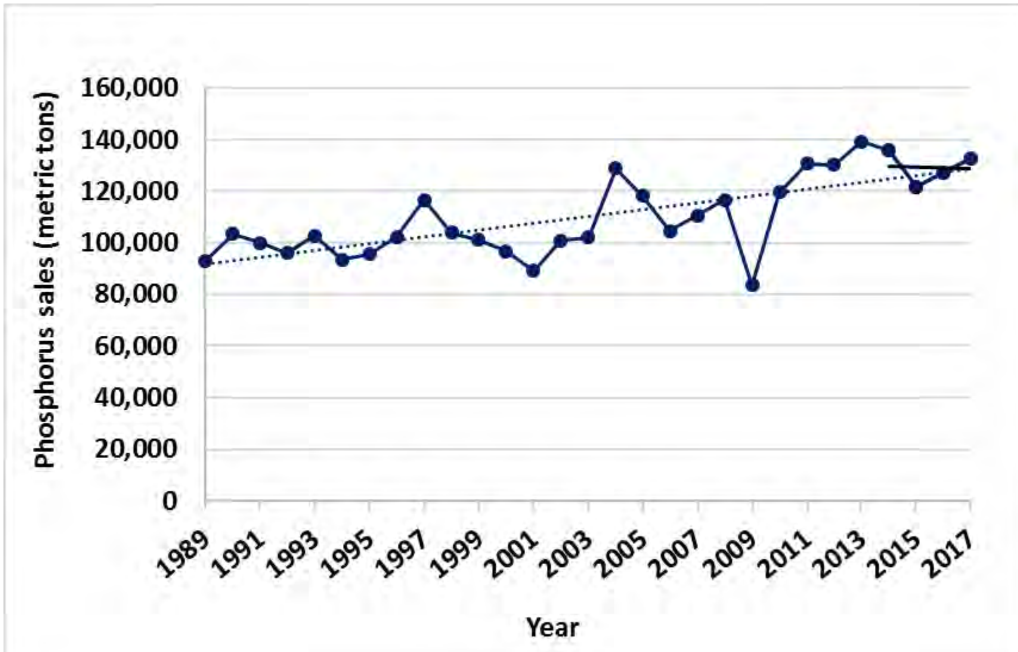


Figure 29. Annual phosphorus sales (as elemental P) during 1989 – 2017.

The phosphorus application rates suggested by the University of Minnesota Extension are based on the expected crop yield and soil phosphorus levels determined through soil sample analysis. Figure 30 shows the distribution of Minnesota phosphorus soil test levels tracked by the International Plant Nutrition Institute (IPNI) for samples collected in 2001, 2005, 2010 and 2015 (IPNI 2019). Soil test levels between 20-25 ppm (Bray P1) are normally considered optimum for corn production. No additional phosphorus application is typically suggested above 25 parts per million (ppm) (University of Minnesota Extension 2019). The change in relative frequency from 2001 to 2015 in Figure 31 shows a trend towards higher soil phosphorus levels. For example, more fields show high levels of phosphorus (above 25 ppm) in 2015, as compared to other earlier years. However, considering that the tested fields are not selected from a random sampling, statistically valid conclusions are not possible.

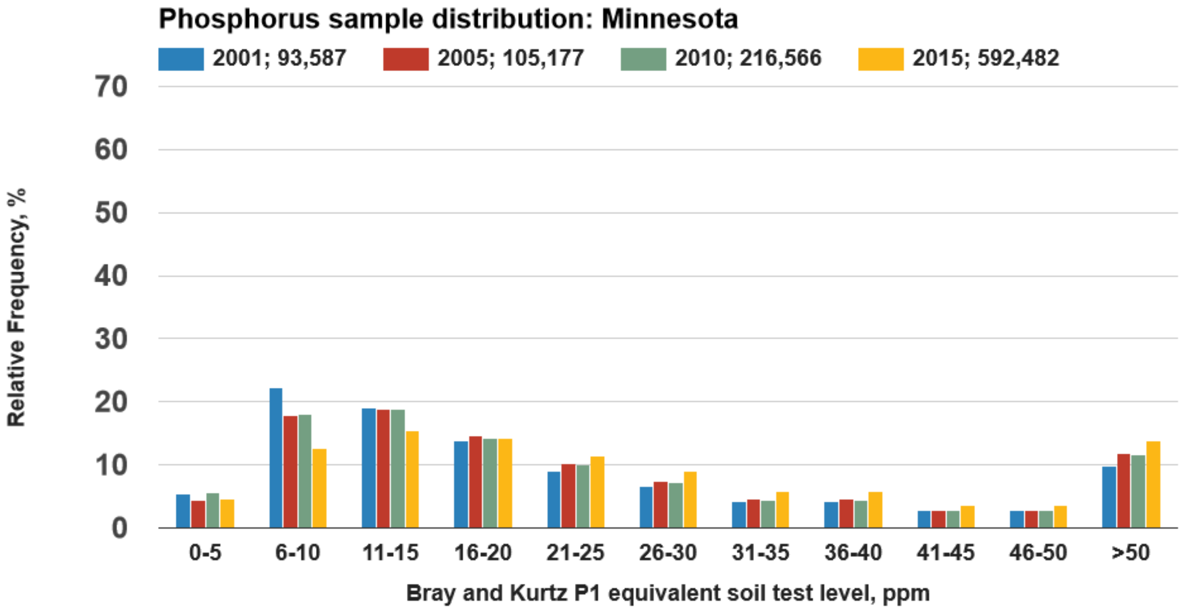


Figure 30. Frequency of phosphorus level in soil samples from Minnesota for 2001, 2005, 2010 and 2015. Soil test levels between 20-25 ppm are normally considered optimum for corn production. Source: IPNI 2019.

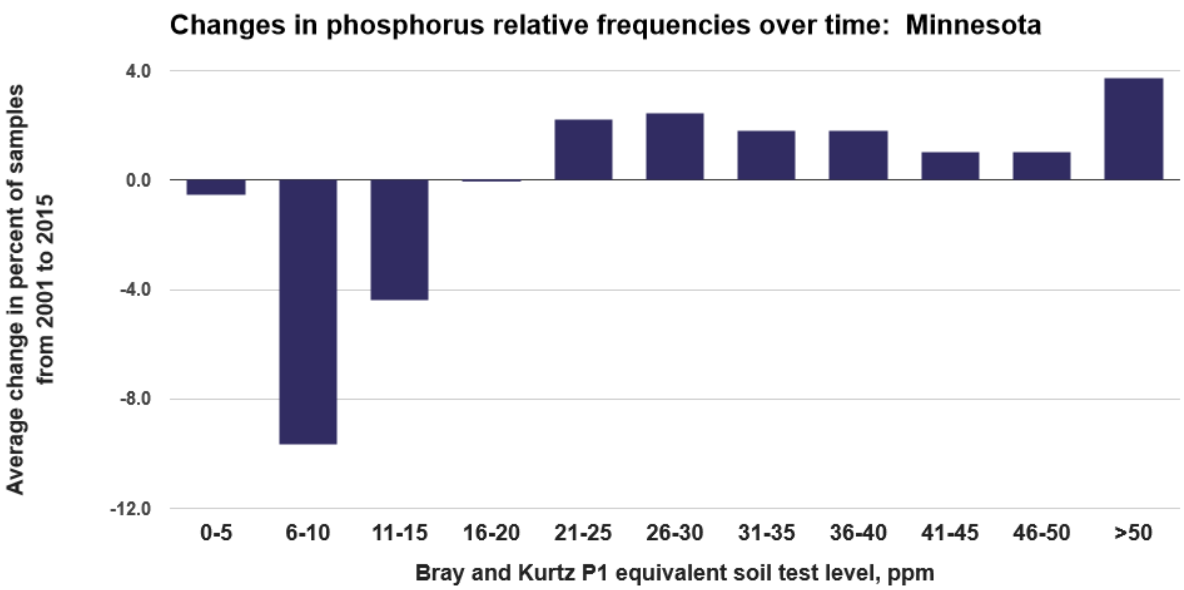


Figure 31. Change in relative frequency of soil phosphorus tests from 2001 to 2015. Source: IPNI 2019.

Summary of Minnesota's Progress on Nutrient Management Efficiency

Why important

- Nutrient management efficiency gains are among the most economically profitable ways to achieve nutrient reductions. The NRS scenario is to improve nutrient management efficiency on roughly 6.8 million acres.
- This type of change is often accomplished outside of government program funding, and it is important to consider a variety of progress indicators apart from government programs.

Findings

- Government-funded fertilizer/nutrient management practice (i.e., 590 standard) acreages have decreased considerably in recent years.
- Fertilizer use surveys for corn lands showed fairly constant nitrogen rates from 2010 to 2014, with over 35% of corn/soybean rotation fields having received nitrogen rates exceeding the upper end of the recently increased University of Minnesota corn N rate recommendations.
- Statewide, nitrogen and phosphorus fertilizer sales have leveled off during recent years and have started to decrease but remain higher than sales during years prior to 2012. Phosphorus fertilizer sales are 25% higher now than in 1989.
- Nitrogen fertilizer use has shifted in recent years to forms that are more challenging to prevent losses to water, especially when applied during the fall.
- Soil phosphorus test results are showing more fields testing very high. It is unknown if this is an actual increase or otherwise just represents an increasing emphasis to re-test fields previously found to have high soil phosphorus.
- None of the indicators of nutrient management practice adoption show changes during the past five to ten years expected to yield measurable nutrient reductions to surface waters at a large scale.

Follow-up

- More work is needed to identify improved fertilizer and manure use BMP metrics to track progress with such practices as subsurface banding of phosphorus and split application of nitrogen.
- Continue programs that create greater awareness of the connections between nitrogen fertilizer efficiency, farm profitability and water quality protection.
- Gain a better understanding of the current potential for improving nutrient use efficiency and how to overcome barriers for making such improvements.
- Minnesota's new Groundwater Protection Rule should move the state toward greater nitrogen fertilizer efficiencies in geographic areas with vulnerable groundwater. The lessons learned from these areas can be applied to other geographic areas.

5.2.3 Living cover practices

As discussed in the 2014 NRS, the additional use of vegetative cover during fall and spring months provides protection from soil erosion during times of the year when crops are not in place or of sufficient size. Perennials and cover crop roots capture nitrate that is moving through the soil, preventing it from leaching to tile waters or groundwater. These practices can also improve soil health by increasing soil organic matter, and thereby hold more water in the soil and reduce runoff.

2014 NRS recommended agricultural BMPs

Increase and target living cover, emphasizing**:**

a. Cover crops on fallow and short season crops such as sweet corn, corn silage, peas, small grains, and potatoes
b. Perennials in riparian zones and on marginal cropland
c. Research and development of marketable cover crops to be grown on corn and soybean fields
d. Research and development of perennial energy crop(s)

Living cover practices selected for phosphorus and nitrogen reduction analysis in Chapter 5 of the 2014 NRS include cover crops, perennial buffers, forage and biomass planting, perennial energy crops, and conservation easements and land retirement. Other living cover agricultural BMPs, including conservation cover, conservation crop rotation, critical area planting, and filter strips, can be used to achieve similar benefits. Adoption levels of living cover practices since 2014 were assessed using information tracking systems of practices installed through government program support, along with overall indicators of adoption provided by the U.S. Census of Agriculture and satellite imagery.

5.2.3.1 *Progress of living cover practice adoption through government programs*

Statewide living cover acres tracked by the MPCA's Healthier Watersheds website and those acres enrolled in the CRP, together provide a summary of living cover practices being adopted through government programs.

Estimated non-CRP government program acreages affected by newly funded living cover practices (adopted and tracked through the state and federal government programs) are shown in Figure 32 and Table 13. A marked increase in acreage occurred from 2015 to 2017, coinciding with additional NRCS cover crop funds through EQIP. The recently added cover crop acreages are considerably higher than added acreages of perennials. The total acres of non-CRP living cover practices installed varies greatly from year to year (Figure 34).

Many increases in living cover practices resulted from concerted local watershed efforts. For example, the Cannon River Watershed Partnership contracted with farmers for cover crop planting on 11,870 acres in the Cannon River Watershed. For more information on the cover crop program and for an interactive map of cover crop installations see: https://crwp.net/conservation/cover-crops/

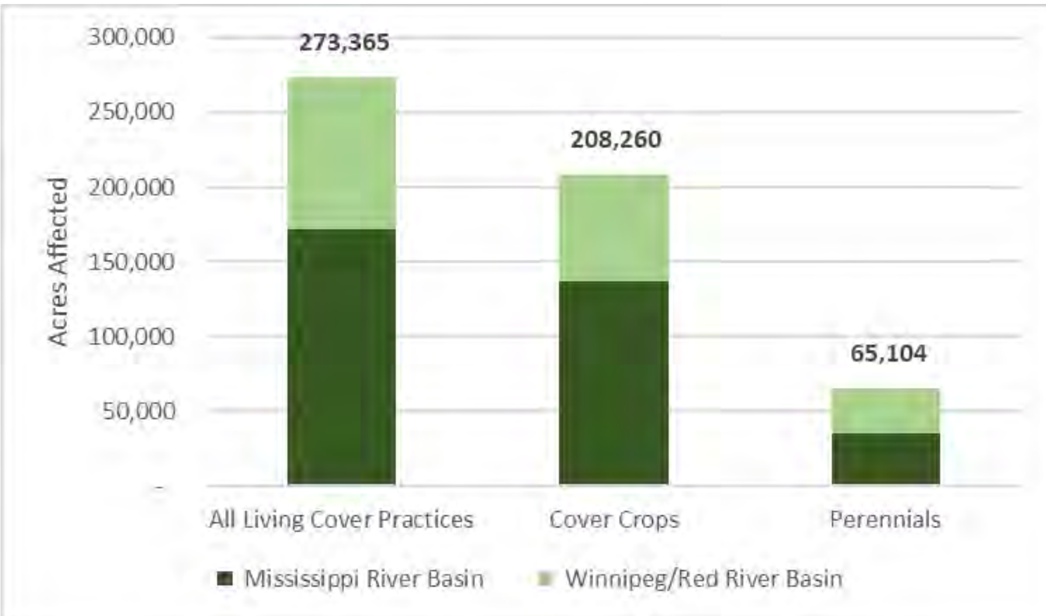


Figure 32. Acres affected by new living cover practices funded by non-CRP government programs from 2014 to 2018 (MPCA's Healthier Watersheds BMP tracking system).

*Perennials include conservation cover, conservation crop rotation, conservation easements, critical area planting, filter strip, forage and biomass planting, riparian herbaceous cover, and windbreak/shelterbelt establishment.

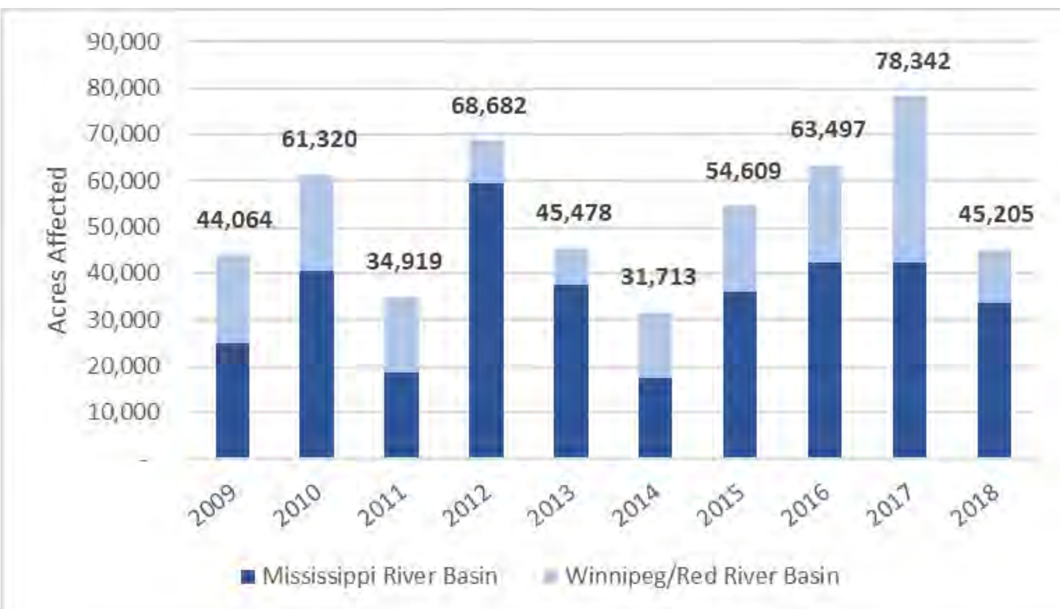


Figure 33. Acres affected by new living cover practices funded by non-CRP government programs from 2009 to 2018 (MPCA's Healthier Watersheds BMP tracking system).

Table 13. Acres of living cover practices 2014 to 2018 funded from non-CRP government programs (MPCA's Healthier Watersheds BMP tracking system).

	2014-2018 Cover crops	2014-2018 Perennials [a]	Living cover practices (non-CRP) – total acreage affected
Mississippi Basin	136,673	35,319	171,992
Red River Basin	71,588	29,785	101,373

a. Perennials include conservation cover, conservation crop rotation, conservation easements, critical area planting, filter strip, riparian forest buffer, riparian herbaceous cover, forage and biomass plantings. This table does not include CRP perennials.

The CRP has historically supported much of the planted perennials in agricultural areas of the state. The CRP is a voluntary program that helps agricultural producers safeguard environmentally sensitive land. CRP participants plant long-term, resource-conserving covers to improve water quality, control soil erosion, and enhance wildlife habitat. In return, Farm Service Agency provides participants with rental payments and cost-share assistance.

Minnesota agricultural land enrolled in USDA's CRP peaked in the 1993 to 1995 and 2007 to 2008 periods, with about 1.8 million acres under contract each year during those timeframes (Figure 34). Minnesota CRP enrolled acreage has dropped from 2008 to 2015 and leveled off with a 2018 enrollment of 1.14 million acres. CRP enrollment during the 2014 to 2018 period averaged 1.17 million acres, 28% lower than the long-term 1987 to 2013 average enrollment. Between 2014 and 2018, the number of CRP acres enrolled decreased by 163,000 acres. Most of this recent drop occurred between 2014 and 2015, with relatively stable CRP total enrollment between 2015 and 2018.

Figure 34. Annual CRP enrollment (1987 to 2018; www.fsa.usda.gov).

5.2.3.2 *Additional progress information on living cover practice adoption*

Information from farmer surveys and satellite imagery can provide additional information on the overall adoption trends for living cover practices.

Cover crops – non-government programs

Two main information sources exist to estimate overall state-level cover crop planting and establishment acreage estimations: the U.S. Census of Agriculture and satellite imagery. The U.S. Census of Agriculture provides survey results of cover crop acreages planted. Both the University of Minnesota (working in partnership with BWSR) and The CTIC OpTIS have been evaluating successful growth of cover crop acreages through satellite imagery. Actual acres of cover crops that emerge or germinate are typically less than the acres planted.

Based on the U.S. Census of Agriculture, between 2012 and 2017, cover crops planted in the state of Minnesota increased by more than 171,000 acres for a total of 579,147 acres in 2017, a 5-year increase of 41%, showing cover crop planting on just under 3% of all cropland in Minnesota. By comparison, government programs supported the addition of 260,954 acres of cover crops over that same 2012 to 2017 timeframe. Some of the cover crop acres tracked through government programs may have dropped out of the program after contract periods ended.

Satellite imagery analysis conducted by the University of Minnesota and BWSR provides an indication of cover crop acreages over southern Minnesota. Example outputs in Figure 35 show cover crops by county growing in fall of 2016, with a total of 214,000 acres. The 2016 outputs can also be viewed for major and minor watersheds. Estimates for cover crop acreage in the fall of 2017 and 2018 were limited because of difficult harvest conditions and early (November) onset of snow cover during those growing years in parts of Minnesota. These conditions made it difficult to get consistent results for cover crops using remote sensing satellite imagery. The University of Minnesota is currently exploring additional techniques to use other satellite-derived data products from synthetic aperture radar, which is less sensitive to cloud cover. This Minnesota-specific assessment with considerable in-state field validation shows promise for assessing long-term cover crop acreage trends.

Figure 35. Cover crop acres estimated using satellite imagery, Fall 2016. (University of Minnesota Soil, Water and Climate Department, and BWSR).

Satellite imagery analysis conducted through the CTIC OpTIS program at the CTIC at Purdue University show that 1.2% of corn and soybeans, on average, had vegetative cover in the winter time between 2005 to 2013 (cover crops, winter annuals or perennials). This percentage has remained about the same in the past five years (2014 to 2018), averaging 1.0%. Cover crops on small grains have been increasing and show up on over 11% of small grains statewide. According to the OpTIS program, established cover crop and winter annual crop acreages between 2014 to 2018 averaged 154,883 acres in Minnesota.

Continued work in the next five years will be undertaken to better understand the differences between these datasets and compare the methodologies and assumptions so that the most accurate and cost-effective way of estimating cover crop changes over time can be used.

The various cover crop measurements in Minnesota are not directly comparable. Based on the combined information, it appears that cover crop acreages are increasing, with total planted acres exceeding a half-million and total established cover crops exceeding 200,000 acres during at least some recent years. Depending on the climate conditions and other factors, not all planted acres of cover crops become well-enough established to be detected through the satellite imagery techniques.

Perennials

Trends in large-scale perennial changes can be approximated using satellite-derived land cover datasets, specifically the Cropland Data Layer (CDL) as well as farmer surveys. The U.S. Census of Agriculture shows a decrease in hay (defined as forage and including hay and all haylage, grass silage, and greenchop) between the years 2012 to 2017, indicating a 3.4% decrease (Table 14). The U.S. Census of Agriculture also summarizes information related to land currently under conservation easements, indicating an 11% decrease.

Land cover data between the years 2012 to 2018 were also summarized to determine trends in grasses, pasture, and hay. The total statewide CDL estimates of grass/pasture plus hay/haylage has gradually increased by 6.7% (300,000 acres) between the years 2014 to 2018 as shown in **Error! Reference source not found.**Figure 37. Hay/haylage acreages decreased and grass/pasture increased, with a net gain in the combination of perennials.

Table 14. Acres of perennial crops based on U.S. Census of Agriculture (2012 to 2017).

Practice	2012 Acres	2017 Acres	Change 2012 to 2017
Hay (forage and including hay and all haylage, grass silage, and greenchop) [a]	1,499,586	1,448,195	Decreased 51,391 acres
Conservation Easements [b]	244,482	218,215	Decreased 26,267 acres

a. Source: USDA NASS U.S. Census of Agriculture, Table 35 – Minnesota Specified Crops by Acres Harvested
b. Source: USDA NASS U.S. Census of Agriculture, Table 47 – Minnesota Land Use Practices

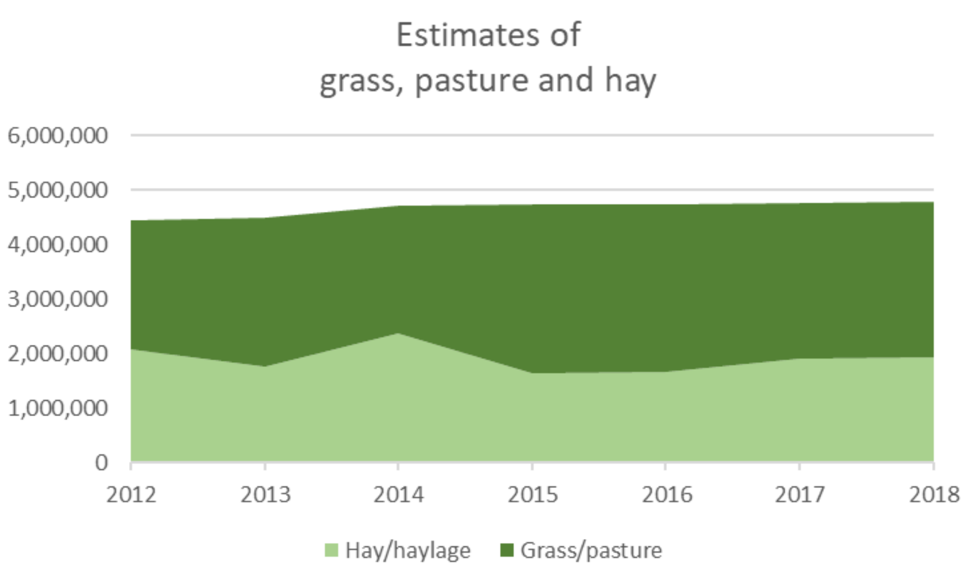


Figure 36. Estimates of grass, pasture, and hay in Minnesota from 2012-18 (Cropland Data Layer).

Summary of Minnesota's Progress on Living Cover Practices

Why important

- The NRS anticipated that the first five years of living cover practices would be largely focused on research and development, and that larger changes would mostly occur after the first five to 10 years.
- Living cover practices are essential for meeting both milestone and long term NRS goals. The NRS set interim targets of 2.2 million acres of new cover crops (largely on early harvest crops) and 440,000 acres of perennial crops and buffers in high priority areas.

Findings

- Some indicators suggest progress with living cover practices; however, adoption rates do not appear to be on track for meeting the needs outlined for 2014 NRS milestone scenario.
    - On average, 40,000 acres of cover crops have been added per year to major basins through government cost-share programs since 2014. Relatively little progress is being made with cover crops on corn/soybean rotations, with an estimated 1 to 1.5% of corn/soybean land currently with cover crops.
    - CRP enrollment remains over 1.1 million acres and has been fairly stable since 2015. However, CRP acreages during the past five years have been lower than most years since 1987.
    - Perennials added through government cost-assistance programs (apart from CRP) affected an average of 13,000 new acres per year between 2014 and 2018.
    - Statewide grass/hay/pasture perennial acreages have been fairly stable since 2014, with indications of slight decreases in hay and increases in grasses/pasture.

Follow-up

- Recent living cover initiatives need to continue while socio-economic information is evaluated to determine how to scale-up adoption rates.
- State water and climate resiliency plans and strategies should be integrated with 2014 NRS goals to work in concert toward new and expanded approaches to vastly increase living cover over the next five years.

5.2.4 Field erosion control practices

As stated in the 2014 NRS, field erosion control is one of the most effective methods for limiting export of cropland total phosphorus, although certain practices in some places can increase losses of the dissolved portion of phosphorus. Field erosion control practices selected for phosphorus reduction analysis in Chapter 5 of the 2014 NRS emphasized conservation tillage and residue management, terraces, grassed waterways, and sediment control basins, while recognizing that many other practices are important and effective for reducing cropland field erosion and associated phosphorus losses.

Adoption levels of field erosion control practices implemented in Minnesota between 2014 and 2018 were assessed using information from government program data bases, along with overall indicators of adoption through satellite imagery and the U.S. Census of Agriculture.

2014 NRS recommended agricultural BMPs

Field erosion control, emphasizing:

a. Tillage practices that leave more than 30% crop residue cover or alternative erosion control practices that provide equivalent protection
b. Grassed waterways and structural practices for runoff control

5.2.4.1 *Progress of field erosion control practice adoption through government programs*

Figure 37 and Table 15 provide a summary of field erosion control practices installed through government programs from 2014 to 2018 by major basin as tracked in the MPCA Healthier Watersheds program (NRS version found at: https://public.tableau.com/profile/mpca.data.services#!/vizhome/MinnesotaNutrientReductionStrategyBMPSummary/MinnesotaNutrientReductionStrategyBMPSummary). Most acres installed were residue and tillage management practices. Annual additions of new acreages of field erosion control practices decreased steadily from 2009 to 2013. In 2014, a slight recovery began, and in 2018 increases in agricultural loans for reduced tillage equipment increased the estimated new acres of adoption (Figure 38).

Figure 37. New acres for field erosion control practices enrolled through government programs, 2014 to 2018 (MPCA's Healthier Watersheds BMP tracking system).

*Other erosion control include: alternative tile intakes, contour buffer strips, field borders, grassed waterways, mulching, sediment basins, stripcropping, terraces, water and sediment control basins. Residue and tillage management practices include no-till/strip till, reduced till, and ridge till practices.

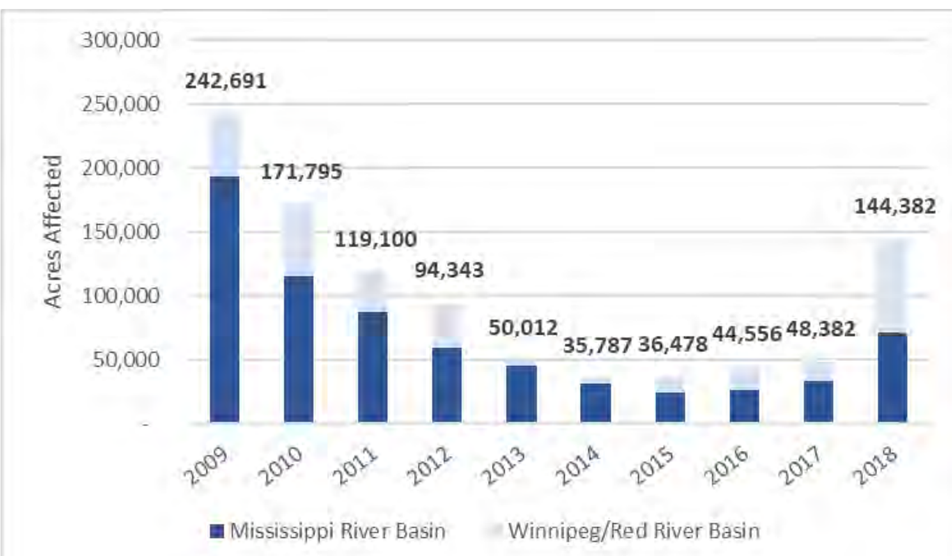


Figure 38. New acres of field erosion control practices added through government support programs 2009 to 2018 (MPCA's Healthier Watersheds BMP tracking system).

Table 15. Acres of field erosion control practices enrolled through government support programs, 2014 to 2018 (MPCA's Healthier Watersheds BMP tracking system).

	2014-2018 Residue and tillage management practices	2014-2018 Other field erosion control practices	Field erosion control – total acreage affected
Mississippi Basin	141,506	44,185	185,691
Red River Basin	117,773	6,122	123,896

5.2.4.2 *Additional progress information on field erosion control practice adoption*

Table 16 provides a comparison of tillage practices in Minnesota using the U.S. Census of Agriculture data from 2012 and 2017. The comparison of data from each census shows an increase in conservation tillage acres and a corresponding decrease of conventional tillage acres.

Table 16. Minnesota tillage practices (2012 and 2017).

Practice	2012 Acres	2017 Acres	Change 2012 to 2017
No-Till Practices Used	818,754	1,091,337	Increased 272,583 acres
Reduced Tillage/Conservation Tillage	6,109,886	8,214,896	Increased 2,105,010 acres
Intensive/Conventional Tillage	11,517,373	9,499,259	Decreased 2,018,114 acres

Source: USDA NASS U.S. Census of Agriculture, Table 47 – Minnesota Land Use Practices
No-till practices used. Using no-till or minimum till is a practice used for weed control and helps reduce weed seed germination by not disturbing the soil.
Reduced tillage. Conserves the soil by reducing erosion and decreasing water pollution. In 2012 this category was labeled conservation tillage. This is a wording change only; data are comparable.
Intensive/conventional tillage. Refers to tillage operations that use standard practices for a specific location and crop to bury crop residues. In 2012, this category was labeled conventional tillage.

Satellite imagery analysis conducted by the BWSR and University of Minnesota shows 2017 crop residue levels between 16 and 50% over most of the cropland regions of the state (Figure 40). The fraction of land with over 30% residue cover varies spatially and is lowest in south-central Minnesota and parts of northwestern Minnesota where land slope is generally lower.

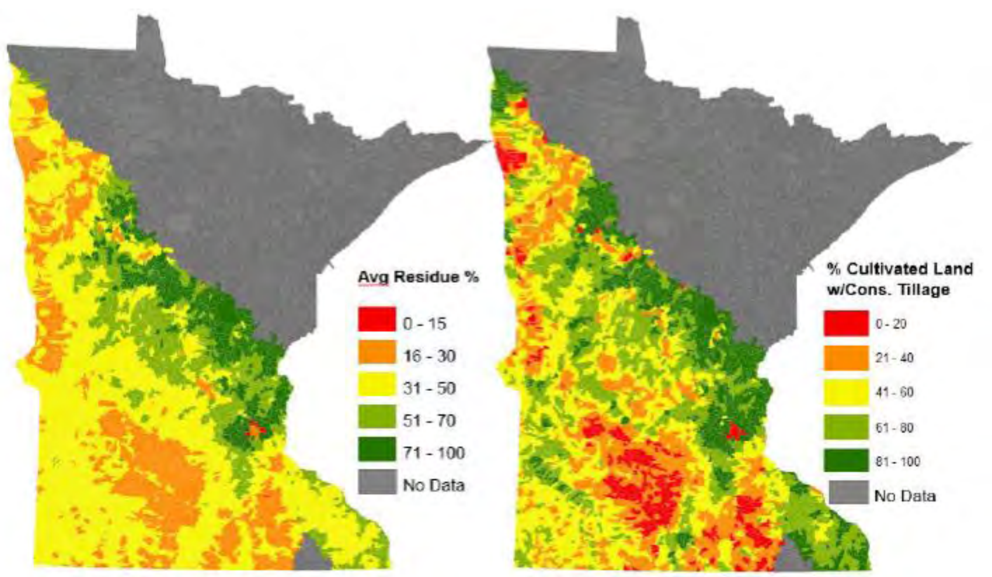


Figure 39. Average crop residue and conservation tillage by subwatershed in 2017 Data source University of Minnesota (Soil, Water and Climate Dept.) and BWSR.

Satellite imagery analysis conducted through the OpTIS program at the CTIC at Purdue University shows historical conservation tillage adoption data over time from 2009 to 2018 (Figure 41). The University of Minnesota compared the outputs of the remote sensing work shown above with the recently released information from the OpTIS program. For this comparison, the University of Minnesota used residue estimates for spring of 2017 based on Landsat 8 and Sentinel 2 imagery. Results between the Tillage and Erosion Survey Project estimates and the OpTIS estimates show relative consistency for cropland percentages falling in the four categories of residue cover, but OpTIS results reported higher acreage of crops grown, as shown in Figure 42. Future analysis will help explain the correlation between the estimates from each of these projects.

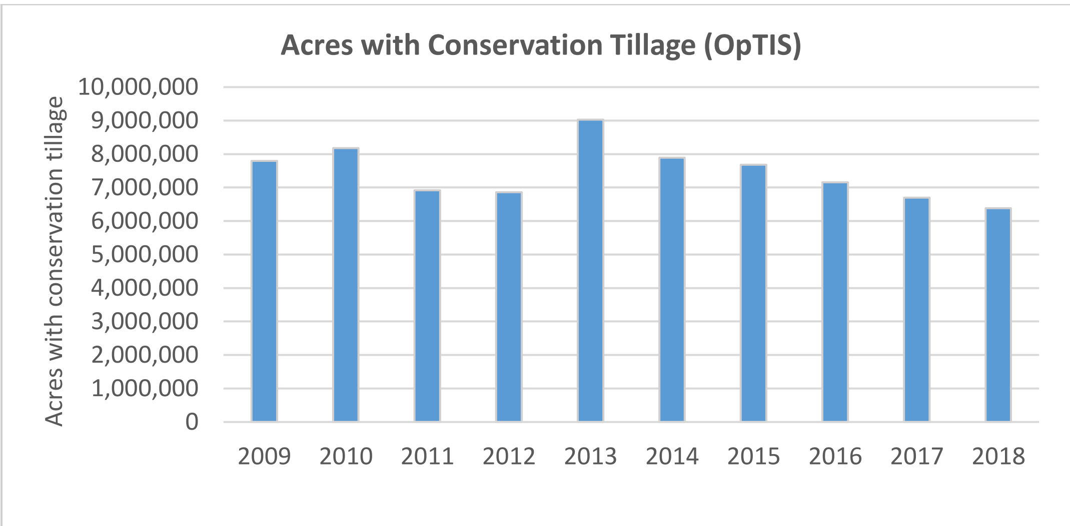


Figure 40. Acres in conservation tillage in Minnesota based on satellite imagery (OpTIS).

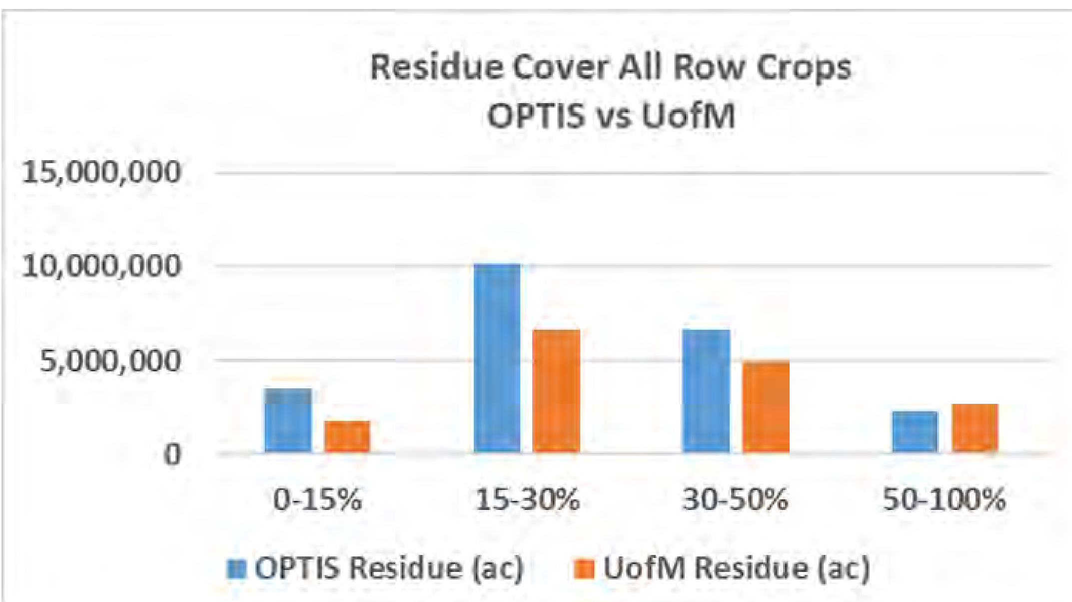


Figure 41. Comparison of residue cover on all row crops for 2016 (y-axis represents acres).

Summary of Minnesota's Progress on Field Erosion Control

Why important

- Conservation tillage, reduced tillage and no-till are common practices throughout Minnesota, with conservation tillage (>30% residue) or no-till on nearly half of cropland acres.
- While considerable progress was achieved with soil erosion control through past decades, crop residue surveys conducted prior to the NRS indicated considerable room for additional progress. An additional 4.9 million acres of erosion control acreage increases was called for in the NRS scenario due to its importance for phosphorus loss reductions, relatively low cost, and multiple benefits for also soil health, carbon storage, and keeping sediment out of waters.
- Tracking progress with soil erosion control practices is important to better plan for future strategy implementation goals and approaches.

Findings

- The rate of new erosion control practice additions appears to have decreased in recent years. An average of 60,000 acres of field erosion practices have been added annually through government cost-share and equipment-funding programs. The vast majority of these affected acres are residue management practices. Not all of these acreages will continue with conservation tillage after the contracted period ends.
- Satellite imagery through OpTIS and University of Minnesota studies shows 8-9 million acres of land with over 30% residue cover. This is generally consistent with the U.S. Census of Agriculture findings in 2017 of 9.3 million acres of conservation tillage plus no-till.
- Satellite imagery suggests about the same acreage of conservation tillage in 2012 and 2017. However, 2017 census information shows a substantial increase in conservation tillage/reduced tillage (on average adding 475,000 acres per year) between 2012 and 2017. If the census information reflects a real increase, it is predominantly outside of government assistance programs, since the total acreage in government programs during that timeframe represents only a small fraction of the census reported increase.

Follow-up

- Minnesota will continue tracking residue cover practices with satellite imagery and reconcile differences between census survey information and aerial imagery techniques.
- Since initial work to map structural conservation BMPs using LiDAR imagery has proven successful in providing a more complete picture of cumulative practices over the years, continuation of this work to statewide levels should be explored.

5.2.5 Tile drainage water treatment and storage practices

As discussed in the 2014 NRS, nitrogen is more mobile in the soil environment compared to phosphorus, and cycles within the air, land, and water. For example, 37% of the statewide nitrogen load to rivers in Minnesota moves through subsurface tile drainage systems on agricultural fields.

Subsurface tile drainage installation has continually increased in Minnesota during the past two decades. The 2017 U.S. Census of Agriculture showed 8,079,994 acres of land drained by tile in Minnesota, over 1.6 million acres more than shown in the 2012 census (Table 17). With approximately 20 million acres of row crops, small grains, and hay grown statewide, Minnesota tile-drains affect approximately 40% of the state's cropland.

2014 NRS recommended agricultural BMPs

Tile drainage water quality treatment and storage, emphasizing:

a. Constructed and restored wetlands
b. Controlled drainage when expanding or retrofitting drainage systems
c. Water control structures
d. Research and development of bioreactors, two-stage ditches, saturated buffers and other ways to store and treat drainage waters

Table 17. Drained land in the state of Minnesota (2012 and 2017) from the U.S. Census of Agriculture.

Practice	2012 Acres	2017 Acres	Change 2012 to 2017
Land Drained by Tile	6,461,173	8,079,984	Increased 1,618,811 acres
Land Drained by Ditches	4,548,977	4,674,449	Increased 125,472 acres

Source: USDA NASS U.S. Census of Agriculture, Table 41 – Minnesota Land Use Practices

Methods for storing and treating agricultural drainage waters for nutrient removal have been researched and demonstrated for many years. Drainage water retention practices selected for nitrogen reduction analysis in Chapter 5 of the 2014 NRS include constructed wetlands, controlled drainage, bioreactors and two stage ditches. Saturated buffers also show promising results for tile-drainage nitrate removal. Reuse of stored drainage waters for surface or subsurface irrigation is another practice being studied; however, reuse is not widely practiced in Minnesota.

Adoption levels for tile drainage water treatment and storage practices since 2014 are determined in this progress report using information from the MPCA's Healthier Watersheds BMP tracking system. Most of the tile drainage water treatment and storage practices are installed through government assistance programs because all require design and construction, and most have limited benefits for agricultural production. As such, the MPCA's Healthier Watersheds BMP tracking system likely captures the majority of existing tile-drainage water treatment and storage practices and no additional tracking methods are used. It is important to note that the MPCA's Healthier Watersheds BMP tracking system does not capture all locally-funded BMPs. Additional information on drainage-water storage practices implemented at the multi-state level in the Red River Basin is provided in Appendix A.

5.2.5.1 *Progress of tile drainage water treatment and storage practice adoption through government programs*

The majority of the government-assistance program BMPs for drainage water treatment were for wetland restoration, with drainage water management also constituting a significant portion of impacted acreages (Figure 42 and Table 18). A total of 15,074 acres were affected by these practices between 2014 and 2018. However, many of the wetland restoration and creation projects were not designed to treat tile drainage waters; therefore, the total acres of drained cropland affected by wetland restoration practices since 2014 is lower than the 9,879 acres noted in Figure 42. Since 2009, annual acreages of new tile drainage water treatment and storage practices has fluctuated (Figure 43). The Red River basin shows a sharp decline in state and federal government program supported implementation starting in 2016. In 2018, the Mississippi River basin experienced its highest rate of implementation since 2009, according to practices recorded in the MPCA Healthier Waters tracking system.

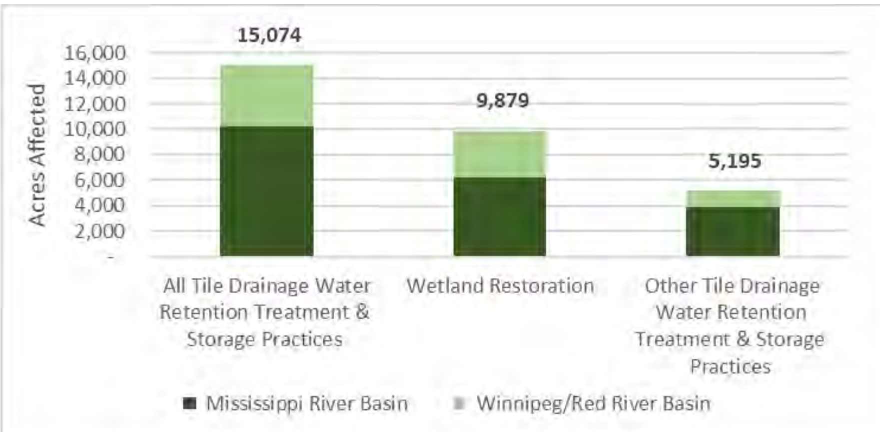


Figure 42. New acres of tile drainage water treatment and storage practices enrolled through government programs, 2014-2018 (MPCA's Healthier Watersheds BMP tracking system).

*Other tile drainage water treatment and storage practices include denitrifying bioreactor, drainage water management, saturated buffers.

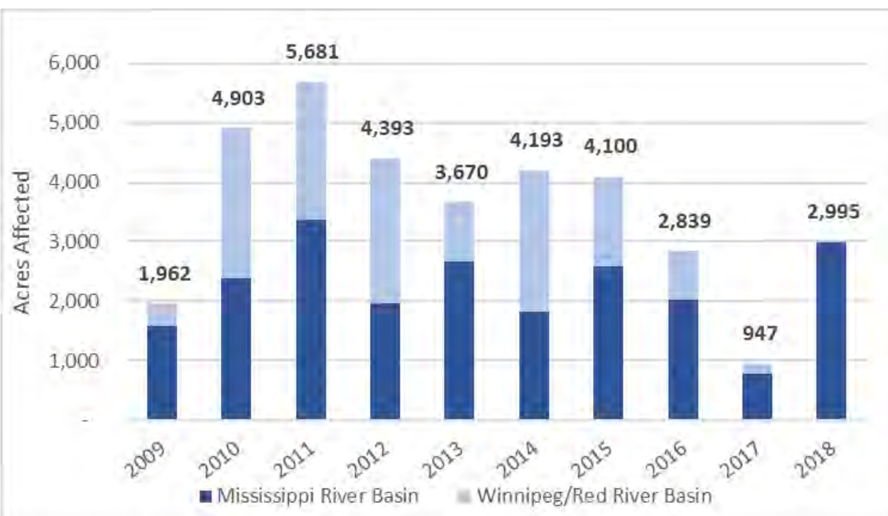


Figure 43. New affected acres of tile drainage water treatment and storage practices added through government support programs 2009 to 2018 (MPCA's Healthier Watersheds BMP tracking system).

Table 18. New affected acres of tile drainage water treatment and storage practices added through government programs, 2014 to 2018 (MPCA's Healthier Watersheds BMP tracking system).

	2014-2018 Wetland Restoration	2014-2018 Other tile drainage treatment practices	Drainage treatment – total acreage affected
Mississippi Basin	6,257	3,926	10,183
Red River Basin	3,622	1,269	4,891

Summary of Minnesota's Progress on Tile Drainage Water Treatment and Storage Practices

Why important

- Tile drainage waters are the largest source pathway of nitrate to rivers in Minnesota. In-field practices such as fertilizer/manure management and cover crops can reduce nitrate leaching to tile-lines. However, to achieve the nitrogen reductions in the NRS, additional measures are needed, including edge-of-field tile water storage and treatment.
- The NRS example milestone scenario calls for 620,000 acres of tile-drainage waters treated through edge-of-field practices (equivalent to 62,000 newly treated acres per year).

Findings

- Tile-drainage water treatment practices have not gained traction in Minnesota. Acreages affected are very low and are still mostly in demonstration mode. Few existing drivers or programs are expected to dramatically increase the use of these practices (i.e., saturated buffers, treatment wetlands, controlled drainage management and bioreactors):
  - The total amount of Minnesota tile-drained lands has increased by over 1.6 million acres between 2012 and 2017, based on the U.S. Census of Agriculture.
  - Tile water treatment for nutrient reduction is increasing by about 3,000 acres per year based on government program records over the past 5 years.

Follow-up

- A better understanding of the socio-economic barriers and opportunities is needed in order to implement more successful strategies for storage and treatment of tile-drainage waters. Emphasizing the multiple benefits of certain practices, such as constructed wetlands and two-stage ditches, may also help boost adoption.

5.3 Are we on track to meet agricultural BMP milestones?

The 2014 NRS includes example cropland BMP scenarios that are predicted to achieve the nutrient reduction goals and milestones, as described in Section 4.1. The short timeframe of this progress report makes it difficult to draw conclusions around actual in-water progress during the past five years. While nitrogen and phosphorus water quality trend monitoring are ideal for long-term evaluation of NRS progress, short-term evaluation through river monitoring is complicated by patterns of climate variability, lag times, margin of error, and other complicating factors. To address these complexities, the 2014 NRS emphasizes the need to track BMP adoption across major basins, and to compare adoption levels with milestone BMP scenarios identified in the 2014 NRS. As was previously noted, considerable cropland acreages were affected by BMPs prior to the beginning of the 2014 NRS, especially reduced tillage and soil erosion control. The focus now is on practices above and beyond the BMP adoption that occurred historically. This section of the 5-year NRS progress report summarizes the progress detailed in section 4.2 concerning 2014 to 2018 changes in BMP adoption compared with NRS-identified benchmark acreages. The government assistance program progress is first summarized, followed by a summary of additional indicators of progress that include efforts outside of government programs.

Considering only BMP adoption tracked through government programs between 2014 and 2018, the recently added BMP acreages are not on a trajectory to meet the 2025 milestone scenario goals, as depicted in Figure 44.

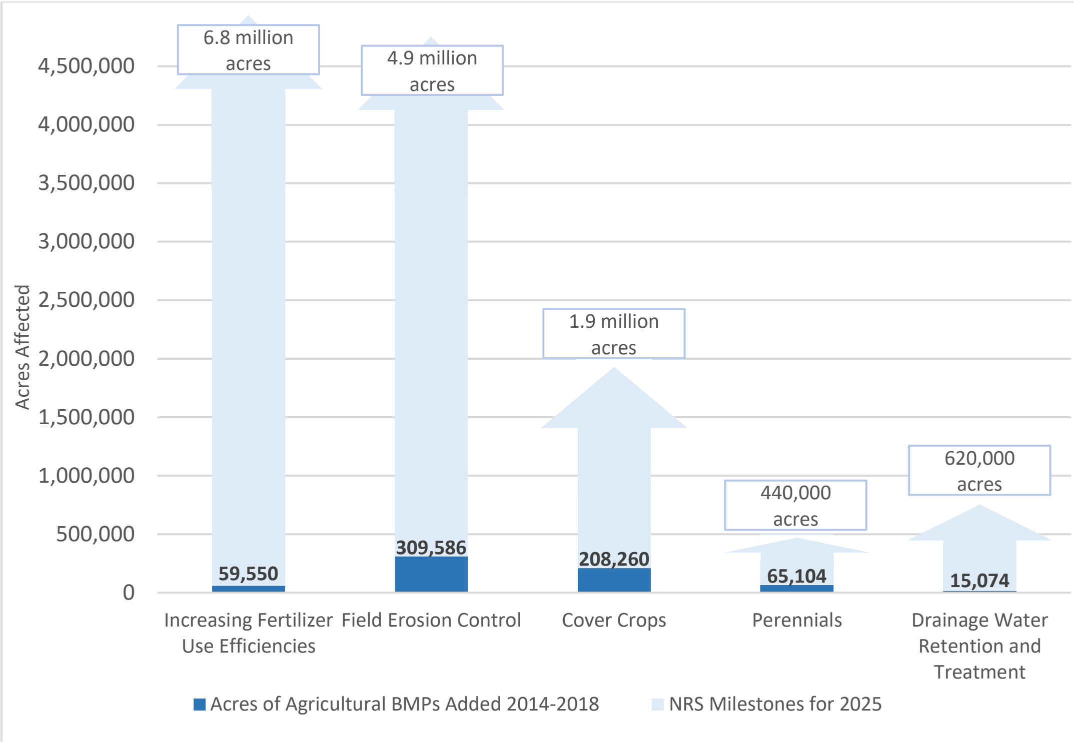


Figure 44. Newly affected acreages of agricultural BMPs (2014-2018) implemented through government programs in the Mississippi River and Lake Winnipeg Basins toward the NRS milestone scenario outlined in the 2014 NRS for completion by 2025. Note: this depiction does not include private adoption of practices outside of government programs.

Progress with government program BMP adoption in the four NRS categories is summarized below.

Nutrient management efficiency practices – From 2014 to 2018, a total of 59,550 new acres of nutrient management efficiency practices were added to the Mississippi River basin under government-tracked programs, representing only 1% of the 6.1 million acres in the milestone scenario. A total of 3,900 acres was added to the Red River basin under government-tracked programs, less than 1% of the 700,000-acre 2024 milestone.

Living cover practices – In the Mississippi River basin, new acres of government program supported cover crops totaled 136,673 acres, 10.5% of the milestone outlined in the 2014 NRS. 71,588 acres of cover crops were added in the Red River basin, representing 10% of the milestone. Perennials in the CRP dropped from 2014 to 2015 and has remained stable since 2015. 65,104 newly affected acres of perennials were added between 2014 and 2018 through other government programs, compared to the milestone scenario 2024 target of 440,000 acres.

Tile drainage water treatment and storage practices – From 2014 to 2018, a total of 10,183 new acres of tile drainage water treatment and storage practices were added to the Mississippi River basin, only 1.6% of the milestone scenario of 600,000 acres. A total of 4,891 acres were added to the Red River basin, or 23% of the 20,000-acre milestone.

Field erosion control practices – 185,691 new acres of government program supported field erosion control practices were added in the Mississippi River basin from 2014 to 2018, representing 4% of the 4.5-million-acre milestone scenario goal by 2024. A total of 123,895 acres were added to the Red River basin, around 31% of the 400,000-acre milestone.

The scale of agricultural BMP adoption through government programs has not been on-pace during recent years to achieve the example NRS milestone BMP scenario. Living cover practices show potential to achieve the milestones, but the rate of adding those practices would need to increase considerably between 2020 and 2025. Two key follow-up questions need to be considered:

(1) Are private industry BMP adoption efforts making up the difference between the government program BMPs and the NRS scenario levels of adoption?
(2) Are the new and advancing programs (see Section 2) ramping-up enough to increase BMP adoption in 2020 to 2025, as compared to 2014 to 2019?

Both private industry efforts and full implementation of recently advancing state programs can potentially make a substantial difference in the rate of BMP adoption.

Indicators of overall BMP adoption rates (including adoption outside of government programs) during the past 5 to 10 years also suggests that Minnesota is likely to fall short of achieving the needed scales of adoption outlined in the NRS scenarios. This assessment is based on a combination of survey information, sales data, satellite imagery findings, soil testing and other sources that reflect the combination of government program and private industry influences. However, the metrics need improvement and further study to gain a greater understanding of overall progress. One area of conflicting information is progress with conservation tillage and residue cover. While the U.S. Census of Agriculture suggests a substantial increase in conservation/reduced tillage acreage, satellite imagery results show decreasing acreages of land with over 30% residue.

Based on the program advancements made during the past five years, it is anticipated that BMP adoption will accelerate in 2020 to 2024, as compared to 2014 to 2018. These program advancements include private/public partnerships, educational programs, watershed plans, BMP funding programs, research findings, rules in place, and other developments reported in Section 2 and Appendix A. While the full effects of these advancing programs won't be apparent for several years, it seems unlikely based on the progress identified in this report that existing program advances alone will achieve the scale of BMP adoption needed to reach nutrient reduction strategy scenario targets.

To increase the likelihood for an improved NRS assessment in 2024, Minnesota should consider what additional information, advancements, and implementation efforts are necessary during 2020 to 2024 to make additional progress toward long-term nutrient reduction success. Section 6 describes recommended next steps for the 2020 to 2024 period.

6 Wastewater and other sources – Is progress consistent with NRS direction?

The implementation strategies outlined in the 2014 NRS provided recommendations and guidance to also reduce phosphorous and nitrogen loading from non-cropland sources. This section examines the progress made in nutrient reduction from wastewater, feedlots, urban stormwater, and septic systems.

6.1 Wastewater

2014 NRS recommended wastewater strategies

a. Implementation of the Phosphorus Rule and Strategy
b. Implementation of River Eutrophication Standards
c. Influent and effluent nitrogen monitoring at wastewater treatment facilities
d. Nitrogen management plans for wastewater treatment facilities
e. Nitrogen effluent limits
f. Add nitrogen removal capacity with facility upgrade
g. Point source to nonpoint source trading

According to the 2014 NRS, wastewater phosphorus and nitrogen loads account for approximately 18% and 11% of the phosphorus loads in the Mississippi and Red Rivers, respectively, and 9% and 6% of the nitrogen loads in the two respective rivers. In the Lake Superior drainages within Minnesota, the overall wastewater nutrient loads are much lower than in the Mississippi, but the fraction of the loads from wastewater is higher (24% for phosphorus and 31% for nitrogen). The 2014 NRS included goals and strategies for nutrient reductions from permitted wastewater sources based on the best available information at the time. Additional phosphorus and nitrogen monitoring data collected since 2014 are now available to refine existing nutrient loads from wastewater. This section presents the updated loading and goals, as well as recent progress on phosphorus and nitrogen reductions.

6.1.1 Updated existing loading and goals

New effluent monitoring and data analysis methods result in a shift in the baseline loads attributed to wastewater compared to the baselines cited in the 2014 NRS. Table 19 summarizes the 2014 NRS loads and new phosphorus information along with the updated current load that represents an average over 2016 to 2018. Overall, using the updated values, there has been an approximate 70% statewide reduction in phosphorus loading from wastewater sources since 2000 to 2002, and a reduction of about 20% since the 2010 to 2012 average.

Baseline nitrogen loads for wastewater in the 2014 NRS were derived from the SPAtially Referenced Regression on Watershed Attributes (SPARROW) model and represent the 2005 to 2006 time period. Table 20 summarizes the new nitrogen information collected through increased monitoring initiated in 2010 and expanded after 2014.

Phosphorus reduction goals for the wastewater sector continue to be based on full implementation of the Phosphorus Strategy (codified as Minn. R. Ch. 7053.0255) and water quality-based effluent limits based on lake and river eutrophication standards. To meet the 2025 milestones for wastewater nitrogen, the reduction goals are based on a 20% reduction in overall nitrogen loading needed in the Mississippi River basin and a 13% reduction in the Red River basin.

Table 19. Revised existing phosphorus loads from permitted wastewater.

Basin	Phosphorus			
	2014 NRS wastewater baseline load (average 2010-2012) (MT/yr)	**Updated wastewater baseline load (average 2010-2012) (MT/yr)**	**Current load (average 2016-2018) (MT/yr)**	**Change since updated baseline**
Statewide	796	737	584	-21% (153 MT/yr)
Mississippi River	Not defined	620	490	-21% (130 MT/yr)
Red River	Not defined	73	54	-26% (19 MT/yr)
Lake Superior	Not defined	43	35	-19% (8 MT/year)

Table 20. Revised existing nitrogen loads from permitted wastewater.

Basin	Nitrogen			
	2014 NRS wastewater baseline load (SPARROW representing the 2005-2006 time period) (MT/yr)	**Updated wastewater baseline load (average 2010-2012) (MT/yr)**	**Current load (average 2016-2018) (MT/yr)**	**Change since updated baseline**
Statewide	10,879	13,824	14,327	+4% (503 MT/yr)
Mississippi River	9,363	11,718	12,593	+7% (875 MT/yr)
Red River	304	487	469	-4% (18 MT/yr)
Lake Superior	1,212	1,645	1,109	-33% (536 MT/yr)

6.1.2 Phosphorus reduction

The total phosphorus load discharged by statewide wastewater sources decreased between 2010 and 2014, maintaining a relatively even trend since 2014, as shown in Figure 45. Statewide, there has been a 71% reduction in phosphorus for wastewater since 2000. Overall, 92% of wastewater phosphorus loads reported here are derived directly from effluent monitoring data, providing a high degree of confidence in these estimates.

Phosphorus limits are required on 89% of the wastewater flow volume in the state. Phosphorus limits are derived from three different standards:

- Lake eutrophication standards – Water quality standards approved in 2008.
- River eutrophication standards – Water quality standards approved in 2015.
- State discharge restriction – Regulation-based effluent limitations that vary with facility size, location, and upgrade timing. These limits are largely the result of implementing the MPCA's Phosphorus Strategy and are gradually being supplemented by limits set to meet lake and river eutrophication standards.

Importance of wastewater phosphorus loads by scale

Wastewater phosphorus loads discharged by industrial facilities are relatively minor on a statewide basis (17% of statewide wastewater phosphorus load totals in 2018) but can be very important on a local watershed scale.

For example, in the Rainy River Basin (HUC-4 0903) the industrial phosphorus load for 2018 is 94% of the total wastewater load.

Table 21 summarizes the number of permits with phosphorus limits. A permit can contain more than one type of phosphorus limit. Table 22 shows the wastewater volume associated with each type of limit. While municipal wastewater facilities discharge the vast majority of statewide effluent phosphorus loads, industrial wastewater is an important local source of nutrient additions in certain areas and are also included in the assessment. Forty-six percent of industrial facilities monitor phosphorus and 9% of the facilities have phosphorus limits.

Table 21. Permits with phosphorus limits (August 2019).

	Permits with phosphorus limits
Lake Eutrophication Standard limits	363
River Eutrophication Standard limits	113
State Discharge Restriction limits	121

Table 22. Permitted flows associated with different phosphorus limits.

Current limit type	2018 Flow (MG)			Municipal	Industrial
	Municipal	Industrial	Total	% of total permitted flow	% of total permitted flow
Lake eutrophication standard	112,943	4,415	117,358	66%	4%
State discharge restriction	39,907	7,432	47,339	23%	6%
River eutrophication standard	578	196	774	0.3%	0.2%
No limit	17,122	105,088	122,210	10%	90%
Total flow	*170,550*	*117,131*	*287,681*	*100%*	*100%*

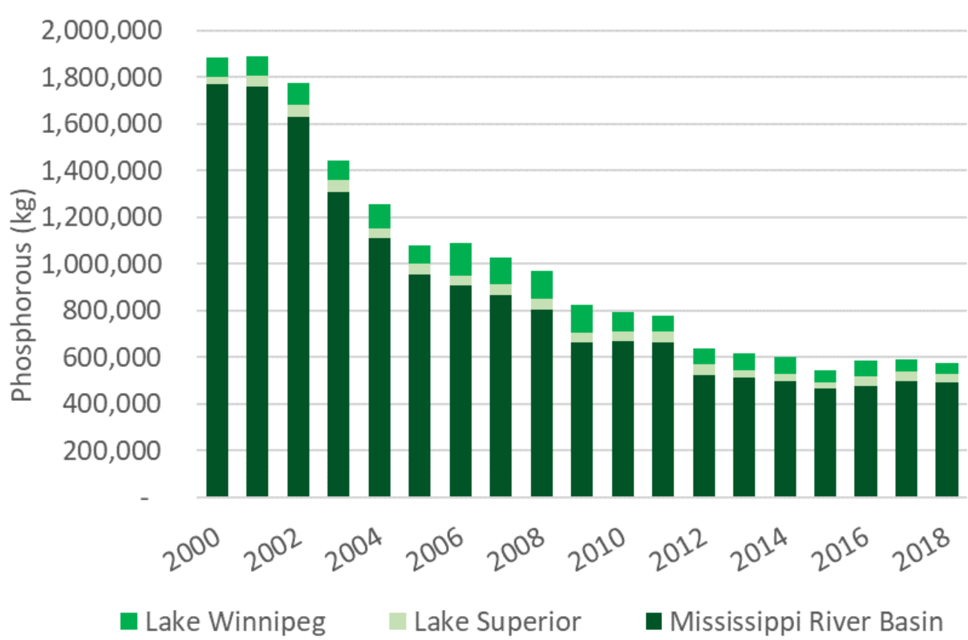


Figure 45. Statewide wastewater phosphorous loads (2000-2018).

Phosphorus loadings by major basin are provided in Figure 47 through Figure 48:

- **Mississippi River** – Between 2014 and 2018, 201 municipal and 82 industrial facilities made reductions. As noted earlier, there was a 21% reduction between the 2010 to 2012 period and the 2016 to 2018 period. From 2014 to 2018, the fraction of decrease was much smaller. The slight increase during the last three years in Figure 47 can be explained by population increases and wet weather, generating greater volumes of wastewater discharge (Figure 47).
- **Lake Winnipeg** –Industrial sources of phosphorus contribute a large fraction of phosphorus discharge. Decreases in phosphorus loading are due in part to actual reductions, and in part to better monitoring of industrial discharges (Figure 47).
- **Lake Superior** – Western Lakes Sanitary Sewer District (WLSSD) in Duluth is the largest wastewater discharger in the Lake Superior Basin and discharged 56% of the total permitted wastewater in this basin in 2018. The WLSSD and the City of Virginia Wastewater Treatment Plant started making phosphorus reductions in 2013, resulting in wastewater phosphorus reductions to Lake Superior between 2012 and 2015. Wastewater phosphorus increased from 2016 to 2018 in part due to increased phosphorus loading from WLSSD, however, total loading is still below the long-term 2000 to 2011 average (Figure 48).

Adoption and implementation of River Eutrophication Standards has generated resistance from some sectors of the wastewater community. This has taken the form of various legal challenges to the adoption of water quality standards (Minn. R. Ch. 7050.022) and implementation at the individual permit level. It is anticipated that RES TMDLs will also face similar legal hurdles. In general, opposition from point sources has centered around challenges to the technical basis for the standards, concern about the costs of implementation and concern that point source investment in further phosphorus reductions will not be effective unless non-point source reductions are also accomplished.

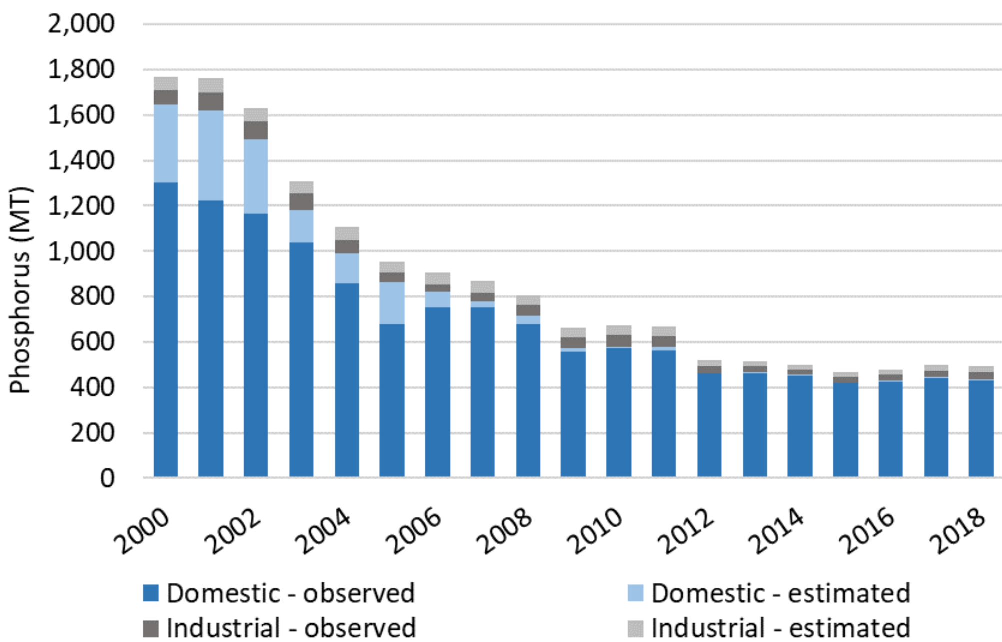


Figure 46. Mississippi River basin phosphorous loading.

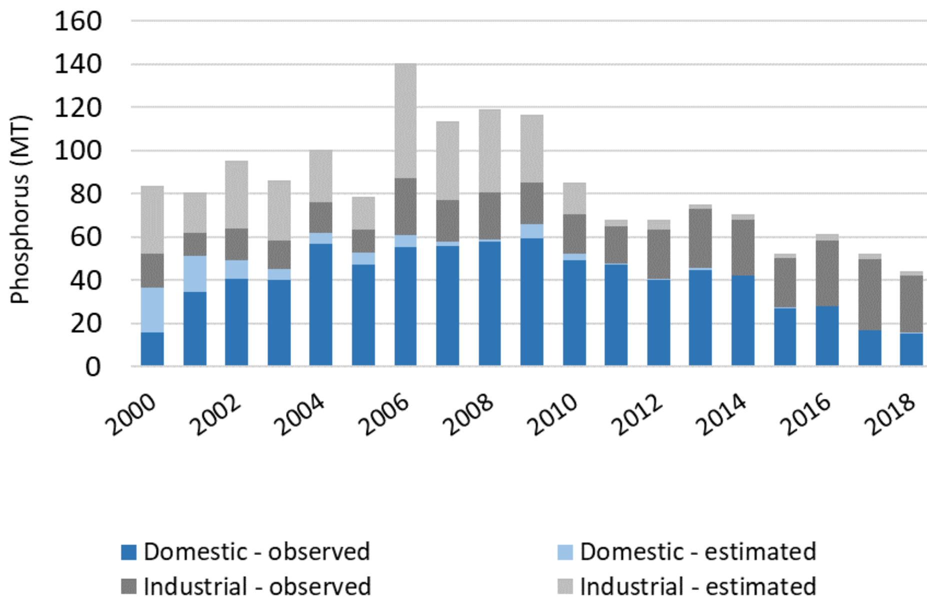


Figure 47. Lake Winnipeg basin phosphorous loading.

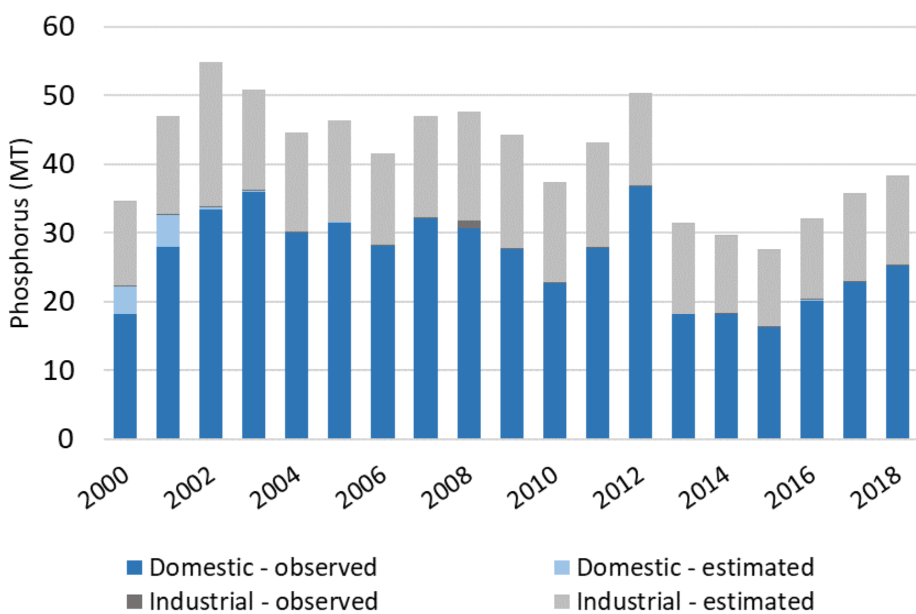


Figure 48. Lake Superior basin phosphorous loading.

6.1.3 Nitrogen reduction

Nitrogen load reductions from wastewater were not expected within the first five years of NRS implementation. Instead, Minnesota focused on collecting new monitoring data from wastewater sources to better determine existing nitrogen loads. Table 23 summarizes updated nitrogen concentrations for treated municipal wastewater based on the new monitoring data. There are 205 facilities with continuous discharge (i.e., mechanical) and 50 facilities with controlled discharge (i.e., stabilization ponds) that monitor nitrogen in their wastewater (Figure 49).

Table 23. Updated average nitrogen concentrations for treated municipal wastewater.

Facility category	Nitrogen concentration assumptions (mg/L)
Class A municipal – large mechanical	21
Class B municipal – medium mechanical	21
Class C municipal – small mechanical/ pond mix	12
Class D municipal – mostly small ponds	6

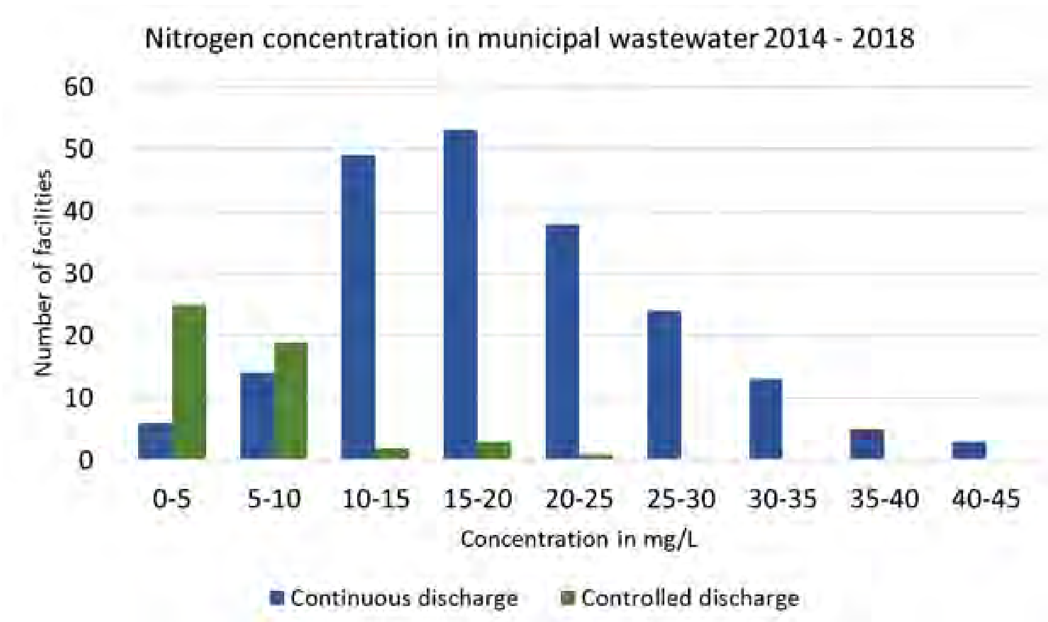


Figure 49. Effluent total nitrogen concentrations for facilities in Minnesota.

Figure 50 provides the best estimate of statewide nitrogen loading from wastewater. Since very few wastewater treatment systems remove nitrate or total nitrogen, statewide load reductions are not evident. Observed trends are due to a combination of improved monitoring information and population increases. The increase in nitrogen monitoring data is evident beginning in 2010 and ramped up considerably in 2016 (Figures 52 to 54). Pre-2016 nitrogen loading estimates are largely based on assumed concentrations; therefore, it is challenging to accurately determine changes in loading. Figure 51 through Figure 54 provide the best estimates of nitrogen loading by major drainage basin.

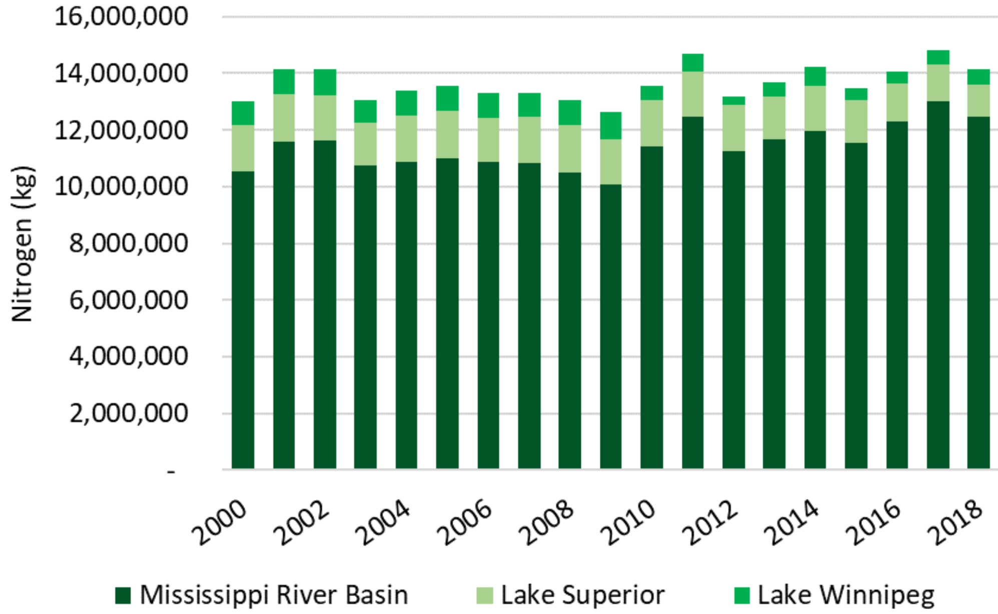


Figure 50. Statewide wastewater nitrogen loads (2000 – 2018).

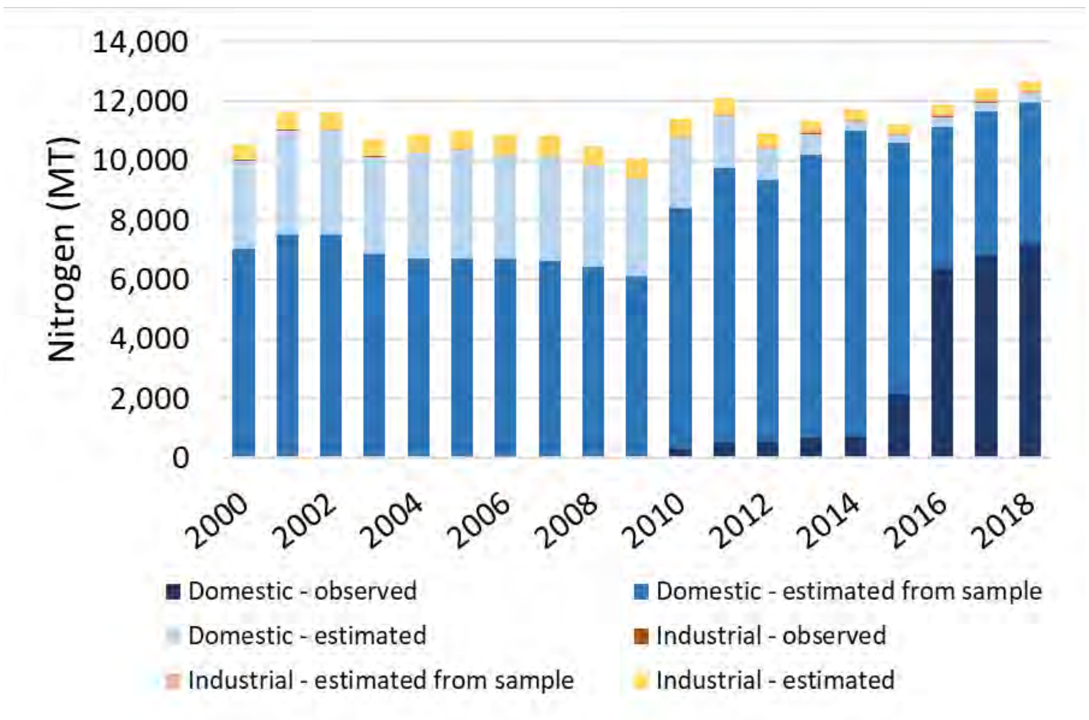


Figure 51. Mississippi River basin nitrogen loading.

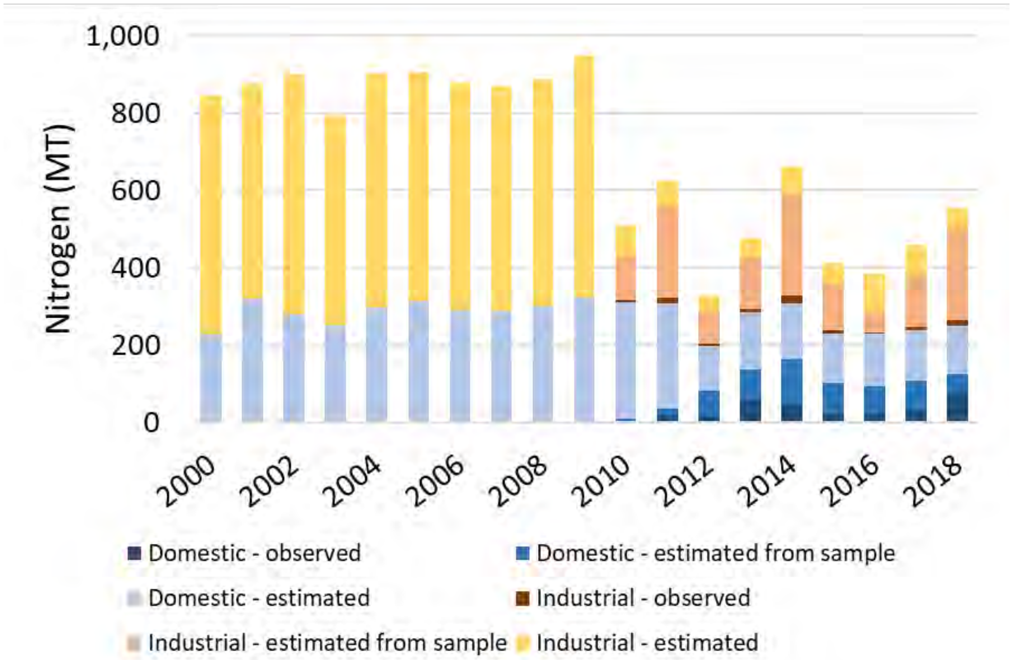


Figure 52. Lake Winnipeg basin nitrogen loading.

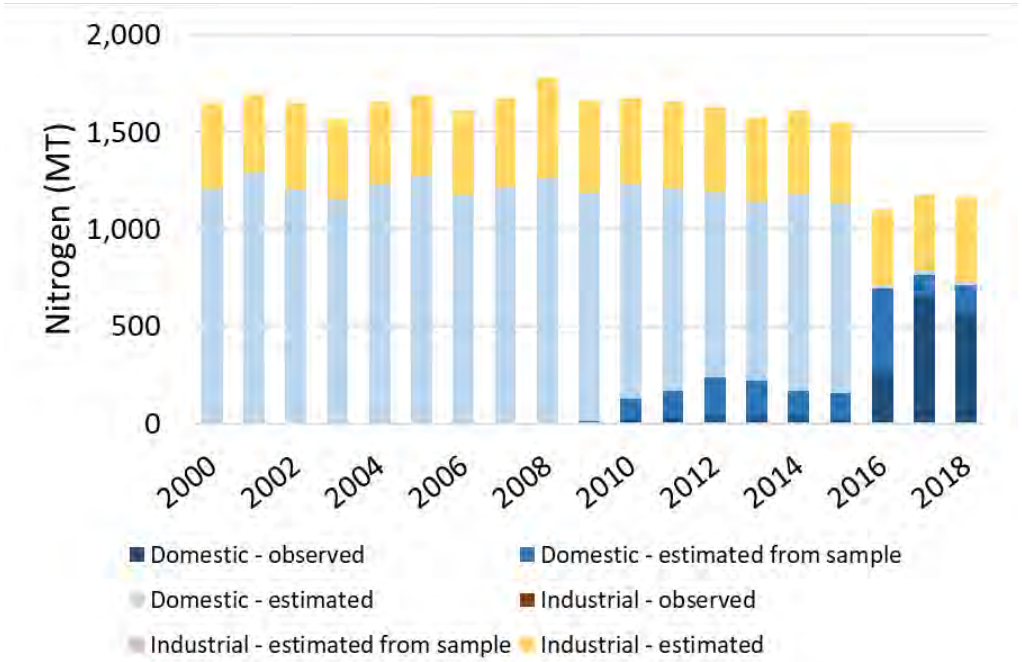


Figure 53. Lake Superior basin nitrogen loading.

Summary of Minnesota's progress on wastewater

Why important

- Municipal and industrial wastewater represent the largest manageable nutrient source category following cropland. The relative proportion of river nutrient loads from wastewater becomes greater during times of low flow, and in areas where agricultural sources are minimal.
- The NRS called for continued phosphorus reductions through wastewater permit limits established to help achieve eutrophication standards, and it also outlines a series of steps to make progress with nitrogen treatment.

Findings

- NPDES phosphorus permit limits apply to approximately 90% of municipal wastewater flows and 10% of industrial wastewater flows (600 wastewater permits), as driven by the Lake Eutrophication Standards, River Eutrophication Standards and/or State Discharge Restriction Limits.
- While much of the 70% reduction in statewide phosphorus wastewater discharges occurred prior to the 2014 NRS, wastewater dischargers have maintained these improvements and achieved additional reductions in alignment with the direction set forth in the NRS.
- One of the first NRS steps for wastewater nitrogen was to increase monitoring. Now, 255 facilities regularly monitor nitrogen in their effluent.
- Estimated statewide nitrogen loads from wastewater have generally remained steady, increasing slightly along with population and precipitation.

Follow-up

- Minnesota will continue taking the steps outlined in the NRS for achieving nitrogen reductions from wastewater, while at the same time maintaining and continuing the progress with phosphorus.

6.2 Miscellaneous sources

The 2014 NRS provides recommended strategies for feedlots, urban stormwater, and septic systems to reduce their runoff and nutrient pollution. The following section outlines each source individually, summarizes the recommended strategies, and summarizes progress made from 2014 to 2018.

6.2.1 Feedlots

Over 20,000 registered feedlots in Minnesota generate manure for land spreading on roughly 4 million acres of cropland. Runoff from feedlot sites (animal holding areas and manure storage systems) and from manure-treated cropland can be an impactful localized source of nutrients. Yet statewide, runoff from feedlot sites represent less than 1% of nitrogen and less than 2% of phosphorus. The 2014 NRS accounts for nutrients directly from feedlot sites in the total phosphorus load "miscellaneous" reductions.

Land application of manure from feedlots to cropland is a more important statewide potential pathway for nutrients than runoff from feedlot animal-holding sites. Proper crediting of nutrients from manure with high organic nitrogen content is challenging compared to inorganic nitrogen sources. Nutrient availability is highly dependent on the type and size of animal, climatic conditions and is influenced by bedding, storage, application method, and other practices. MDA (2014) reported that the average nitrogen rate from manure applied in combination with non-manure sources such as fertilizer is higher than when only non-manure sources are used (MDA 2014). Manure nutrient crediting requires that manure nutrient content be tested, and records shared with the fertilizer dealer so they can accurately adjust commercial inputs.

Land application of manure contributes about 25% of the added nitrogen to cropland throughout Minnesota (MPCA 2013), with the other dominant source being cropland fertilizer. The 2014 NRS includes land application of manure to cropland in the "fertilizer use efficiency" reductions for both phosphorus and nitrogen.

2014 NRS recommended feedlot strategies

Operational measures through the MPCA Feedlot Program:

- All large concentrated animal feeding operations (CAFOs) and feedlots with greater than or equal to 1,000 animal units should be in compliance with discharge standards at the time of inspection.
- All large CAFOs and feedlots with greater than or equal to 1,000 animal units should be in compliance with nitrogen and phosphorus management requirements at the time of inspection.
- All feedlots not covered by a National Pollutant Discharge Elimination System (NPDES) or State Disposal System (SDS) permit should be in compliance with discharge standards at the time of inspection.
- All feedlots not covered by a NPDES or SDS permit should be in compliance with nitrogen and phosphorus management requirements at the time of inspection, including management of land application of manure activities.

An overview of progress made in the feedlot program since 2014 is provided below. Progress since 2014 is determined using information from land application and feedlot inspections and compliance rates.

6.2.1.1 *Land application of manure inspections and compliance*

Feedlot regulation in the State of Minnesota

Feedlot runoff and storage and manure spreading onto cropland are regulated by the MPCA and 50 counties delegated by the State to administer the program for non-CAFOs. In Minnesota, all feedlots (CAFO and non-CAFO) must meet certain feedlot runoff and manure application requirements, including agronomic rates of application and setbacks from waters. As the size of the feedlot increases, additional requirements are added, such as record-keeping, manure and soil testing, manure storage, and nutrient planning.

Inspection records prior to 2018 did not consistently distinguish between non-compliance due to nutrient related regulations and non-nutrient related regulations. Beginning in 2018, the feedlot regulatory program implemented an improved inspection checklist and developed a more rigorous quality assurance/quality control process for compliance rate data (available on MPCA's feedlot website).

The MPCA documented 1,697 land application of manure inspections between 2014 and 2018 (Table 24). In 2018, 97 inspections were of in-field land application of manure and 96 were of nitrogen and phosphorus management records. The inspected sites are not necessarily representative of all feedlots around the state and may depict a different rate of non-compliance than actual statewide averages.

Table 24. Number of land application of manure inspections, 2014-2018.

Year	Total number of land application inspections
2014	656
2015	445
2016	314
2017	89
2018	193
Total	*1,697*

Half of the 2018 land application of manure related inspections were in-field inspections and half were inspections of records documents. The 2018 inspection reports at sites selected for inspection showed the following percentages of inspections that were *non-compliant* with rules and requirements of land application of manure:

In-field inspections of manure spreading practices

- 33% of the 97 *in-field inspections* resulted in non-compliance due to inadequate phosphorus testing and or not complying with state requirements for phosphorus management.
- 10% of the 97 *in-field inspections* resulted in non-compliance due to application of manure within required setback zones to waters or discharging directly to waters.
- 29% of the 97 *in-field inspections* resulted in some level of non-compliance with manure applied at agronomic rates.

Records inspections of manure spreading practices

- 22% of the 96 nitrogen and phosphorus management *record inspections* resulted in non-compliance for one or more of the following: inadequate records, total nitrogen rates exceeding agronomic needs, or manure not incorporated into the soil where and when it is required.

6.2.1.2 *Feedlot inspections and compliance (facility)*

The MPCA and delegated counties documented 9,236 feedlot inspections between 2014 and 2018 (Table 25). Three percent (3%) of all feedlot inspections conducted in 2018 resulted in some level of non-compliance with feedlot facility requirements. These requirements include discharges from open lots, feed storage, process wastewater, stockpiles, mortality management areas, or liquid manure storage areas, and do not include land application of manure.

Table 25. Feedlot inspections (facility), 2014-2018.

	Conducted by Delegated Counties	Conducted by MPCA
2014	1,822	334
2015	1,736	234
2016	1,535	226
2017	1,465	206
2018	1,430	248
Total	*7,988*	*1,248*

Government assistance programs helped to fund construction of 194 manure storage facilities statewide between 2014 to 2018. Many of these storage facilities were constructed to reduce feedlot runoff and/or provide greater management flexibilities for applying manure at more optimal times of the year.

Summary of Minnesota's Progress on Feedlot Program

Why important

- The NRS acknowledges that runoff from feedlot facilities contributes a very small percentage of nutrients on a regional scale, but locally can cause problems. Manure generated at feedlots and applied to cropland, however, is a significant potential source of nitrogen and phosphorus to waters and needs to be carefully and judiciously applied.
- Regulations for land application of manure generated at all Minnesota feedlots increased markedly in 2000.

Findings

- Inspections of land application of manure activities from in-field observations and farm-office records were conducted at 1,697 sites between 2014 and 2018. Inspections during 2018 show that more progress is needed to improve setbacks, rates of nitrogen applied, keeping records, and phosphorus testing and management.
    - Depending on the land-application requirement evaluated, compliance rates were between 67% and 90% at the targeted inspection sites; however, the inspected sites are not necessarily representative of all feedlots.
- The vast majority of feedlot facility sites meet feedlot runoff requirements, with compliance rates at 97% during 2018 inspections.

Follow-up

- Continued and increased emphasis on land application of manure practices is important for reaching NRS goals.
- Cover crops and other conservation and living cover practices should increasingly be used to reduce nutrient leaching and runoff stemming from manure application.

6.2.2 Urban stormwater

2014 NRS recommended urban stormwater strategies

- Regulated stormwater source permitting (MS4, construction, industrial)
- Stormwater technical assistance in the form of the Minimal Impact Design Standards (MIDS) and the Minnesota Stormwater Manual
- Stormwater research and demonstration

Implementation of the MPCA stormwater program serves as the primary strategy to reduce nutrient loads from stormwater. The MPCA stormwater program regulates the discharge of stormwater and snow melt runoff from MS4s, construction activities, and industrial facilities, mainly through the administration of NPDES and SDS permits. For more information go to https://www.pca.state.mn.us/water/stormwater, or search "stormwater" on the MPCA webpage. Nutrients from stormwater (regulated and non-regulated) are accounted for in the "miscellaneous" reductions in total phosphorus load in the 2014 NRS.

An overview of progress made in the stormwater program is provided below. Progress since 2014 is determined using information collected from the stormwater permitting program. Additionally, many watershed organizations, particularly those in the Twin Cities Metropolitan area, have made progress beyond Minnesota's permit requirements.

Three Minnesota general stormwater permits reduce and/or prevent new nutrient additions in stormwater: MS4 Permit, Construction Stormwater Permit (between 2,000 and 2,500 permits issued annually over the past five years), and Industrial Stormwater – Multi-sector General Permit (3,920 permits in 2019).

In addition to the above general permits, other regulatory mechanisms are in place to further protect local waters, such as permitting land-disturbing activities by municipalities or watershed organizations. In addition to regulatory requirements, many volunteer programs exist to encourage and incentivize stormwater treatment. Activities not associated with the MPCA's stormwater program are not tracked at the state level, and therefore are not included in this NRS progress tracking. However, these additional activities do contribute to overall nutrient reduction.

The MPCA only collects and tracks data for regulated (permitted) MS4s. Currently, there are 247 regulated small MS4s in Minnesota, and 2 large permitted MS4s (Minneapolis and St. Paul). Approximately 4% of the land area in the state is covered under a MS4 permit as shown in Figure 55.

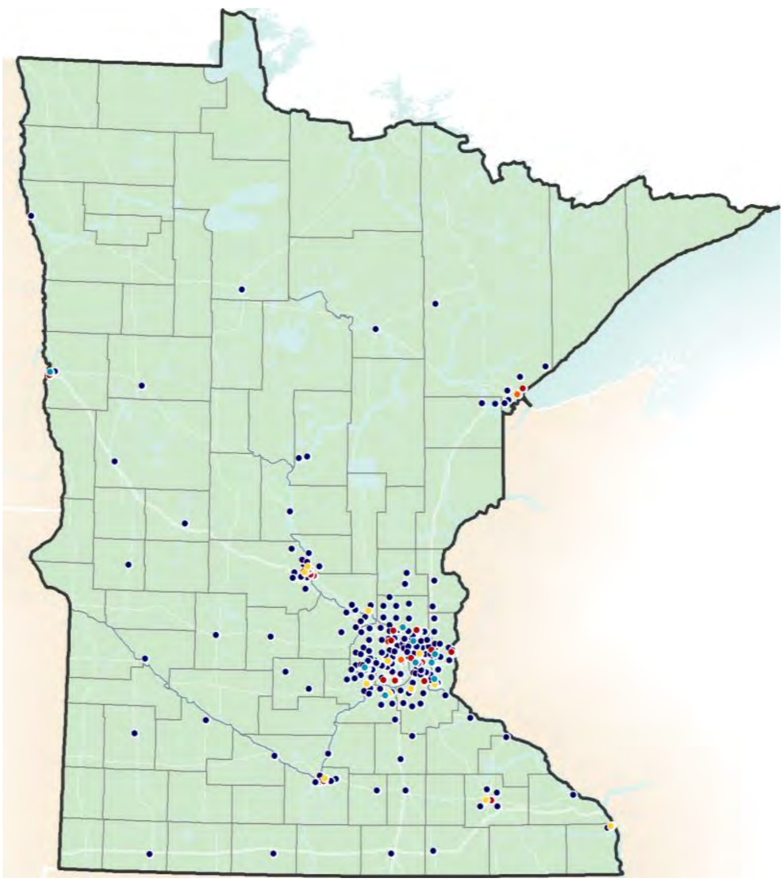


Figure 54. Regulated MS4s.

In addition to making progress towards meeting pollutant load reductions needed to comply with water quality standards and TMDLs, regulated MS4s are also required to meet post-construction volume requirements that will also reduce nutrient loads. The most common method for controlling runoff volume at a site is infiltration or other treatment of the first one inch of runoff from impervious surfaces.

The MPCA collects and tracks data for regulated (permitted) MS4s. Data on structural and non-structural BMPs is provided in required MS4 annual reports. The MS4 permittee must provide a summary of the progress toward achieving TMDL wasteload allocations (WLAs). The summary must include a list of BMPs implemented, the implementation status of BMPs that were included in the permittee's compliance schedule, and an estimate of cumulative total sediment and total phosphorus load reductions.

MS4 permittees with TMDL WLAs were first required to report the BMPs implemented in 2014. Note that the MS4 permittees self-report the data to MPCA and MPCA does not necessarily conduct thorough quality checks of the data reported. The year in which a BMP was reported does not necessarily indicate which year the BMP was implemented.

Structural BMPs

MS4 permittees assigned a WLA in a TMDL approved by the U.S. Environmental Protection Agency (EPA) prior to issuance of the most current MS4 permit (August 1, 2013), and who were not meeting that WLA(s) when they applied for permit coverage, must annually complete a TMDL Report to demonstrate progress toward meeting the WLA(s). Currently, of the 247 regulated small MS4 permittees, 78 permittees are required to complete the TMDL Annual Report under the 2013 MS4 permit. This requirement will continue when the new MS4 permit is re-issued in 2020. When the new MS4 permit is re-issued, 228 regulated MS4s will have a nutrient or sediment WLA and will be required to report progress on meeting these WLAs annually. The data collected from these reports includes the number and type of structural and nonstructural BMPs implemented since the baseline year to make progress towards meeting MS4 WLAs.

From 2015 to 2017, a total of 418 structural BMPs were reported by 78 MS4 permittees (Table 26). The data provided in “pre-2015” represents all BMPs implemented up to and including the year 2014. As of 2017, 1,764 structural BMPs were reported by 78 permittees. The most commonly implemented BMPs include:

- Constructed basin BMPs (e.g., ponds, wetlands) comprised 52% of all BMPs implemented. Wet ponds accounted for 55% of the reported constructed basin BMPs.
- Filter BMPs (e.g., biofiltration, sand filter, permeable pavement, and iron enhanced filter) comprised 10% of all BMPs implemented. Biofiltration (rain garden with an underdrain) accounted for 64% of the reported filter BMPs.
- Infiltrator BMPs (e.g., bio-infiltration, infiltration basins/trench, underground infiltration, tree trench) comprised 33% of all BMPs implemented. Bio-infiltration (rain garden with no underdrain) accounted for 55% of the reported infiltrator BMPs.
- Swale or Strip BMPs (e.g., filter strip, dry swale, and grass channel) comprised 5% of all BMPs implemented. Grass channel/waterway accounted for 69% of the reported swale/strip BMPs.

Table 26. Structural BMPs reported by regulated MS4s

Data provided under “pre-2015” represents all BMPs implemented up to and including the year 2014.

	Reporting Year				
Structural BMP	**pre-2015**	**2015**	**2016**	**2017**	**Grand Total**
Constructed basin	827	25	46	27	925
Filter	88	29	38	21	176
Infiltrator	403	55	63	59	580
Swale or strip	28	4	4	47	83
Grand Total	**1,346**	**113**	**151**	**154**	**1,764**

Non-structural BMPs

In addition to structural practices, MS4 permittees also reported implementing 2,887 non-structural BMPs. Non-structural BMPs include enhanced street sweeping, employee or public education and outreach, establishing ordinances, enhanced road salt management (which can affect phosphorus), improved lawn care practices, etc. Pollutant load reductions associated with non-structural BMPs are difficult to quantify. Properly implemented, however, they will lead to reductions in pollutant loading.

For example, from 2014 to 2017, 42 permittees reported implementing enhanced street sweeping BMPs. These practices included increased frequency of sweeping and implementing vacuum sweeping.

Another example is supplemental public education and outreach, which includes activities such as developing and distributing publications (650), giving presentations (244), and conducting workshops/clinics (126).

Summary of Minnesota's Progress on Urban Stormwater

Why important

- Stormwater runoff contributes relatively little nitrogen to regional surface waters but is a more important source of phosphorus.
- The NRS called for continued attention to phosphorus reduction through the MPCA and local community stormwater program. The MS4 general permit requires reductions in sediment and phosphorus by regulated entities subject to WLAs.

Findings

- Once the 2020 MS4 general permit is issued, 228 regulated MS4s will be required to report progress on sediment and phosphorus reductions annually, compared to 78 permittees reporting under the 2013 general permit.
- Prior to 2015, constructed basins were the most prevalent BMP installed for compliance with MS4 permit requirements. However, since 2015 practices that focus on infiltration, have more commonly been constructed, providing benefits in addition to water quality treatment (e.g., volume control, groundwater recharge, etc.).

Follow-up

- Minnesota will continue improving its tracking of the specific practices implemented to reduce nutrients from urban stormwater runoff.

6.2.3 Septic systems

Implementation of Minnesota's SSTS program serves as the primary strategy in the 2014 NRS to reduce nutrient loads from septic systems. Nutrients from septic systems are accounted for in miscellaneous reductions for total phosphorus in the NRS. Implementation of the SSTS program emphasizes continued progress to reduce the number of failing SSTS and imminent public health threats. An overview of progress made in the SSTS program is provided below. Progress since 2014 is determined using information from SSTS inspections and compliance rates.

2014 NRS recommended Subsurface Sewage Treatment Systems (SSTS) strategies

- Implement existing SSTS Program to reduce the percentage of failing SSTS to less than 5%
- Implement the Large Subsurface Sewage Treatment System Groundwater Nitrogen Policy

SSTS inspections have been occurring at a consistent rate since 2014 (Table 27). Of the reported 575,726 existing systems in Minnesota, 14,923 systems or 2.6 % of existing systems were evaluated for compliance in 2018. Inspections are triggered most commonly during a point of sale of the property. There are currently 166 local government units (80%) that have a point of sale inspection requirements included in their local SSTS ordinance. This includes 61 (71%) county SSTS programs.

Table 27. SSTS compliance inspections.

Year	Number of systems inspected	% of systems inspected
2014	12,805	2.4%
2015	14,543	2.7%
2016	14,847	2.7%
2017	15,250	2.8%
2018	14,923	2.6%

Since 2002, local government units have issued over 96,000 SSTS construction permits for replacement SSTS, or systems that replace an existing sewage system that was identified as non-compliant for either failing to protect groundwater or an imminent threat to public health and safety (ITPHS) through an inspection (Figure 55). While inspection rates have remained fairly steady since 2014, the number of compliant systems has increased and the number and fraction of septic systems that fail to protect groundwater or are otherwise considered ITPHSs has dropped to less than 5% (Figure 57). The number of estimated compliant systems has increased from 424,000 systems in 2014 to roughly 463,500 systems in 2018. Compliance rates in 2018 were estimated at 81%.

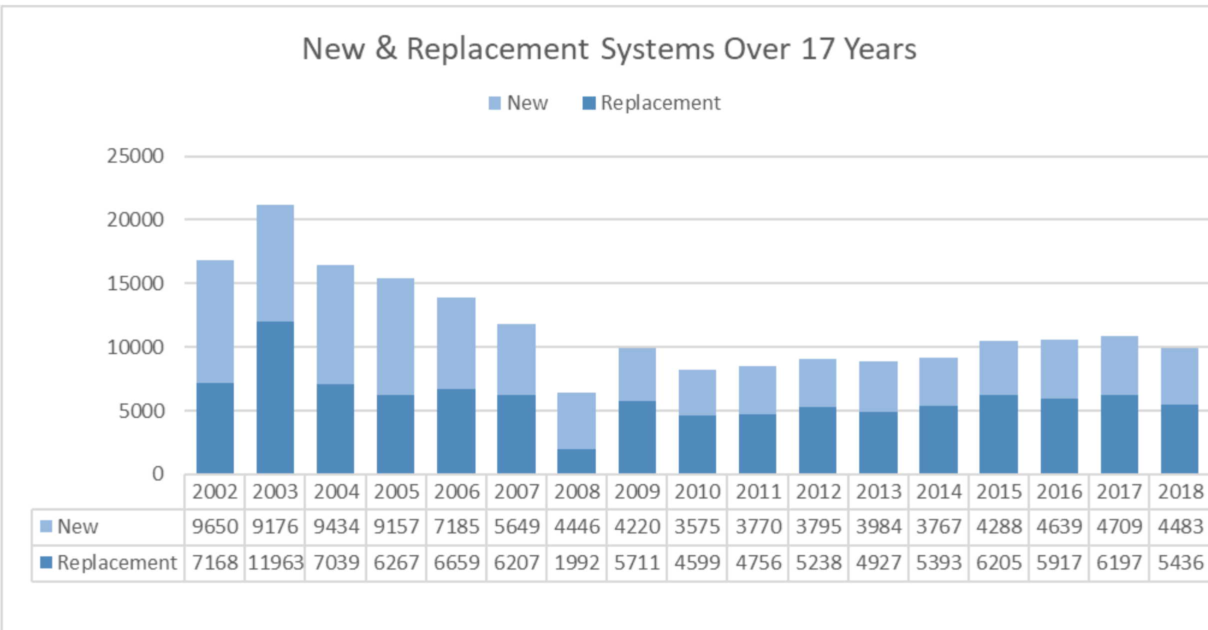
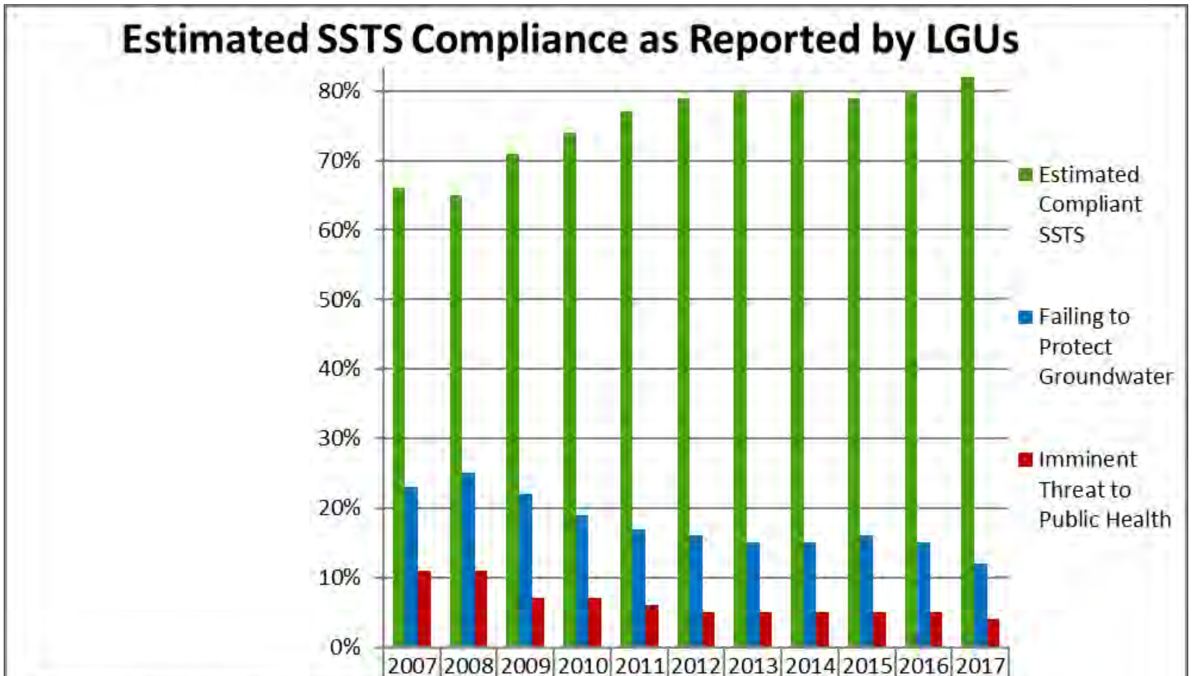


Figure 55. New and replacement SSTSs over time (2002-2018).



	2007	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017
Estimated Compliant SSTS	66%	65%	71%	74%	77%	79%	80%	80%	79%	80%	82%
Failing to Protect Groundwater	23%	25%	22%	19%	17%	16%	15%	15%	16%	15%	12%
Imminent Threat to Public Health	11%	11%	7%	7%	6%	5%	5%	5%	5%	5%	4%

Figure 56. Estimated compliance (2007-2018).

Summary of Minnesota's Progress on Subsurface Sewage Treatment Systems

Why important

- Septic systems are a small nutrient contributor statewide but can create local groundwater and surface water problems when improperly sited, constructed and maintained.
- The NRS called for continued progress with Minnesota's regulatory program for Septic Systems.

Findings

- Between 2014 and 2018, over 13,000 annual inspections of septic systems occurred each year.
- The number of septic systems considered imminent public health threats has dropped to less than 5%, thus meeting the NRS strategy target.
- During 2014 to 2018, between 12 and 15% of inspected septic systems failed to protect groundwater.

Follow-up

- Continued implementation of the SSTS program to better protect groundwater and surface waters.

7 What are the next steps for the NRS (2020-2024)?

All Minnesotans are part of the nutrient reduction solution. Only with large-scale collaboration at all levels, in all sectors, among all citizens, can Minnesota achieve the scale of change needed to significantly reduce nutrients and meet NRS goals.

Minnesota has advanced most of the numerous program areas identified in the 2014 NRS intended to achieve nutrient reductions. However, as discussed in previous sections, more time is needed for the programs to reach their full potential to significantly reduce nutrients. During the next five years, it is necessary for Minnesota partner agencies to continue developing, advancing and implementing the NRS programs identified in Section 2 and Appendix A. Yet, based on our indicators of progress thus far it is likely that continuation of existing programs alone won't be sufficient to achieve the scale of BMP adoption needed to reach nutrient reduction goals.

Achieving NRS goals depends on large-scale, multi-million acre new adoption of practices such as:

- Cover crops and other continuous living cover vegetation;
- Nitrogen and phosphorus fertilizer (and manure) applied at times, forms, rates and methods that maximize economic efficiencies along with environmental outcomes (i.e., such as split N based on in-field monitoring, sufficient crediting of N from manure and legumes, phosphorus fertilizer banding/incorporation, etc.);
- Increasing crop residue cover through innovative systems, such as strip till, along with other traditional soil conservation practices;
- Treatment-wetland construction and other tile-drainage water storage and treatment systems; and
- Other BMPs proving to be the most promising for *multiple agricultural and ecosystem benefits.*

In addition, wastewater treatment for nitrogen removal is important for meeting the NRS long-term goals.

To further move us toward increased scales of BMP adoption and to set the stage for the 2024 NRS republishing, four next steps are recommended, as follows:

1) Maximize the multiple benefits of NRS practices by coordinating efforts with other plans and strategies that use similar practices to achieve resiliency to climate change and ecosystem improvements. For example, soil health and living cover strategies in the EQB State Water Plan not only help us to become more resilient to precipitation increases but also help us reduce nutrients in water. We need to increase these practices in ways that can best meet both needs.
2) Identify and remove social, economic, and other human-dimension barriers to scaling-up BMP implementation,
3) Use the latest research to continue refining the optimal combination of practices that will achieve the needed nutrient reductions in our waters,
4) Optimize wastewater nitrogen treatment.

Each of these next steps are described in more detail below.

1) Maximize the multiple benefits of NRS practices by coordinating with other plans and strategies that use similar practices to achieve resiliency to climate change and ecosystem improvements.

NRS implementation should be increasingly coordinated and integrated with EQB's State Water Plan, Minnesota Clean Water Council's Strategic Plan, and other water and climate resilience plans and strategies. These plans and strategies can work in harmony to maximize the multiple benefits and increase adoption of practices providing continuous living cover, soil carbon build-up and crop nutrient efficiencies.

Many of the practices identified in the Nutrient Reduction Strategy will result in benefits beyond nutrient reduction. Public agencies and private organizations responsible for administering programs that affect nutrient reductions to waters should integrate planning efforts and prioritize practices and locations to achieve multiple benefits, including:

- Greenhouse gas reduction;
- Sediment reduction in rivers and downstream lakes;
- Resiliency to climate variability;
- Long-term agricultural sustainability and profitability;
- Soil health;
- Wildlife habitat and pollinator increases;
- Lake and river health;
- Nutrient reductions for drinking water source protection (public and private wells), and
- Other ecosystem benefits.

The cost and effort to increase nutrient-related practices to waters can often be further justified when considering the multiple benefits of the practices. For example, if all of the milestone NRS BMPs were implemented, the agricultural cropland portion of greenhouse gas emissions in Minnesota could be expected to be reduced by roughly 10%, and meeting final NRS goals would result in an even greater reduction (based on typical greenhouse gas reductions for BMPs as reported in MPCA, 2019).

Implement soil health and living cover measures in water and climate change plans - The strategy of improving soil health incorporates many of the practices and changes critical to meeting the long-term goals of the NRS, including reduced tillage, cover crops, and perennial crops. Soil health and living cover strategies in Minnesota's 2020 State Water Plan coordinated by EQB and Clean Water Council's (CWC) Strategic Plan are generally consistent with NRS goals and should be a high priority for implementation.

A monumental movement toward building soil health in Minnesota will not only work toward meeting NRS goals, but will also help achieve the other goals outlined above. An important component of building soil health and meeting NRS goals is the addition of cover crops on millions of row crop acres. The CWC's 2020 draft strategic plan sets a goal of adding 5 million acres of cover crops or continuous living cover to row crop agriculture by 2034. This goal is generally consistent with the pace of cover crop additions needed to meet NRS 2025 milestone goals and estimates of what it will likely take to achieve NRS 2040 final goals.

Additionally, Minnesota's Executive Order 19-37 establishes the Climate Change Subcabinet and the Governor's Advisory Council on Climate Change to promote coordinated climate change mitigation and resilience strategies in the state of Minnesota. Strategies for natural and working lands and for resiliency and adaptation to meet the goals are closely related to many of the NRS strategies for increasing living cover, crop residue and overall soil health. Implementing the recommendations of climate action team strategies will have co-benefits to achieving nutrient reductions in waters, along with several other benefits.

Prioritize local watershed efforts to achieve multiple benefits - The NRS emphasized Minnesota's local watershed management approach for implementing state-level programs at the local level, in ways that are prioritized, targeted and measurable. Local watersheds are a scalable unit for planning, priority setting, and implementation, and provide a good place to try approaches that can lead to scaling-up multi-beneficial practices across the landscape.

Minnesota has been developing watershed-scale science-based strategies and plans (i.e. through WRAPS and 1W1P, as shown in the maps below), but has had only a few years to implement the plans. As watershed-scale planning and implementation progresses, it is important to optimize practices and strategies to achieve the multiple benefits identified above. Prioritizing local water planning and implementation efforts to achieve such multiple benefits should increase the probability of success and maximize the use of limited resources.

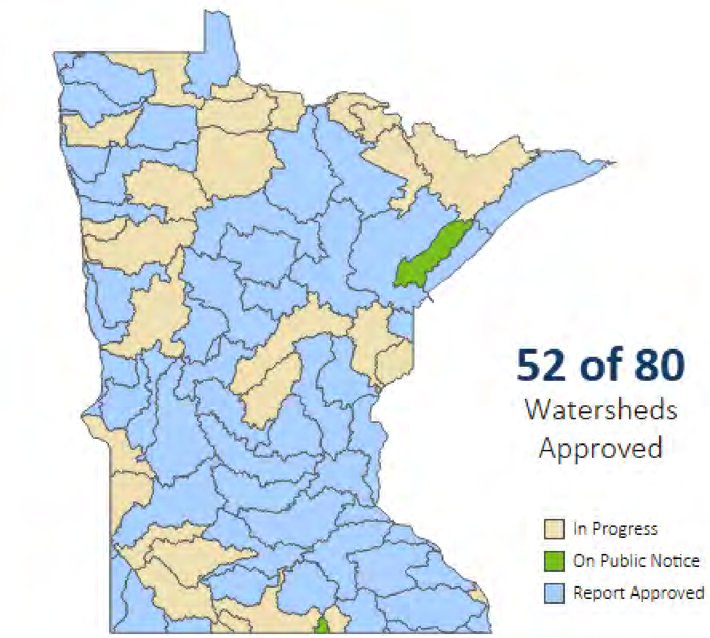


Figure 57. Completion status of Watershed Restoration and Protection Strategies (WRAPS).

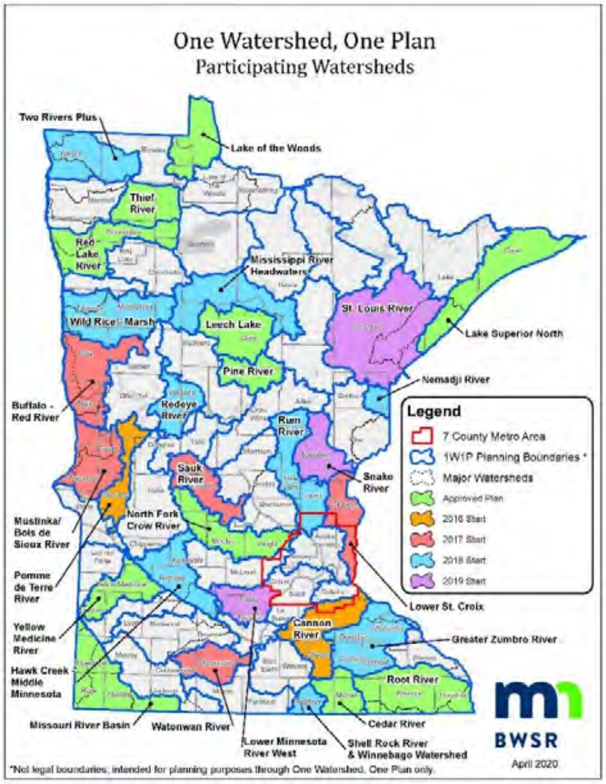


Figure 58. Watersheds participating in the One Watershed, One Plan program.

Specific actions

A. State agencies and partner organizations should seek opportunities to prioritize full implementation of strategies in the CWC Strategic Plan, EQB State Water Plans, NRS, and Climate Change Subcabinet plans that will result in significant increases in living cover and soil health for multi-purpose benefits. The combinations of strategies and plans will work toward:

    - Two million acres by 2025 on our way to over 10 million acres by 2040 of a combination of the following:
        - Cover crops with short-season crops;
        - Cover crops with full-season crops;
        - Expansion of grass-fed meat and dairy;
        - Strategic long-term permanent placement of perennial crops and plants in high-priority areas;
        - Perennial growth and harvesting of perennials for food, livestock feed, biomass and other uses;
        - Combined systems of perennials and annual row crops; and
        - High value winter annuals for incorporation into existing row-crop systems.
    - Increasing soil health practice incentives by adding more market-based funding approaches, carbon market linkages, soil water retention goals, crop insurance rebates, and connections to climate change and agricultural resiliency;
    - Implementing the Nitrogen Fertilizer Management Plan and its associated Alternative Management Tools;

- Supporting private-public partnerships, research and demonstration to promote 4R nutrient management stewardship and increase the adoption of fertilizer and manure BMPs;
- Investing in perennial crop research and development, including sustainable market and supply chain development;
- Multi-million acre enrollment in Minnesota's Agricultural Water Quality Certification Program; and
- Protecting approximately 400,000 acres of vulnerable land surrounding drinking water wellhead areas by investing in living cover and other strategies.

B. State agencies, working in conjunction with the University of Minnesota, should provide guidance and tools to comprehensive local water planners for evaluating and increasing multi-purpose benefits. Supplement or modify tools (i.e. HSPF-SAM, PTMApp) used for nutrient and sediment reduction planning to also include an assessment of other benefits such as resilience to climate change. Additionally, provide guidance on ways to concurrently achieve both downstream and local nutrient reduction goals.

2) Identify and remove social, economic and other human dimension obstacles to scaling-up BMP implementation

Recognizing the challenges of scaling-up practice adoption to the levels needed for NRS nutrient reduction goals, Minnesota should gain more clarity about the factors influencing decisions to adopt BMPs, barriers to adoption, and effective ways to overcome obstacles. At the same time that Minnesota progresses with its many nutrient-related programs that have advanced during recent years, we need to continue developing a better understanding of the human dimension associated with BMP adoption and how that varies across the state.

Specific actions

A. Minnesota should establish a multi-organizational socio-economic team focused on agricultural nutrient BMP adoption. This socio-economic team should build upon existing information from local, regional and national sources and develop recommendations on how to overcome obstacles and barriers to making large-scale changes across the landscape similar to those outlined in the Nutrient Reduction Strategy. The University of Minnesota should work in partnership with state and federal agencies, stakeholders, and national groups such as the Gulf of Mexico Hypoxia Task Force.

B. The above team should develop a report that includes recommendations to state, federal and local organizations on how to overcome identified barriers and achieve large-scale adoption of NRS practices. Where socio-economic information gaps are identified, plans should be made to obtain the needed information, where possible. The findings and recommendations will help Minnesota refine effective, socially acceptable, and financially feasible approaches for programs, policies, and incentives that drive increased BMP adoption. The recommendations and supporting documents from this assessment should be completed by December 2023, so that it can be used for the 2024 NRS revision process.

During the development of this progress report, contributing organizations identified several examples of possible impediments and solutions to increasing practice adoption. The socio-economic evaluation will provide greater insight on how to best resolve potential needs and gaps that might include:

- **Reducing risk when trying new practices** – Increase farmer (and city) protections, assurances and confidences when taking on real or perceived risk to adopt practices (i.e., use a crop insurance supplement for such practices).
- **Building trust and community** – Build stronger relationships, trust and community (landowner to renter, rural to urban, farmer to conservation professional, farmer to financer, etc.).
- **Equipment barriers** – Identify and help provide for equipment needs that include personally-owned, shared, and rented equipment. Also, address the timing of jointly-shared equipment availability.
- **Rented land challenges** – Identify and reconcile rented land obstacles and solutions for making long-term investment in conservation, and develop options for renters to be more involved with increasing conservation and living cover practices.
- **Practice maintenance** – Identify and address management obstacles and solutions related to maintaining practices.
- **Economics** – Understand costs, markets, funding and economic information for short-term (1-5 years) and long-term (over 10 years) practice adoption, including:
    - How to best support practices that have a public benefit but little to no short or long-term economic benefit to farmers;
    - Quantifying benefits of practices such as cover crops and reduced tillage that can lower costs (e.g. fertilizer, fuel, chemicals and labor) and increase resiliency, and include those quantified benefits in farm-profitability decision support tools;
    - Market-based pollutant trading (i.e. urban-rural trading);
    - Market development for crops providing continuous living cover; and
    - Shifting mindsets to longer-term economic planning horizons.
- **Moving beyond crop yields** – Increasingly shift from a crop-yield goal mindset to such things as increasing farmer competitiveness on metrics that focus on return on investment, community building, soil health, and ecosystem gains.
- **Self-assessment tools** – Provide landowners with more affordable tools and on-farm trial approaches to self-assess soil health progress, tile water nitrate, and other ways to independently obtain feedback on how their practices are working for soil and water protection.
- **Farmer Innovation** – Support on-farm innovative farmer-driven practices, tools and technologies for soil and water protection.
- **Farmer-to-farmer learning** – Develop innovative ways to communicate and showcase farm nutrient loss reduction success stories. Communicate stories and narratives of how farmers shifted from long-standing ways of farming and cultural norms to different ways that are good for agriculture, farmers, and ecosystem services.
- **Policy barriers** – Identify and minimize federal and state policy barriers and challenges for farmers, as well as private industry influences. Identify how government and industry programs can offer greater management flexibility. This could involve adjusting current policies to allow more flexibility in conservation practices, such as "working wetlands," that may be utilized to cut hay or for other profit-generating activities. Also, assess potential differences between fertilizer retailer recommendations and long-term optimization of farmer economic and environmental return.
- **Private/public partnerships** – Initiate additional private/public partnerships that build off past successes and also involve coop and independent crop advisors, and potentially bankers.

- **Confidence in the solutions** – Increase local knowledge of the key practices and confidence in their effectiveness, including an understanding of how well individual practices can resolve multiple environmental issues.
- **Addressing downstream waters** – Identify barriers and solutions for individuals and watershed planners to increase consideration of downstream impacts outside of their jurisdiction.

The identification and resolving of barriers to success should be addressed by processes that welcome and support culturally diverse voices and different ways of knowing and relating to water issues.

3) Use the latest research to continue refining the optimal combination of practices that will achieve the needed nutrient reductions in our waters

The NRS BMP adoption scenarios outline a combination of agricultural and urban practices that will achieve nutrient reduction milestones and goals. While most of this information is still applicable and relevant at this time, our scientific understanding has continued to evolve. The BMP science used to develop the 2014 NRS reflects information generated largely from 2004 to 2012. To maintain the highest level of NRS credibility into the future and to most effectively achieve multi-benefit goals, Minnesota needs to begin working toward updating and improving the BMP adoption scenarios while using the most updated and relevant scientific understanding.

Specific actions

A. An agricultural nutrient water-science team from the University of Minnesota and scientists from agencies and other organizations should be established to evaluate the collective body of recent findings around Minnesota and the upper Midwest to set the stage for an updated strategy in 2024. The team should assess and document the following:

   - **BMP selection** – Identify which BMPs should be central to an updated BMP scenario, especially emphasizing BMPs that provide multiple benefits and that have a relatively low cost to benefit ratios. An updated BMP effectiveness assessment should be included that uses the latest research to update and refine expected water quality improvements afforded by the BMPs.
   - **BMP suitability** – Update GIS-based suitable acreage estimates of potential lands that are well-suited for additional adoption of BMPs, accounting for where BMPs already exist and land limitations for BMP adoption.
   - **BMP combination scenarios** – Use updated tools, models and inputs (such as updated precipitation patterns) to re-assess best combinations of practices and associated adoption acreages to meet nutrient load reduction goals and at the same time achieve other ecosystem and agricultural sustainability benefits.
   - **BMP costs** – Include cost estimates for the BMP scenarios developed, focusing on net cost to landowners with and without existing government cost-share assistance.
   - **BMP progress tracking** – Building from this NRS progress report and recent advancements at the University of Minnesota and elsewhere, recommend the best ways of tracking progress toward adoption of the BMPs outlined in the scenarios, including metrics and measures to assess progress with each BMP category.

   The recommendations and supporting documents from this assessment should be completed by December 2023, so that it can be used for the 2024 NRS revisions and republishing. This effort, along with the socio-economic analysis, should lead to a 2024 NRS update that is most consistent with the latest socio-economic and water-science findings and set the stage for increased scaling-up of highly-effective and feasible BMPs between 2025 and 2035.

B. Where scientific information gaps are found, the team should recommend where to focus future research and data collection efforts so we can develop the most promising technologies for significantly reducing nutrients in waters. Examples of existing research needs identified through this progress report development process include: advanced precision nutrient management for crops; best ways to store and retain water across the landscape; economically sustainable continuous living cover cropping options and building associated markets and supply chains; solutions to in-channel sediment phosphorus sources; and ways to combat detrimental effects of precipitation extremes.

4) Optimize wastewater nitrogen treatment

Minnesota will continue working toward wastewater nitrogen reductions by developing and implementing a detailed strategy consistent with the direction established in the 2014 NRS.

Specific actions

A. MPCA will work with U of MN, Met Council and others to complete more specific steps and considerations for the next five years that will move us further toward increased wastewater nitrogen reduction. Action steps will emphasize pollution prevention and facility optimization of nutrient removal through the use of existing infrastructure.

B. MPCA will analyze and distribute nitrogen monitoring data reported by wastewater dischargers, continue work towards development of a water quality standard for nitrate based on aquatic life toxicity, and work with others to develop nitrogen management plan templates for use by wastewater permittees.

C. U of MN will model and evaluate the potential for optimizing wastewater total nitrogen reductions, while at the same time maintaining phosphorus reduction progress.

D. Depending on the outcome of the above efforts, the MPCA may establish total nitrogen effluent limits in certain locations for attainment of water quality standards and nitrogen reduction goals. Development of nitrate standards and related effluent limits could result in the need to upgrade some wastewater treatment facilities by adding denitrification capacity. Water quality trading and other funding alternatives should continue to be developed.

8 References

Barr Engineering. 2004. Detailed Assessment of Phosphorus Sources to Minnesota Watersheds. Prepared for Minnesota Pollution Control Agency, by Barr Engineering Company, Minneapolis, MN.

Bierman, P., Rosen, C., Venterea, R., and Lamb, J. 2011. Survey of Nitrogen Fertilizer Use on Corn in Minnesota. University of Minnesota and USDA-ARS. St. Paul. MN. www.mda.state.mn.us/sites/default/files/inline-files/nfertilizersurvey2011_0.pdf.

Blann, K. 2019. Personal communications. The Nature Conservancy, Minnesota.

BWSR (Board of Water and Soil Resources). 2019. Climate Change Trends and Action Plan. Available online at: https://bwsr.state.mn.us/practices/climate_change/index.html.

IPNI (International Plant Nutrition Institute). 2012. 4R Plant Nutrition Manual: A Manual for Improving the Management of Plant Nutrition. North American Version (Bruulsema, T., Fixen, P.E., Sulewski, G.D., eds.) International Plant Nutrition Institute, Norcross, GA.

IPNI (International Plant Nutrition Institute). 2019. Soil Test Levels in North America. Online. International Plant Nutrition Institute [http://soiltest.ipni.net/]. Last accessed September 16, 2019.

Kaiser, Kim, Brennon Schaefer, and Bill VanRyswyk,. (2019). Nitrate Results and Trends in Private Well Monitoring Networks 2008-2018. Minnesota Department of Agriculture. https://wrl.mnpals.net/islandora/object/WRLrepository%3A3395.

Keeler, B., J. Gourevitch, S. Polasky, C. Tessum, J. Hill, and J. Marshall. 2016. The social costs of nitrogen. Published 5 October 2016, Sci. Adv. 2, e1600219 DOI: 10.1126/sciadv.1600219.

Keeler, B. and S. Polasky. 2014. Land-use change and costs to rural households: a case study in groundwater nitrate contamination. Environ. Res. Lett. 9 (2014) 074002, 10pp.

Limno Tech. 2019. Draft Memorandum: Draft Task A-1 Summary: Review of WRAPS and 1W1P. Provided to the Minnesota Pollution Control Agency, December 27, 2019.

Met Council (Metropolitan Council Environmental Services). 2018. Regional Assessment of River Water Quality in the Twin Cities Metropolitan Area (1976 – 2015). Metropolitan Council, Saint Paul, MN.

MDA (Minnesota Department of Agriculture) 2014. Fertilizer and Manure Selection and Management Practices Associated with Minnesota's 2010 Corn and Wheat Production. Minnesota Department of Agriculture. 193 pp.

MDH (Minnesota Department of Health). 2018. Nitrate Report: Community Public Water Systems. Minnesota Department of Health. 16 pp.

Meyer, R.L., R.J. Zeng, V. Giugliano, and L.L. Blackall. 2005. Challenges for Simultaneous Nitrification, Denitrification, and Phosphorus Removal in Microbial Aggregates: Mass Transfer Limitation and Nitrous Oxide Production. *FEMS Microbiology Ecology*, 52: 329-338.

MPCA (Minnesota Pollution Control Agency). 2013. Nitrogen in Minnesota Surface Waters. Saint Paul, MN. Document number: wq-s6-26a.

MPCA (Minnesota Pollution Control Agency). 2014. The Minnesota Nutrient Reduction Strategy. September 2014. Document number wq-s1-80.

MPCA (Minnesota Pollution Control Agency). 2019a. DRAFT Lake Pepin Watershed Phosphorus Total Maximum Daily Loads. Saint Paul, MN. Document number: wq-iw9-22b.

MPCA (Minnesota Pollution Control Agency). 2019b. The Condition of Minnesota's Groundwater Quality, 2013-2017. Saint Paul, MN. Document number: wq-am1-10.

Nustad R.A. and Vecchia A.V. 2020. Water-Quality Trends for Selected Sites and Constituents in the International Red River Basin, Minnesota and North Dakota, United States, and Manitoba, Canada, 1970-2017: U.S. Geological Survey Scientific Investigations Report 2020-5079, 75 p., https://doi.org/10.3133/sir20205079.

U of M Extension. 2019. Fertilizing Corn in Minnesota. Online. University of Minnesota Extension. [https://extension.umn.edu/crop-specific-needs/fertilizing-corn-minnesota#phosphorus-and-potassium-rate-tables-1087910]. Last accessed September 16, 2019.

USDA NASS (National Agricultural Statistics Services). 2012 and 2017. 2012 and 2017 Census of Agriculture. State level data for Minnesota.

USDA NASS CDL (National Agricultural Statistics Services Cropland Data Layer). 2012-2018. Data available: https://data.nal.usda.gov/dataset/cropscape-cropland-data-layer.

Appendices

Appendix A – State-level Nutrient Reduction Program Advancements

Appendix B – External Factors Affecting Nutrients in Waters

Appendix C – River Nutrient Trends in Minnesota

Appendix D – Maximum Return to Nitrogen (MRTN) Values

In Minnesota's Farm Country, Nitrate Pollution of Drinking Water Is Getting Worse

By Anne Weir Schechinger, Senior Analyst of Economics

WEDNESDAY, MARCH 4, 2020

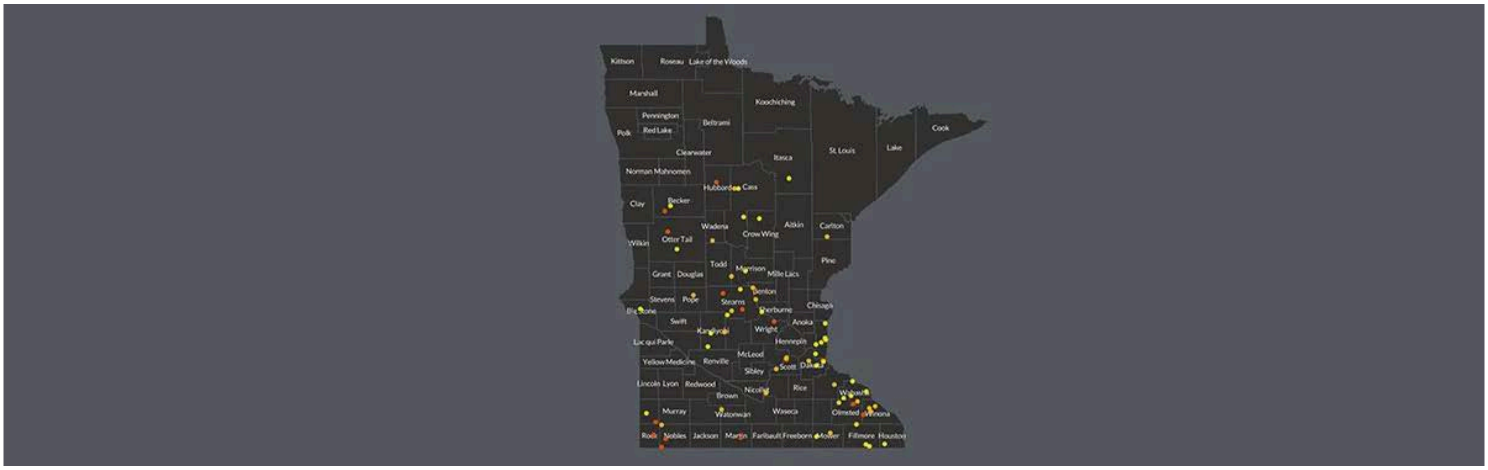
Nitrate contamination of drinking water is getting worse in much of rural Minnesota, an Environmental Working Group analysis of state data found.

Between 1995 and 2018, tests detected elevated levels of the toxic chemical in the tap water supplies of 115 Minnesota community water systems.[1] In that period, nitrate levels rose in almost two-thirds of those systems – 72 communities, or about 63 percent. Those water systems serve more than 218,000 Minnesotans, mostly in farming areas in the southeast, southwest and central parts of the state.

EWG's interactive map shows where nitrate contamination rose during the study period, based on Minnesota Department of Health data obtained under the state's public records law.

Minnesota Communities With Increases in Nitrate Contamination of Drinking Water Supplies, 1995 to 2018

Explore the Map



EWG's analysis underscores what we reported in a study and map issued in January 2020. The earlier analysis found that in 95 mostly rural Minnesota communities that draw their drinking water from groundwater, elevated nitrate levels were detected at least once since 2009. Our new analysis looked at communities that use either surface water or groundwater and tracked trends over 24 years.

Health Hazards of Nitrate

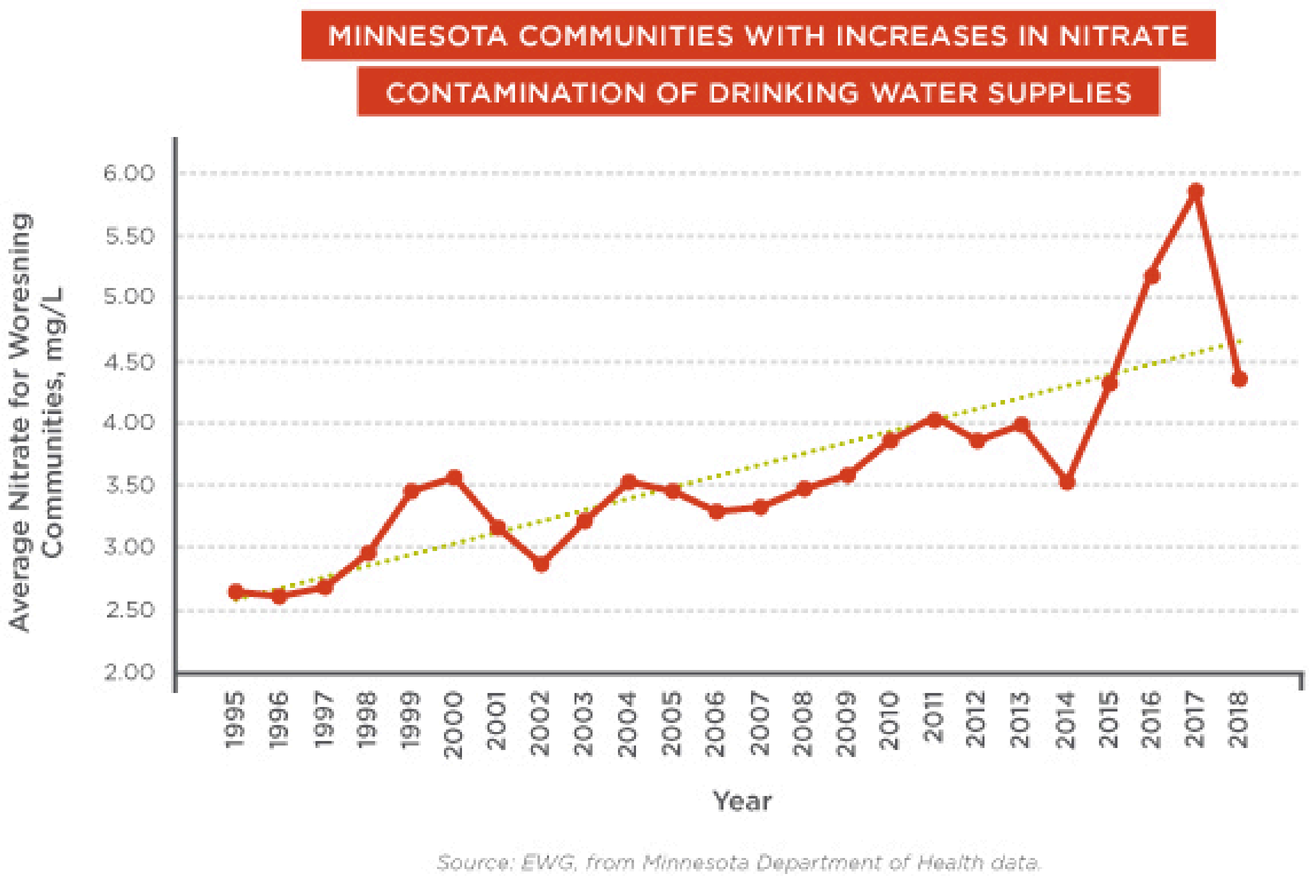
Nitrate is a primary chemical component of fertilizer and manure that can run off farm fields and seep into drinking water supplies. Under the federal Safe Drinking Water Act, the legal limit for nitrate in drinking water is 10 milligrams per liter, or mg/L. This limit was set in 1962 to guard against so-called blue baby syndrome, a potentially fatal condition that starves infants of oxygen if they ingest too much nitrate.

But newer research indicates that drinking water with 5 mg/L nitrate or even lower is associated with higher risks of colorectal cancer and adverse birth outcomes, such as neural tube birth defects. And the Minnesota Department of Health says a level of 3 mg/L indicates that "human-made sources of nitrate have contaminated the water and the level could increase over time."

We analyzed data on all 115 community water systems that had at least one test at or above 3 mg/L. More than a third of those communities showed decreasing nitrate levels. However, it is clear that in most places with the most serious contamination, the problem is getting worse. Of the community water systems where nitrate exceeded the federal legal limit, fully 67 percent, serving about 48,500 Minnesotans, showed increased contamination over the study period.

For the 72 communities we analyzed where contamination rose, average nitrate contamination of drinking water jumped by 61 percent between 1995 and 2018. In 1995, average contamination was 2.7 mg/L. By 2009, average contamination had increased to 3.6 mg/L and continued climbing to 4.4 mg/L in 2018.

Figure 1. Average Nitrate Levels in Minnesota Communities Where Contamination Rose, 1995 to 2018



Spikes in nitrate contamination in two smaller systems in southern Minnesota drove the sharp increase in average contamination in 2016 and 2017 (Figure 1). Both systems draw their drinking water from surface water.

- In the Rock County Rural Water District, serving 2,256 people, the average levels of nitrate contamination jumped from 1.6 mg/L in 2015 to 9.5 mg/L in 2016 and peaked at

15.2 mg/L in 2017 before falling to 6.6 mg/L in 2018, still much higher than in 2015. (See Case Studies.)

- In the City of Fairmont water system, serving more than 10,000 people in Martin County, average nitrate contamination increased from 0.2 in 2015 to 7.2 mg/L in 2016 reached 4.3 mg/L in 2017 and fell to 2.9 mg/L in 2018.

Who Is Affected?

Agriculture pollution often disproportionately affects low-income rural Americans who cannot afford to buy bottled water or install effective but expensive in-home filter systems. Of the 72 Minnesota systems we analyzed, 61 percent were in a U.S. Census block group with median household income below the state's average. Installation of expensive treatment technologies to reduce nitrate levels can be a struggle in these communities. (See Case Studies.)

The type of test data available for community water systems is not available for private wells. It is likely that nitrate contamination has also increased over time in the thousands of private wells in the state, since many draw water from the same groundwater sources as community water systems. EWG's earlier report found that between 2009 and 2018, more than 3,300 private wells in the state had nitrate levels at or above the federal legal limit of 10 mg/L.

Case Studies

Hastings

The town of Hastings is named after Minnesota's first elected governor. It sits at the confluence of the Mississippi and Vermillion rivers in the southeast corner of the state. The Hastings community water system serves 22,335 residents.

In 2015, the Pioneer Press of St. Paul reported that about a decade earlier, "Hastings saw nitrate levels in its groundwater rise toward unsafe levels. City officials believed farm runoff, likely delivered to the aquifer by the Vermillion River that cuts through miles of farmland, was to blame."

The newspaper reported that in 2008, the city spent $3.5 million on a new water treatment plant to lower nitrate levels, at an estimated cost of $410 per household. EWG's research found that average nitrate contamination leveled off at around 6.4 mg/L after 2008, still an increase of 93 percent between 1995 and 2018.

In 2019, Hastings Public Works Director Nick Egger told the Minneapolis Star Tribune that since he has no authority over agriculture operations and their pollution, his only option other than spending taxpayer funds on cleanup is to "ask politely" for farmers to control dangerous chemicals running off crop fields.

Adrian

The community water system in Adrian, in the southwest corner of the state, serves 1,211 people from groundwater wells. In 2015, town leaders were forced to shut down a water treatment plant and issue vouchers for free bottled water, after nitrate levels were declared unhealthy for infants and pregnant women. EWG found that Adrian's average nitrate contamination increased by 96 percent between 1995 and 2018.

Adrian's 2015 water system shutdown was the second such incident since the town bought a nitrate removal system, in 1998. The town's deputy clerk-treasurer, Rita Boljes, told the Star Tribune that treating the water for nitrate is now Adrian's largest non-salary expenditure.

"It's just part of living in Adrian," she said.

Rock County Rural Water System

Rock County, in Minnesota's farthest southwest corner, houses the historic Blue Mounds State Park and is home to the geographically unique Sioux Quartzite bedrock and a large bison herd. The Rock County Rural Water System serves 2,256 people. EWG calculated that the water system's average nitrate concentration increased by a staggering 890 percent from 1995 to 2018.

After years of increasing nitrate levels in the system's wells, in 2016 the water district board created a cost-share program that pays farmers to implement agricultural conservation practices in areas near well heads. It remains to be seen how effective this approach will be.

Conclusion and Outlook

It is clear that Minnesota's community water systems have a worsening nitrate contamination problem. Nitrate in Minnesota's drinking water threatens the health and the pocketbooks of citizens who have done nothing to contribute to the problem. For nearly 30 years, the state has had voluntary programs in place to address the massive quantities of nitrates from agriculture. But as this report clearly shows, during that time the majority of the community water systems most contaminated with nitrate have continued to get worse.

In January 2020, the Minnesota Department of Agriculture began implementing its new nitrate groundwater protection rule. However, the rule fails to provide the same protections to private well owners that it provides to people getting drinking water from community water systems. And the minimal additional protections for community water systems that are contemplated under the new rule are largely uncertain.

For example, the new rule includes an unclear and unnecessarily drawn-out timeline for requiring farmers growing crops near public wells to take any additional steps to reduce their nitrate pollution. Instead of requiring immediate action to determine excess commercial fertilizer application and mandating reduction, the new rule gives farmers more time to continue the same practices that have failed to improve water quality over the past 30 years.

Although the new rule is a laudable first step, more is undoubtedly needed to protect Minnesotans already drinking contaminated water and to ensure that all Minnesotans are protected from additional harm to their health.

To see the methods of this study, click here.

Notes

[1] Water systems are public water supplies that serve residents in cities and towns year-round.

Methodology

EWG.org | EWG's Guide to Sunscreens | EWG's Food Scores | EWG's Guide to Healthy Cleaning | EWG's Shopper's Guide to Pesticides in Produce™

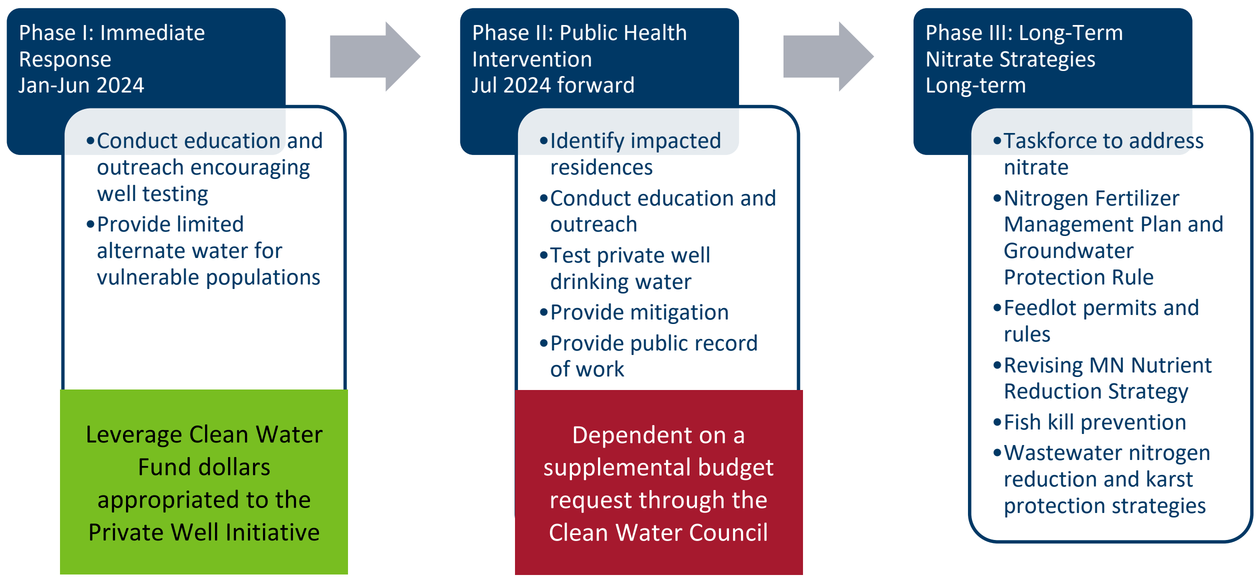
DEPARTMENT OF HEALTH

Public Health Work Plan and Budget Overview: Nitrate in Southeast Minnesota Private Wells

JANUARY 22, 2024

Overview

Minnesota Department of Health (MDH), Minnesota Pollution Control Agency (MPCA), and Minnesota Department of Agriculture (MDA) are addressing the requests in the U.S. Environmental Protection Agency's (EPA) letter in three phases. [1]



MDH is the lead agency for Phase I: Immediate Response and Phase II: Public Health Intervention. This overview focuses on those two phases. MDH will work closely with the existing TAP-IN Collaborative[2] members to further refine and carry out the strategies in this work plan. The TAP-IN Collaborative is an existing group of primarily local public health and soil and water conservation districts that implemented a pilot grant (funded by Clean Water Fund through the Private Well Initiative) to offer free well testing and income-based remediation to private well owners in southeast Minnesota. MDH may also form an advisory council consisting of petitioners, local government leaders, and other local partners to help guide the work. We (MDH and local partners) will implement the strategies below in the eight counties named in

[1] Initiatives in Phase III are a snapshot and do not represent all long-term strategies.

[2] The TAP-IN (Test your water, Ask a professional, Protect your water quality, Inspect your well and septic system, and Note important information) Collaborative includes representatives from local public health and Soil and Water Conservation Districts (SWCD) in the 9 counties included in this work plan. The collaborative formed as a result of a Clean Water Fund grant to Olmsted County SWCD in 2020 to provide free private well testing and financial assistance for water quality mitigation.

the EPA letter (Dodge, Fillmore, Goodhue, Houston, Mower, Olmsted, Wabasha, and Winona) to address the public health need of ensuring private well users have safe drinking water as soon as possible.

Phase I: Immediate Response (January-June 2024)

The focus of Phase I: Immediate Response is to provide education and outreach about the importance of private well testing and how households can use an accredited laboratory to get their water tested and offer mitigation strategies to reduce risk for vulnerable populations. **The education and outreach strategies will be funded through the FY24-25 Clean Water Fund appropriation for the Private Well Initiative.** Initial mitigation efforts, including the local partner coordination, implementation, water treatment system monitoring, and evaluation will be supported with **FY24-25 Clean Water Fund appropriation for nitrate in groundwater and pesticide sampling in private wells program.**

Conduct education and outreach

Encourage residents in southeast Minnesota to "know the quality of their drinking water".

- Community water system customers can be confident in their water quality and check their Consumer Confidence Report.
- Private well users can test their well water for nitrate (along with coliform bacteria, arsenic, lead, and manganese[3]) at an accredited laboratory.

Key strategies:

- **Print and mail private well educational materials to partners** who work with private well households with an infant under one year of age or pregnant person (e.g., WIC and child care providers).
- **Launch a paid social media campaign** focused on people of childbearing age, southeast geographic area, and health professionals to encourage well testing.
- **Send media releases** to local television, print, and radio news outlets.
- **Translate private well educational materials** into Spanish, Somali, and Hmong. Other languages will be provided as requested.
- **Minnesota Private Well Education and Steward Network:** Through a contract with the University of Minnesota, develop a peer-to-peer education program where neighbors provide education about private well water safety in their community.
- **Provide necessary equipment, standard operating procedures, and support to local partners who can provide free water screening** at the local office or locally organized events. MDA has multiple spectrophotometers on loan to partners in the southeast region to support a "walk-in" style water screening clinics with the goal of increasing public awareness of nitrate contamination.

[3] These are the five main contaminants MDH recommends every private well owner test for.

Provide alternate water for vulnerable populations

The goal is to identify wells with elevated nitrate, establish prioritization criteria for well owners seeking cost share, and offer a reverse osmosis system to reduce the risk for vulnerable people.

Key strategies

- **Reach out to Township Testing Program (TTP) participants who had elevated nitrate** and gather information on if they have a pregnant person or baby in the home. (Due to limited funding, participants in the TTP are considered in the initial response phase while a larger population of residents could be included during the Phase II response.)
- **Establish prioritization criteria** for well owners seeking cost sharing for mitigation. Prioritization will be for particularly vulnerable populations.
- **Local partner** (through joint powers agreement) will use prioritization process to **select well owners for cost sharing** and coordinate treatment system installation.
- **Develop a protocol and audit of installed reverse osmosis treatment systems** to evaluate effectiveness at reducing risk to acceptable levels. Evaluation and monitoring of installed water treatment systems are key components.

Phase II: Public Health Intervention (July 1, 2024-June 30, 2025)

This phase focuses on conducting a well inventory to identify all the private wells in the area, offering free well testing for all private well households, providing mitigation for eligible households, and education and outreach about these efforts. **This phase is dependent on additional funding** for conducting a well inventory, private well testing, and mitigation. **Some of the additional education and outreach in this phase can be funded through existing Clean Water Funds** appropriated to the Private Well Initiative. MDH is submitting a supplemental budget request for Clean Water Fund dollars to support the additional elements of this phase.

Identify impacted residences

The goal is to identify all private wells in the eight-county area. We estimate that around 60% (23,495) of the private wells in the area are in the Minnesota Well Index (MWI). Through several methodologies, we estimate there are about 12,000 more private wells that were constructed before the Minnesota Well Code was implemented in 1974 and are not included in MWI and likely poorly constructed. We will conduct a well inventory to find those additional private wells and enter them into MWI.

Key strategies:

- **Use GIS and tax parcel data** to identify properties that are outside community water system boundaries and are not in MWI—these likely have a private well.
- **Send a letter to potential private well households not in MWI**, requesting they voluntarily share information if they have a private well.
- **Incorporate the information into MWI**.

Conduct education and outreach

Education and outreach in Phase II will build on the strategies in Phase I, adding strategies that require additional funding. Messaging will expand to include information about the well inventory, how to get private well water tested for free, and how to get mitigation assistance.

Key additional strategies:

- **Direct mailing to private well households** about how to access free testing and mitigation if needed.
- **Billboards** about well testing, well inventory, and mitigation.
- **Paid radio spots/streaming services** (e.g., Pandora) with messages about well testing, well inventory, and mitigation.
- **Meetings and townhalls** with residents and local leaders.

Test private well drinking water

Offer free private well testing for nitrate to all private well households in southeast Minnesota. We aim to have 10 percent of private well households (around 3,600) participate in the first year, with increasing participation in future years.

Key strategies:

- **Send a postcard** to all potential private well households inviting them to participate.
- Households can have a **test kit mailed** to them or get one at **local pick-up sites.**
- Households can **drop the test kit off at the laboratory** or **return it via a pre-paid mailer**.
- The laboratory will **share analysis results via email or mail** (per the household's preference), along with information about what their test results mean, and, if needed, further actions.
- Households can **contact MDH, the laboratory, or local partners for additional help** understanding their test results.

Provide alternate water (mitigation)

Mitigation will be offered as soon as practical to each residence where water tests show an exceedance of the maximum contaminant level (MCL) for nitrate in the private well. If funding becomes available, most of the funding will be passed through to the TAP-IN Collaborative.

Key strategies:

- MDH will **mail a communication** to all private well households that have a known nitrate test result from an accredited laboratory that was above the nitrate MCL of 10 parts per million in the past 5 years to let them know about the opportunity for follow up testing and mitigation.
- When sending water analysis results, the **laboratory will also include information about how the household can access mitigation if necessary**.

- Private well households with a nitrate concentration above the MCL can **connect with a mitigation navigator**. The navigator will help assess the best mitigation approach for the household: point-of-use treatment, well repairs, or a new well.[4]
- The private well household is then responsible for getting a **quote from a well contractor or water treatment professional** and submitting the quote to the local agency for approval. MDH will maintain a public reference list of well contractors and water treatment professionals in the area who are ready to assist.
- **Once approved, the vendor can begin the work.**
- When work is complete, the **vendor will submit an invoice to the local agency for payment**.[5] Mitigation installed without approval or prior to this new effort will not be reimbursed.

Maintain a public dashboard

State agencies will collaborate to develop a public-facing dashboard to measure and communicate progress in implementing this response plan. Key metrics will include the percent of private well households who have tested their well water and percent of eligible households who have received mitigation.

This dashboard will also connect the user with data and visualizations for cumulative well testing results in southeast Minnesota through existing platforms, such as the *Minnesota Public Health Data Access Portal* and *Watershed Health Assessment Framework* tool.

- Minnesota Public Health Data Access: Drinking water quality (https://data.web.health.state.mn.us/drinkingwater)
- Watershed Health Assessment Framework (https://arcgis.dnr.state.mn.us/ewr/whaf2/)

[4] To help inform the best mitigation options for different scenarios, a workgroup will be formed to develop a decision tree. Factors including cost/benefit, long-term protections, and contaminant levels will inform be taken into consideration. Workgroup members may include licensed well contractors, water treatment specialists, members of the TAP-IN Collaborative, and agency staff.

[5] A sub-team of the TAP-IN collaborative will determine the protocol for approval, invoicing, and payment.

Timeline

Below is the general timeline for the Phase I and II strategies.

Key Activities	Jan-Mar '24	Apr-Jun '24	Jul-Sep '24	Oct-Dec '24	Jan-Mar '25	Apr-Jun '25
Phase I						
Education and outreach encouraging well testing	X	X				
Limited alternate water for most vulnerable populations	X	X				
Phase II						
Get contracts in place with local partners			X			
Well inventory				X	X	X
Education and outreach about well inventory, free well testing, and mitigation				X	X	X
Free well testing				X	X	X
Free mitigation available for eligible households				X	X	X
Launch public dashboard				X		

MDH Supplemental Budget Request

An additional $6.354 million will be needed by MDH to carry out the first year of work in Phase II: Public Health Intervention.

Public Health Intervention Budget (July 1, 2024-June 30, 2025)

Category	Rounded Totals (in thousands)	Description
Well Inventory	$737	• 6.3 FTEs for local partners (likely student workers) • Printing and postage costs
Testing	$180	• All private well households invited to participate (estimated 36,000). • Planning for 10% to participate in the first year, which is about 3,600 private wells. • Wells will be tested for nitrate ($50 per well).
Alternate water	$3,866	Of the 3,600 private wells that participate in testing, 12% will have nitrate above the MCL. Of those: • 75% will be best remedied through reverse osmosis treatment ($2,600) • 25% will be best remedied through well repairs or a new well (average of $28,000)
Education and outreach	$19	• Printing, postage, paid social media and streaming advertisements, billboards • Space rental and travel for local meetings
Funding for additional local staff	$976	**5.5 FTEs**: 1 project manager, 1 grant administrator, 1 mitigation navigator, program management interns (0.5 FTE), 1 laboratory support, 1 laboratory data support
MDH staff	$576	**4 FTEs**: 1 **Hydrologist** for technical assistance; 1 Information **Technology Specialist** to work with data from multiple sources, support mailings, participant status, measurable outcomes, and dashboard website; 1 **Planner** as project manager; 1 **Office and Admin Specialist** to assist with communications
Total	**$6,354**	Of the total: • $5.759 million (91%) would go out in contracts to local partners for well inventory, testing, and mitigation • $0.595 million (9%) would go to MDH (staff and education and outreach)

Assumptions

- There are approximately 36,000 private wells in the area. The aim is to test 10% of them in Year 1.
- The percent of private wells with nitrate above the MCL is based on MDA Township Testing findings and is about 12%.
- Of the wells that have elevated nitrate, 75% will need a reverse osmosis (RO) treatment system (estimated cost of $2,200) plus one year of maintenance valued at $400 a year and 25% of them will need well repairs or a new well constructed (estimated average cost of $28,000).
- The cost of testing for nitrate (including kit assembly, returning by mail, and analysis) is estimated at $50 per well.
- The state would cover 100% of the cost for well testing and for mitigation.

Testing and Mitigation Cost for Year 1

The table below estimates the cost of providing free private well testing for 10% of private wells in southeastern Minnesota and mitigation for the corresponding eligible households. The full cost to offer free water testing to all private wells and mitigation to all eligible households over several years is about $40.5 million (not including staff and program costs).

Estimated total number of wells	Year 1 testing cost for 10% (3,600 wells)	% Wells nitrate above MCL	# Wells nitrate above MCL	Households needing well repairs or new well	Households needing RO treatment	Year 1 mitigation cost	Year 1 testing and mitigation cost
36,000	$180,000	12%	432	108	324	$3,866,400	$4,046,400

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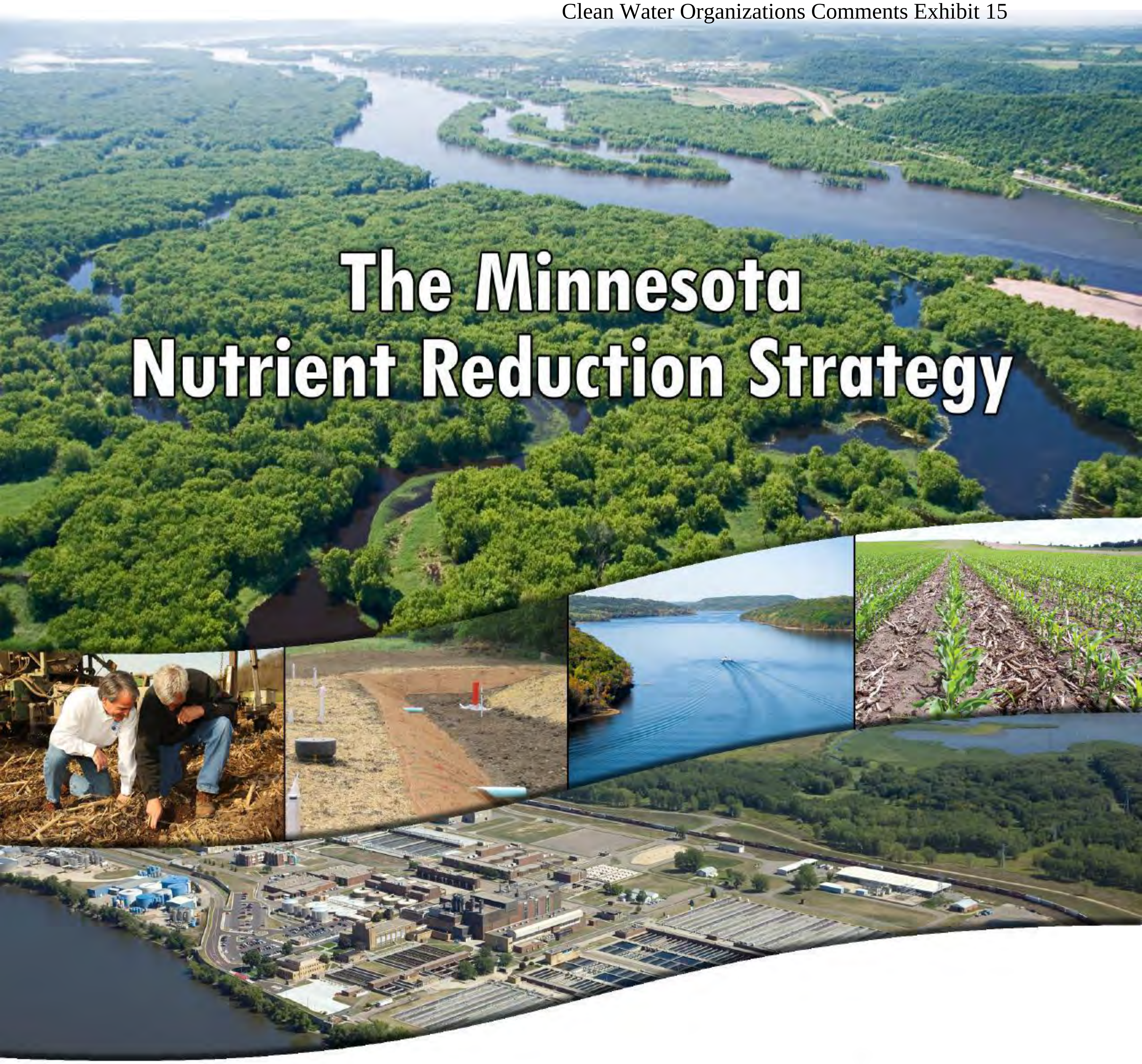
The Minnesota Nutrient Reduction Strategy



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The Minnesota Nutrient Reduction Strategy report was created in cooperation with the following partners:

Table of Contents

Acronyms and Abbreviations

Amendment	Clean Water, Land and Legacy Amendment
BMP	Best Management Practice
BWSR	Board of Water and Soil Resources
CAFO	Concentrated Animal Feeding Operation
CAWT	Commercial Animal Waste Technicians
CDL	Cropland Data Layer
CEAP	Conservation Effects Assessment Project
CGP	Construction General Permit
CHF	Central Hardwood Forest
Chl-a	Chlorophyll-a
CREP	Conservation Reserve Enhancement Program
CRP	Conservation Reserve Program
CSP	Conservation Security Program
CStP	Conservation Stewardship Program
CTI	Compound Topographic Index
CWA	Clean Water Act
CWLA	Clean Water Legacy Act
CWSEC	Manitoba Conservation and Water Stewardship and Environment Canada
DNR	Minnesota Department of Natural Resources
DO	Dissolved Oxygen
EBI	Environmental Benefits Index
ELM	Environmental Learning in Minnesota
EPA	U.S. Environmental Protection Agency
EQIP	Environmental Quality Incentives Program
FANMAP	Farm Nutrient Management Assessment Program
Framework	Minnesota Water Management Framework
FSA	Farm Service Agency
FWMC	Flow Weighted Mean Concentration
HUC8	8-digit Hydrologic Unit Code
ICT	Interagency Coordination Team
ITPHS	Imminent Threat to Public Health or Safety
IRRB	International Red River Board

LGU	Local Governmental Unit
LSTS	Large Subsurface Sewage Treatment System
MCES	Metropolitan Council Environmental Services
MDA	Minnesota Department of Agriculture
MDH	Minnesota Department of Health
Metro Area	Twin Cities Metropolitan Area
MIDS	Minimal Impact Design Standards
MN P Index	Minnesota Phosphorus Index
MnTap	Minnesota Technical Assistance Program
MPCA	Minnesota Pollution Control Agency
MRB	Mississippi River Basin
MRB3	Major River Basin 3
MRBI	Mississippi River Basin Initiative
MS4	Municipal Separate Storm Sewer System
N	Nitrogen
NASS	National Agricultural Statistics Survey
NBMP	Nitrogen Best Management Practice Watershed Planning Tool
NFMP	Nitrogen Fertilizer Management Plan
NGP	Northern Glaciated Plains
NLF	Northern Lakes and Forest
NO3+NO2-N	Nitrate plus Nitrite Nitrogen
NO_3-N	Nitrate-Nitrogen
NPDES	National Pollutant Discharge Elimination System
NRCS	Natural Resource Conservation Service
NRS	Minnesota Nutrient Reduction Strategy
NWQI	National Water Quality Initiative
P	Phosphorus
RIM	Reinvest in Minnesota
RRBC	Red River Basin Commission
SWCD	Soil and Water Conservation District
SDS	State Disposal System
SPARROW	Spatially Referenced Regressions on Watershed
SSTS	Subsurface Sewage Treatment System
SWAT	Soil and Water Assessment Tool
TKN	Total Kjeldahl Nitrogen

TMDL	Total Maximum Daily Load
TSS	Total Suspended Solids
USDA	U.S. Department of Agriculture
USGS	U.S. Geological Survey
WCP	Western Cornbelt Plains
WDIP	Watershed Data Integration Project
WPLMN	Watershed Pollutant Load Monitoring Network
WQBEL	Water Quality-Based Effluent Limit
WRAPS	Watershed Restoration and Protection Strategy
WRP	Wetland Reserve Program
WWTP	Wastewater Treatment Plant

Executive Summary
Minnesota Nutrient Reduction Strategy

The *Minnesota Nutrient Reduction Strategy* (*NRS*) will guide the state in reducing excess nutrients in waters so that in-state and downstream water quality goals are ultimately met.

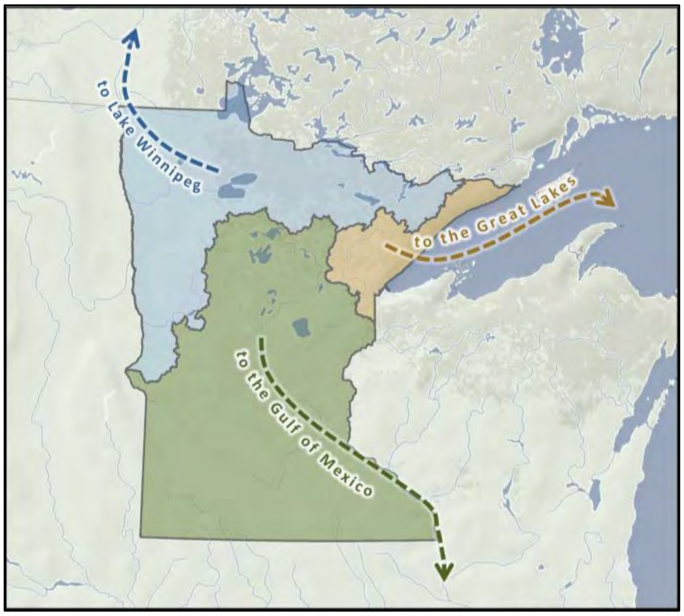


Figure 1. Major drainage basins in Minnesota.

Nutrient impacts are widespread. Excessive nutrients pose a significant problem for Minnesota's lakes, rivers, and groundwater, as well as downstream waters including the Great Lakes, Lake Winnipeg, the Mississippi River, and the Gulf of Mexico. Nutrients are important for human and aquatic life; however, when levels exceed normal conditions, problems can include excessive algae growth, low levels of oxygen, toxicity to aquatic life and unhealthy drinking water.

Substantial nutrient reductions are needed across much of Minnesota. For example, in 433 Minnesota lakes with impairments related to nutrients, an average of 45 percent phosphorus reduction is needed to meet water quality standards. Phosphorus levels in 48 river stretches exceeding the pending river eutrophication standards need an average 41 percent reduction. Many of these rivers flow toward the Mississippi River and into Lake Pepin, where similar levels of phosphorus reduction are needed to achieve a healthy lake. Nitrate, a dominant form of nitrogen in polluted waters, commonly exceeds the levels established to protect drinking water, especially in wells located below sandy soils and shallow soils above fractured bedrock. Nitrate levels are high enough to harm the food chain for fish in some rivers and streams fed by groundwater and drainage ditches.

This NRS is driven by the environmental needs of both waters within Minnesota and waters downstream of Minnesota, including Lake Winnipeg, the Gulf of Mexico and Lake Superior. In-state lake standards and pending river eutrophication standards, as well as planning goals for downstream waters, have clearly defined the magnitude of needed reductions. The timing of NRS development also aligns with several other supportive efforts, some of these efforts are described below:

- The 2009 Minnesota *Clean Water, Land and Legacy Amendment* provides additional funding for water quality protection and restoration until 2034.
- Along with 11 other states represented on the Gulf of Mexico Hypoxia Task Force, Minnesota committed to develop a NRS to protect in-state waters and the Gulf of Mexico.
- The Minnesota Water Management Framework developed in 2014 lays out the state's approach for implementing watershed-based planning that will sustain a 10-year statewide cycle of locally-led water quality improvement plans.
- The Minnesota Department of Agriculture updated its *Nitrogen Fertilizer Management Plan* in 2014 for protecting groundwater from nitrate pollution.
- The legislature directed the Minnesota Pollution Control Agency (MPCA) to develop nitrate standards which will eventually increase protection of Minnesota aquatic life from the toxic effects of high nitrate.
- Manitoba, North Dakota and Minnesota are working together to update plans for protecting Lake Winnipeg from severe algae blooms.

The overall theme of the NRS is ***A Path to Progress in Achieving Healthy Waters***. The NRS guides activities that support nitrogen and phosphorus reductions within Minnesota water bodies. In addition, nutrient reductions will also benefit the Gulf of Mexico hypoxia problem and other waters downstream of Minnesota including Lake Winnipeg and Lake Superior. Fundamental elements of the NRS include:

- Defining progress with clear goals
- Building on current strategies and success
- Prioritizing problems and solutions
- Supporting local planning and implementation
- Improving tracking and accountability

Successful implementation of the NRS will require broad support, coordination, and collaboration among agencies, academia, local government, and private industry. An interagency coordination team, representing 11 agencies, helped develop the draft NRS. Public input was sought and used by the interagency coordination team to produce the final NRS.

Goals and Milestones

The NRS includes nutrient reduction goals and milestones at several levels. For individual water bodies in Minnesota, state water quality standards define the goals. For major basins, such as Lake Winnipeg and the Mississippi River/Gulf of Mexico, planning goals for reducing Minnesota's nutrient contributions were developed (Table 1). These major basin goals are intended to be measured where the basin waters leave the state (e. g., Mississippi River Basin where it leaves Minnesota at the Iowa border). Nutrient reduction targets have been previously developed for major drainage basins and provide a suitable framework for NRS load reduction goals. In addition, the NRS includes a groundwater/source water protection goal to address groundwater as a drinking water source.

Table 1. Major basin-wide nutrient reduction goals

Major basin	Phosphorus reduction goal	Nitrogen reduction goal
Lake Superior [a]	Maintain 1979 conditions	Qualitative – continued implementation of specific nutrient management programs
Lake Winnipeg [b]	10% reduction from 2003 conditions	13% reduction from 2003 conditions
Mississippi River [c]	45% reduction from average 1980–1996 conditions	45% reduction from average 1980–1996 conditions
Statewide Groundwater/ Source Water	Not applicable	Meet the degradation prevention goal of the Minnesota Groundwater Protection Act

a. Great Lakes Water Quality Agreement of 1978, amended by a protocol signed November 18, 1987.
b. 2003 Lake Winnipeg Action Plan. Goals to be updated after completion of the Red River/Lake Winnipeg strategy. Lake Winnipeg Goals are expected to change in the near future, resulting in additional load reduction needs.
c. 2008 Gulf Hypoxia Action Plan; Provisional goal; also includes drainage associated with Missouri, Des Moines, and Cedar rivers.

Milestones provide a realistic and meaningful benchmark of progress toward meeting major basin goals for nutrient reduction. They also establish a point in time to adapt strategies as necessary based on the rate of progress and changes in factors such as land uses, climate, regulatory environment, and technologies. A nitrogen reduction milestone was established for the Mississippi River because the final goals were determined to be impractical at this time. Additional research should enable feasible approaches for achieving the long-term nitrogen reduction needs. The nitrogen milestone for the Mississippi River is set at a 20 percent reduction by 2025. A provisional target date for reaching the 45 percent reduction goal for nitrogen in the Mississippi River is set at 2040, allowing time for the needed research and subsequent demonstration and promotion of new practices. Additional milestones can be added as new nutrient reduction goals are set for downstream waters or as new research and policies inform planning and decision-making. Figure 2 summarizes the timeline for achieving the Mississippi River phosphorus goal and nitrogen milestone.

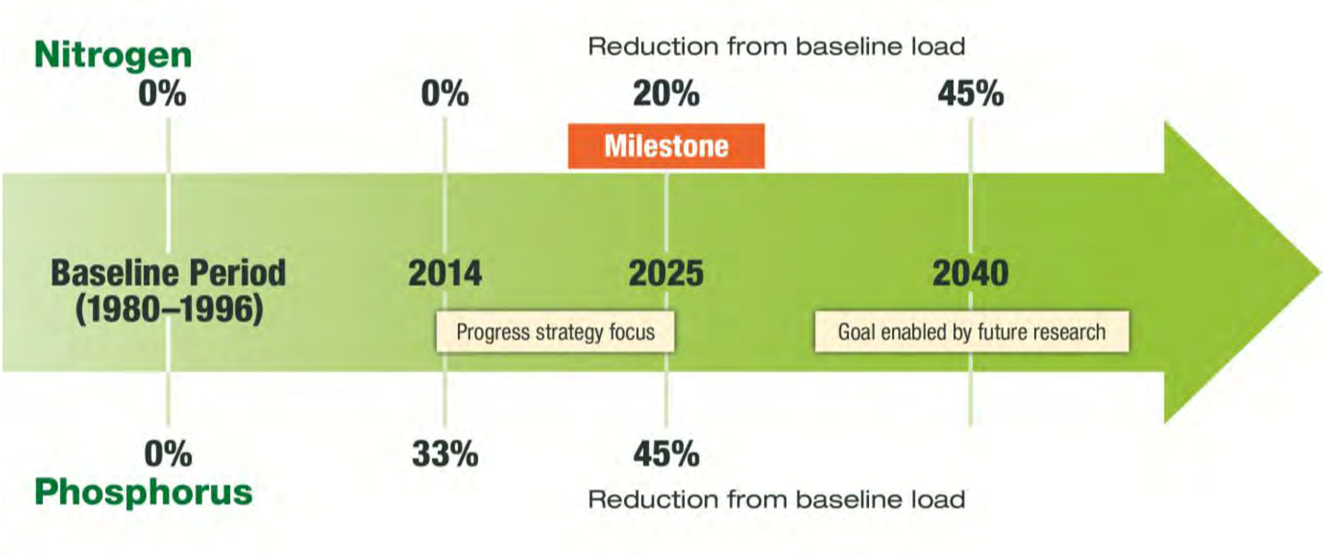


Figure 2. Timeline for achieving the Mississippi River milestone and goal.

Minnesota is implementing a watershed approach that assesses, restores and protects waters under the umbrella of the Minnesota Water Management Framework. This approach sets a 10-year cycle of water assessments, watershed restoration and protection strategy (*WRAPS*) development at the hydrologic unit code 8 (HUC8) watershed level, and local water planning (e. g., *One Watershed One Plan*). The NRS provides the information and collective objectives needed to address watershed nutrient goals downstream of the HUC8 watersheds. These downstream objectives can then be integrated with needs and prioritized actions within the HUC8 watershed. HUC8 watershed goals and milestones should be developed so that cumulative reductions from all watersheds will achieve the goals and milestones in waters downstream.

Water Quality Standards

Nutrient related water quality standards and drinking water *standards* are an important part of the water quality policy framework in Minnesota and nationally. Both lake and pending river eutrophication standards in Minnesota include phosphorus, but they do not include nitrogen. Eutrophication standards were set for lakes in 2008, and finalization of the river eutrophication standards is expected by Fall 2014. Nitrate standards to protect aquatic life in Minnesota surface waters are anticipated in the next few years. Phosphorus loading is often directly related to total suspended solids in rivers, especially during moderate to high flow events. Minnesota has existing standards for turbidity and plans to replace the turbidity standards with total suspended solids standards.

An evaluation of monitoring data indicates that meeting in-state lake and pending river eutrophication standards will likely result in meeting the major basin goals for phosphorus reduction. For example, Lake Pepin, a riverine lake on the Mississippi River, requires a greater phosphorus load reduction from this point in time than reductions needed to meet the Gulf of Mexico hypoxia goal. However for nitrogen, current in-state standards will not drive enough change to sufficiently address Minnesota's share of nitrogen to the Gulf of Mexico and Lake Winnipeg. Future nitrate standards to protect aquatic life will also necessitate nitrate reductions in some waters of the state, but we will not know the effect of those standards on downstream loading until they are established.

Headwaters to the Mississippi River
Photo Credit: MPCA

Evaluating Progress Since the Baseline Period

In developing the NRS, an assessment of recent progress to reduce nutrients in waters was conducted using available government program data. Each of the major basins in Minnesota has a reduction goal that is established according to a designated baseline period when that goal was established. For the Mississippi River, the National Hypoxia Task Force established the load reduction goals based on average conditions that occurred from 1980 -1996. Estimates of recent progress based on best management practice (BMP) adoption were then validated with river monitoring results.

Several regional, state, or federal programs were identified as key nutrient-reducing programs in Minnesota. Program staff provided input on quantifying outputs or outcomes of program implementation. Data from the Natural Resource Conservation Service Environmental Quality Incentives Program (EQIP), Reinvest in Minnesota Program (conservation easements), Minnesota's eLINK database which tracks state-funded nonpoint source BMPs, MPCA's Feedlot Program, and estimated phosphorus reduction from septic system improvements and the statewide lawn phosphorus fertilizer ban were compiled from 2000 to present. Reductions in wastewater nutrients were also quantified. Table 2 summarizes the load reductions that were quantified as part of this effort. While the assessment of progress from BMPs and changes since 2000 does not incorporate all BMPs and land management changes, river monitoring results generally support the magnitude of estimated recent progress.

Table 2. Summary of recent progress by sector as compared to overall load in each major basin.
The load reductions in this table represent estimated load reductions that will occur at the state border as a result of practices since 2000.

	Percent in load change by cropland BMPs		Percent in load change by certain misc. source BMPs		Percent in load change by wastewater		Recent progress (as % of total load delivered)	
Major basin	P	N	P	N	P	N	P	N
Mississippi River	-8%	-2%	-1%	NA	-24%	+2%	-33%	0%
Lake Winnipeg	-3.7%	0%	-0.3%	NA	-0.3%	0%	-4.3%	0%
Lake Superior	-0.7%	NA	-1.3%	NA	+2.8%	NA	+0.8%	NA

Note: P=phosphorus; N=nitrogen. A negative number indicates reduction; a positive number indicates an increase.

The greatest progress during recent years has occurred with phosphorus reductions in the Mississippi River, where the estimated phosphorus reduction is 33 percent since 2000. Mississippi River monitoring showed a similar reduction (31 percent) in Red Wing after accounting for changes in flow conditions. Estimated Mississippi River phosphorus and nitrogen reductions achieved during recent years is shown in Figure 3 and Figure 4, as compared with baseline loads and milestone and goal loads. The NRS addresses the gap between current conditions (which includes quantified recent progress) and goals and milestones.

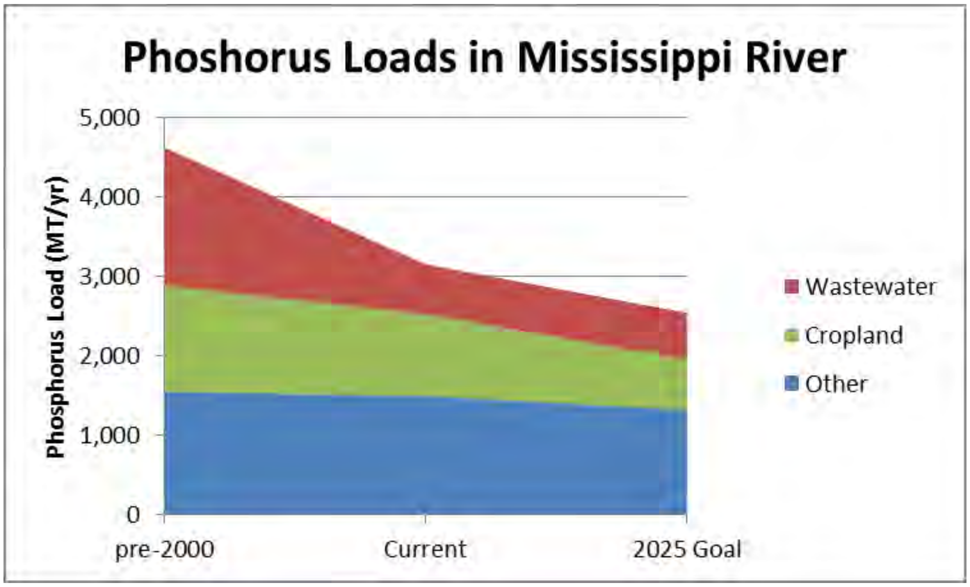


Figure 3. Minnesota's annual phosphorus loading in the Mississippi River at the state border during an average flow year in the past, current and NRS projected future. Other sources include atmospheric deposition, urban runoff, non-agricultural rural runoff, streambank erosion, barnyard runoff and septic systems.

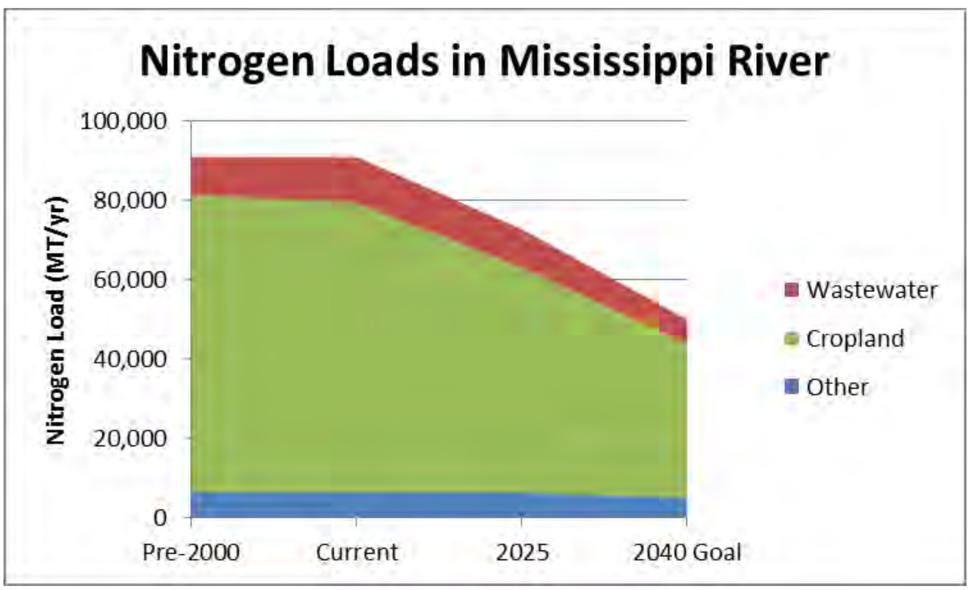


Figure 4. Minnesota's annual nitrogen loading in the Mississippi River at the state border during an average flow year in the past, current and NRS projected future. Other sources include atmospheric deposition, forest, urban runoff, and septic systems.

The full effects of these reductions have not yet been observed in river monitoring at the Minnesota/Iowa border. Lake Pepin and Mississippi River backwaters are likely recycling historically deposited phosphorus, thereby masking the full downstream effects of the load reductions. Evaluation of NRS progress will include a combination of monitoring and modeling at different points along the state's rivers, and will consider such effects as lag time and climate.

Metropolitan Wastewater Treatment Plant
Photo Credit: Metropolitan Council

Priority Management Areas

State level priority sources and major watersheds are based on the highest nutrient-loading to waters. Identifying priority areas within major watersheds occurs through local watershed planning such as "One Watershed, One Plan" and as part of WRAPS. It is important to recognize that while prioritization is an effective management tool for directing limited resources, nutrient reductions needed to meet the NRS goals cannot be achieved through implementation in a limited number of high-priority watersheds. BMP adoption is needed on millions of acres, and thus reductions are needed for priority sources in most watersheds.

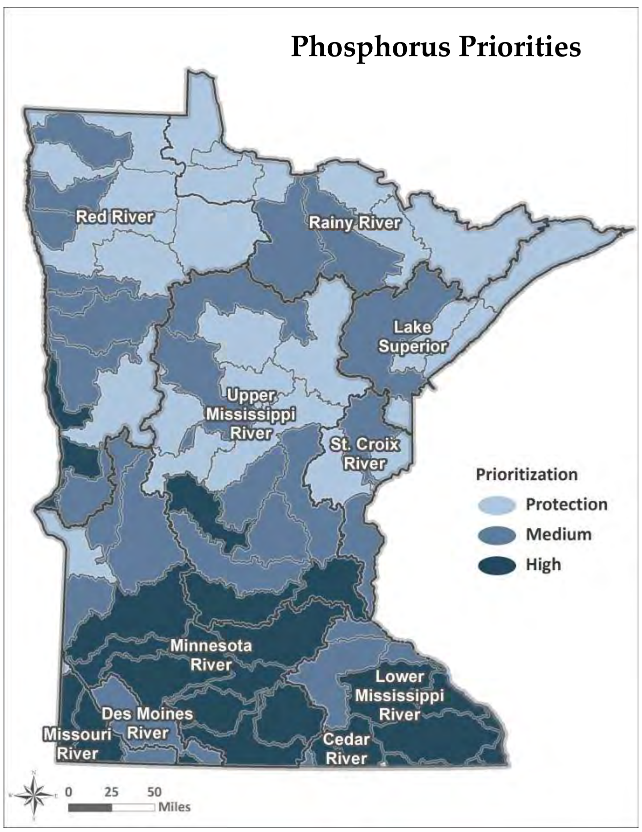
Priority sources (Table 3) are determined on the basin scale, although it should be noted that different sources might be more or less important at the local scale. Priority sources could differ depending on the scale at which reductions are needed and could be adjusted through local and regional planning processes. The NRS does not consider sources that cannot be greatly reduced by local or regional implementation activities which include atmospheric deposition and loads from forested areas as reduction priorities.

Table 3. Priority sources for each major basin

Major basin	Priority phosphorus sources	Priority nitrogen sources
Mississippi River	Cropland runoff, wastewater point sources, and streambank erosion	Agricultural tile drainage and other pathways from cropland
Lake Superior	Nonagricultural rural runoff [a], wastewater point sources, and streambank erosion	Wastewater point sources
Lake Winnipeg	Cropland runoff and nonagricultural rural runoff	Cropland

a. Includes natural land cover types (forests, grasslands, and shrublands) and developed land uses that are outside the boundaries of incorporated urban areas.

Priority watersheds have the highest nutrient yields (loads normalized to area), and also include watersheds with high phosphorus levels in rivers. Figure 5 identifies major watershed priorities.



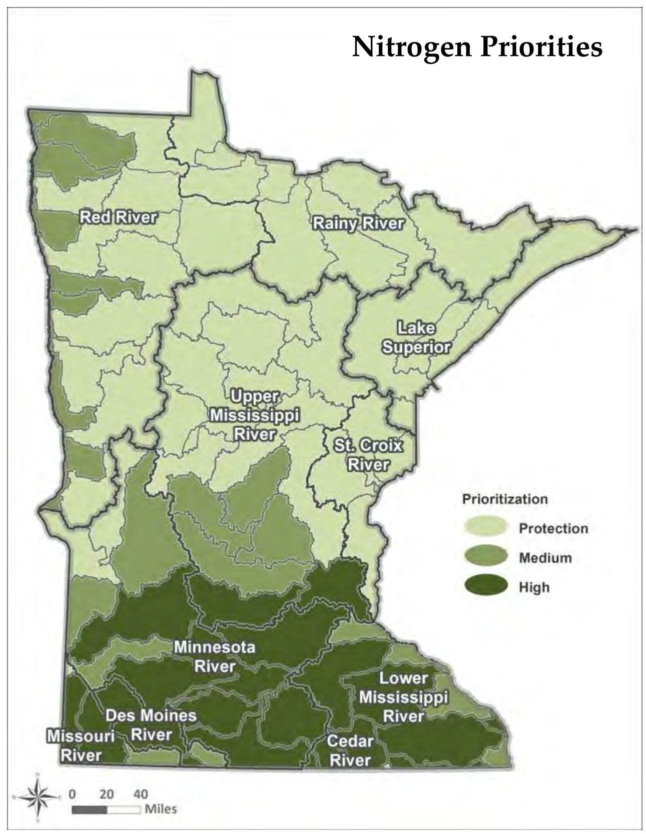


Figure 5. HUC8 watershed priorities.

Nutrient Reduction Strategies

No single solution exists for achieving the level of nutrient reductions needed to meet goals and milestones. It will take many actions and BMPs implemented over large areas of the state. To support the needed widespread change, the NRS includes two overarching strategies:

Develop a Statewide NRS Education/Outreach Campaign. Develop and implement a coordinated NRS outreach campaign that integrates with other efforts to promote statewide stewardship of water resources. This statewide campaign is responsible for raising general public awareness about the need to reduce nutrients in Minnesota waters and will support BMP specific education activities.

Integrate Basin Reduction Needs with Watershed Planning Goals and Efforts. As part of Minnesota's Water Management Framework, ensure that downstream nutrient reduction needs are addressed by cumulative local level efforts. Watershed restoration and protection strategies and accompanying comprehensive watershed management plans (e.g., One Watershed One Plan) should be developed to not only have the goal of protecting and restoring water resources within the watershed, but to also contribute to nutrient reductions needed for downstream waters both within Minnesota and those downstream of the state border. The *Minnesota Nutrient Planning Portal* was recently developed for accessing watershed nutrient-related information. It includes information on nitrogen and phosphorus conditions and trends in local waters, nutrient modeling, local water planning, and other nutrient information. Information from this portal can be used when developing local plans and strategies to reduce nutrient losses to local and downstream waters.

Wastewater Strategies

The current Phosphorus Rule and Strategy has, and will continue, to address phosphorus reductions in wastewater. The adoption of river eutrophication standards in 2014 is expected to result in additional wastewater phosphorus reductions in certain watersheds.

The history of phosphorus management at wastewater treatment facilities in Minnesota starting in 2000 is an example of a successful program to reduce a pollutant of concern. Several steps used in the successful Phosphorus Strategy (MPCA 2000) are also proposed for nitrogen:

- Influent and effluent nitrogen monitoring at wastewater treatment facilities
- Nitrogen management plans for wastewater treatment facilities
- Nitrogen effluent limits

- Add nitrogen removal capacity with facility upgrade
- Point source to nonpoint source trading

An approximate 20 percent reduction in wastewater nitrogen loads, along with reductions from other sources, will enable achievement of the nitrogen milestone for the Mississippi River. Until research and testing are complete, wastewater treatment facilities may be limited in their nitrogen removal achievements. This will be evaluated as more information is gathered throughout the life of the NRS and may result in modification of the nitrogen reduction milestones. As facilities complete these steps, assessment will help to identify changes needed to existing treatment processes and technologies. Major changes to treatment plants will require significant timeframes for design and construction.

Cropland Strategies

The NRS includes select cropland BMPs and treatment options to guide implementation; however, any combination of BMPs and treatment options that achieve the load reduction goals can be used. As new research occurs, additional BMPs and treatment options will likely become part of the NRS.

Agricultural BMPs recommended for the NRS are grouped into the following four categories:

1. Increase fertilizer use efficiencies, emphasizing:
   a. Nutrient management through reduction of nitrogen losses on corn following soybeans
   b. Switch from fall to spring fertilizer applications (or use nitrification inhibitors)
   c. Application of phosphorus in accordance with precision fertilizer and manure application techniques, including applications based on soil test results and University of Minnesota recommendations
2. Increase and target living cover, emphasizing:
   a. Cover crops on fallow and short season crops such as sweet corn, corn silage, peas, small grains, and potatoes
   b. Perennials in riparian zones and on marginal cropland
   c. Research and development of marketable cover crops to be grown on corn and soybean fields
   d. Research and development of perennial energy crop(s)
3. Field erosion control, emphasizing:
   a. Tillage practices that leave more than 30 percent crop residue cover or alternative erosion control practices that provide equivalent protection

   b. Grassed waterways and structural practices for runoff control
4. Tile drainage water quality treatment and storage, emphasizing:
   a. Constructed and restored wetlands
   b. Controlled drainage when expanding or retrofitting drainage systems
   c. Water control structures
   d. Research and development of bioreactors, two-stage ditches, saturated buffers and other ways to store and treat drainage waters

Example BMP scenarios to achieve the nutrient reduction goals and milestones in each major basin were developed. In general, the conceptual strategy for nitrogen includes increasing fertilizer and manure use efficiency through nutrient management, treating tile drainage waters, and implementing living cover BMPs. NRS phosphorus reductions from cropland are based largely on precision use of fertilizer and manure, reducing soil erosion, and adding riparian buffers and other living cover on the landscape.


Residue Management
Photo Credit: NRCS

Increased adoption of agricultural BMPs is critical to implementing the NRS and achieving goals and milestones. The NRS provides many recommendations on how to increase BMP adoption and recognizes that new ideas and strategies are also needed to achieve the high level of BMP adoption. Key cropland strategies include:

- Advance the use of vegetative cover through riparian buffers and adoption of cover crops on short season crops, while working to advance cover crop and perennial crop options for Minnesota's climate and markets for perennials.
- Work with farmers to improve soil health, which will include more crop residue and soil erosion control, especially for protection of soil during the increasing frequency of high intensity rains.
- Work with co-op agronomists, certified crop advisers, and agricultural producers on an educational campaign to achieve greater nutrient efficiencies. Provide greater confidence in reducing rates by offering crop nutrient insurance for reduced fertilizer rates and other self-demonstration projects.
- Increase education and outreach on water quality issues and BMPs needed to reach nutrient reduction goals. Encourage participation and provide education through the Agricultural Water Quality Certification Program. Develop recognition programs for excellent nutrient management such as Watershed Heroes.
- Develop strong public-private partnerships to support increased delivery of voluntary BMPs and optimize opportunities to improve the rate of BMP adoption in targeted areas. Increase demonstrations, promotion and incentives for implementing tile drainage management, wetland construction and other practices to reduce nutrients from tile drainage waters.
- Provide the necessary research and demonstration that will lead to increased adoption of cropland BMPs.

Miscellaneous Source Strategies

Phosphorus reductions from miscellaneous sources such as streambank erosion, subsurface sewage treatment systems, stormwater, and feedlots are needed to meet the overall goals and milestones in the Mississippi River and Lake Winnipeg major basins. Strategies already being used will further the progress toward reducing these nutrient loads. Existing programs have strategies that allow for systematic reductions in loads from subsurface sewage treatment systems, stormwater, and feedlots.

A large-scale strategy is also under development to address sediment reduction. The strategy will help address sediment-related nutrient load reductions. In addition, implementation of Total Maximum Daily Loads (TMDLs), particularly for turbidity-impaired streams, will likely address sediment-bound phosphorus sources that are a result of bank and channel erosion.

Protection Strategies

Protection strategies are needed in watersheds facing development pressures and changes in agricultural and land use practices, as well as in areas with vulnerable groundwater drinking water supplies. The Minnesota Water Management Framework requires protection strategies as part of WRAPS development, and therefore should address the potential for increased nutrient loads at a watershed scale. In addition, protection strategies should consider mitigation measures to address increases in Red River Basin tile drainage.

Specific to groundwater protection, the MDA is completing its Nitrogen Fertilizer Management Plan during 2014. The strategies outlined in that plan serve as the NRS's strategies for groundwater protection and include implementation of BMPs which protect groundwater resources, wellhead protection planning and implementation, a broad education and BMP promotion component, and a phased mitigation strategy to reduce groundwater nitrate concentrations to drinkable conditions in high nitrate zones.

Quantified Overview of Nutrient Reduction Strategy

The following figures for the Mississippi River Major Basin summarize the overall strategies to achieve the phosphorus goal and nitrogen milestone. Similar figures have also been developed for the Red River Basin (see Chapter 5). Each of the figures includes suggested reductions by source for each of the key BMP categories. The figures are organized to provide the baseline load by sector (agricultural, wastewater, and miscellaneous), quantified progress since baseline, and the breakdown of BMPs and implementation activities that are needed to meet the goals and milestone.

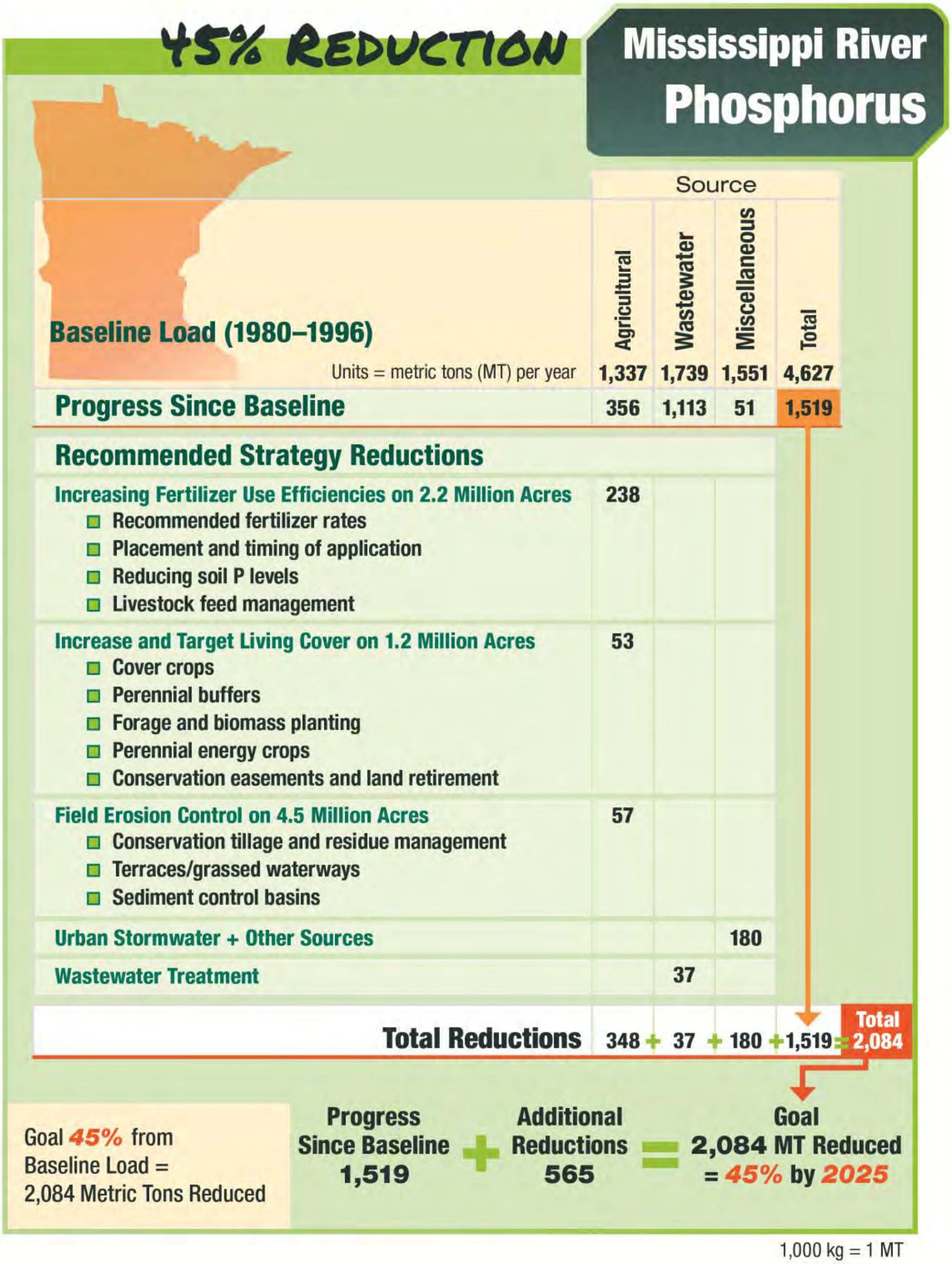
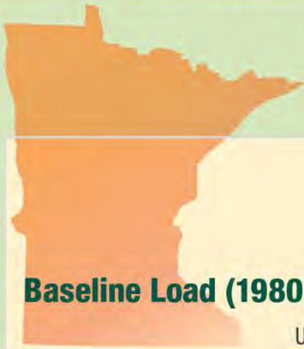


Figure 5. Phosphorus goal reductions for Mississippi River Major Basin.

20% Reduction Milestone — Mississippi River Nitrogen



	Source: Agricultural	Wastewater	Miscellaneous	Total
Baseline Load (1980–1996) Units = 1,000 metric tons (MT) per year	75.0	9.6	6.4	91
Progress Since Baseline	2	-2	0	0
Recommended Strategy Reductions				
Increasing Fertilizer Use Efficiencies on 11.2 Million Acres ▪ Recommended fertilizer rates ▪ Placement and timing of application ▪ Nitrification inhibitors	11			
Increase and Target Living Cover on 1.6 Million Acres ▪ Cover crops ▪ Perennial buffers ▪ Forage and biomass planting ▪ Perennial energy crops ▪ Conservation easements and land retirement	4.0			
Drainage Water Retention and Treatment for 0.6 Million Acres ▪ Constructed wetlands ▪ Controlled drainage ▪ Bioreactors ▪ Two stage ditches	1.2			
Wastewater Treatment		1.9		
Total Reductions	16.2 +	1.9 +	0 +	0 = Total 18.2

Milestone Target *20%* from Baseline Load = 18,200 Metric Tons Reduced

Progress Since Baseline 0 + **Additional Reductions 18,200** = **Milestone 18,200 MT Reduced = *20%* by *2025***

1,000 kg = 1 MT

Figure 6. Nitrogen milestone reductions for Mississippi River Major Basin.

Adaptive Management and Tracking Progress

Progress towards goals and milestones will be tracked over time to determine if strategies are successful and where additional work is needed. To understand the level of nutrient reduction progress being achieved and ensure that on-the-ground implementation is on pace with the NRS goals and milestones, it is important to evaluate both changes in the adoption of BMPs (our actions) and water quality monitoring information (environmental outcomes). The basic components of the NRS's adaptive management plan are as follows:

- Identify data and information needed to track progress toward NRS goals and milestones.
- Create a system or approach for collecting data and information needed to track progress toward NRS goals and milestones.
- Evaluate trends as well as relationships between actions and outcomes.
- Adjust the NRS as necessary.

Implementation tracking will be done through both land management and water quality data. Program implementation data provides early indicator information about nitrogen and phosphorus reductions that, over time, should translate to in-stream nutrient reductions. An integrated and streamlined approach to track BMP implementation should be a priority. The NRS contains a suite of program measures that can be used to measure progress including various implementation activities. It is important to note that the selected program measures reflect government programs and do not capture industry-led conservation activities. As a result, while the selected program measures are strong indicators of program implementation trends, they are conservative indicators of statewide BMP adoption. BMP implementation that is occurring outside of government assistance is likely the largest gap in measuring success of the NRS. Comprehensively determining outcomes will require measuring conservation practices and farming activities that are not funded and tracked through government programs.

Future water quality evaluations will rely upon the Watershed Pollutant Load Monitoring Network and statewide water quality modeling. Many other local, regional, statewide, and national monitoring programs will inform water quality evaluations. No single water quality metric, monitoring site, or period of monitoring will provide the needed information to evaluate environmental outcomes. When monitoring data from multiple sites is used, along with periodic modeling and evaluation of anticipated lag times, then progress toward NRS goals and milestones can be more accurately assessed.

Water quality outcome measures will include the following:

- Trend in actual load
- Trend in flow weighted mean concentration
- Extent of river and lake eutrophication impairments
- Statistical comparisons of baseline loads and concentrations at low, medium, and high flow periods with comparable flow periods during recent years
- Extent of groundwater nitrate above drinking water standards in high-nitrate areas, including those watersheds where nitrate coming from groundwater impairs surface waters

The NRS centers on a series of goals and milestones and targeted actions identified to achieve those goals and milestones over time, with periodic reevaluation and reassessment. Tracking and reporting will occur at 2-year, 5-year, and 10-year intervals. There is currently no integrated reporting, data management and report generating system that will allow for automated tracking of NRS output and outcome information to assess progress over time. The approach for tracking progress requires the development of a system to ensure the efficiency and reliability of progress tracking. Developing a tracking system of this nature will be a multi-agency undertaking that must take into consideration the existing data management approaches used by numerous programs within several agencies.

The NRS provides for accountability, incorporates adaptive management, and ensures that Minnesota stays on the ***Path to Progress in Achieving Healthy Waters***.

Lake Superior
Photo Credit: MPCA

Chapter 1

Development of the Minnesota Nutrient Reduction Strategy

Minnesota's state, federal, and regional partner agencies along with the University of Minnesota have collaborated to provide a statewide strategy to reduce levels of phosphorus and nitrogen, collectively referred to as *nutrients*. The public provided comments and suggestions which helped to create this final strategy. Minnesota will use the statewide strategy as a guide for reduction of nutrients. Excessive nutrient levels pose a substantial threat to Minnesota's lakes and rivers, as well as downstream waters including the Great Lakes, Lake Winnipeg, the Mississippi River, and the Gulf of Mexico.

The *Minnesota Nutrient Reduction Strategy* (NRS) will guide Minnesota to achieve nitrogen and phosphorus reductions within Minnesota surface waters to enhance the health of aquatic life, protect public health and safety, increase the recreational potential of Minnesota's numerous lakes, rivers, and streams. The NRS also addresses groundwater protection as it relates to nitrate in drinking water. In addition, nutrient reductions will benefit the Gulf of Mexico hypoxia problem and other waters downstream of Minnesota including Lake Winnipeg and Lake Superior. The theme of the overall NRS is ***A Path to Progress in Achieving Healthy Waters*** (Figure 1-2).

Figure 1-1. Major drainage basins in Minnesota.

The Minnesota Water Sustainability Framework (University of Minnesota 2011) surveyed Minnesotans' attitudes and beliefs about water. Based on more than 4,500 surveys and 9 listening sessions around the state, the team concluded:

- Minnesotans consider providing drinking water to be the most important use of water, followed by providing ecological services, offering recreational opportunities, and meeting the needs of agriculture.
- Minnesotans rank chemical pollution; nutrients; and non-native plant, animals, and diseases the three most serious problems facing Minnesota's waters.
- Minnesotans understand that we need to change our behavior in order to reverse the trend toward reduced water quality.
- Minnesotans equally value improving polluted lakes and rivers and protecting healthy waters.
- Minnesotans place equal importance on investing in groundwater and investing in surface waters.
- Minnesotans want to address the most serious water problems first, rather than place priority on distributing funding equitably across the state.
- Minnesotans want quantifiable measures of water quality to be communicated and accessible.

Figure 1-2. Pathways to progress.

The mission of the NRS is to recognize the importance of nutrients in protecting water quality whether sources are nearby or many miles upstream. As such it provides a roadmap to address both Minnesota's nutrient contribution to downstream waters, and, at the same time, add value for those who work on local and regional land and water nutrient-related issues within Minnesota. More specifically, the NRS mission includes the following:

1. **Complement Existing State-Level Strategies** – Several state-level plans and strategies for Minnesota water issues have been developed during recent years, and are in various stages of implementation. One goal of the NRS is to add further focus to those efforts, specifically on nutrients, thereby supplementing and coordinating among these other plans and not supplanting.

2. **Work toward Progress in Downstream Waters** – By the time nutrient problems show up in resources downstream of Minnesota such as the Gulf of Mexico or Lake Winnipeg, the contributions can be very large. Rather than comprehensively addressing the long-term goals in these downstream waters, it is beneficial to focus on making incremental progress toward restoring these waters. Minnesota is one of 12 states that have committed to develop state level nutrient reduction strategies. Even with all of these states contributing to load reductions, the level of reduction needed from any individual state can still be significant. Minnesota is approaching this challenge by establishing milestones and providing a plan to reach these meaningful interim goals. Meaningful and achievable nutrient load reduction milestones are developed that allow for better understanding of incremental and adaptive progress toward final goals. Milestones target load reductions from point and nonpoint sources impacting the Gulf of Mexico, Lake Winnipeg, Lake Pepin, Mississippi River backwaters, Lake Superior, and other downstream waters.

3. **Work toward Progress on Meeting In-state Nutrient Criteria** – Meeting Minnesota's beneficial use water quality standards is critical to protecting the waters that Minnesotans value. Whether for recreation, consumption or other uses, Minnesota identifies with its waters in important ways. The NRS complements existing efforts to make progress toward meeting in-state nutrient criteria and proposed standards for Minnesota's lakes and streams, and additionally provides protection to water bodies not yet assessed, or assessed as threatened (or needing protection) by nutrients or eutrophication.

4. **Prioritize and Target** – Major watersheds (i.e., 8-digit hydrologic unit code [HUC8]) are prioritized on a statewide basis relative to nutrient loads and impacts, and implementation activities are targeted to ensure efficient use of resources. Geographic, land use, and best management practice (BMP) priorities are established through technical analyses, resulting in recommended reductions of phosphorus and nitrogen that account for the most substantial impacts to receiving surface waters and groundwater.

5. **Build from Existing Efforts** – Many ongoing efforts are moving the state in the right direction, however the magnitude of these efforts is not sufficient to address the loading reductions needed. At the same time other factors might be contributing toward increased loads. The NRS identifies ways to build on successes of current programs and activities so that we can achieve our local and downstream water quality goals. The NRS is a unifying and organizing step to align goals, identify the most promising strategies, and coordinate the collective activities around the state working to achieve these common goals. The intent is to simplify and support, not complicate. A successful NRS will support and work within the Minnesota Water Management Framework, total maximum daily loads (TMDLs), Agricultural Water Quality Certification, the Nitrogen Fertilizer Management Plan, as well as local and regional planning efforts.

6. **Lead to Effective Local Implementation** –The NRS is directly applicable to state, federal, and regional agencies and organizations to focus and adjust state-level and regional programs, policies, and monitoring efforts. Those agencies often have the local watershed managers and water planners as a key customer focus; therefore the NRS is intended to focus at the state level but be relevant at the local level. These customers will take the large-scale data, priorities, and recommendations and consider that information when developing localized implementation plans (i.e., for HUC8 watershed scale and smaller). Efficiencies will be gained by making large-scale information available to local watersheds. This NRS will enhance and not replace the planning work needed at the HUC8 and finer watersheds scale.

1.1 Driving Forces

The need for a statewide nutrient reduction strategy in Minnesota is driven by a number of federal, regional, and state initiatives coalescing at this particular point in time. At the federal level, Environmental Protection Agency's (EPA) focus on statewide nutrient reduction planning has served as a key driving force for Minnesota's NRS development. Regionally, Minnesota's involvement in the Mississippi River/Gulf of Mexico Watershed Nutrient Task Force has also served as a driving force. In the past decade, nutrient issues downstream of Minnesota have reached critical levels, including the effect of nutrients in the Gulf of Mexico which has resulted in hypoxia (low levels of oxygen), eutrophication problems in Lake Winnipeg, and nutrient concerns in the Great Lakes. Several state-level initiatives and actions have highlighted the need for a statewide strategy that ties separate but related activities together to demonstrate integration toward nutrient reductions. The following sections contain a brief discussion of each primary federal, regional, and state driving force.

Hypoxia Action Plan

The Mississippi River/Gulf of Mexico Watershed Nutrient Task Force developed a *Hypoxia Action Plan* in 2001, which was revised in 2008 and describes a national strategy to reduce, mitigate, and control hypoxia in the northern Gulf of Mexico and improve water quality in the Mississippi River Basin. The Action Plan identified the following action to help achieve nutrient reduction in the Mississippi River/Gulf of Mexico watershed and work toward meeting the goals for reduction in the hypoxia zone in the Gulf of Mexico:

> *Complete and implement comprehensive nitrogen and phosphorus reduction strategies for states within the Mississippi/Atchafalaya River Basin encompassing watersheds with significant contributions of nitrogen and phosphorus to the surface waters of the Mississippi/Atchafalaya River Basin, and ultimately to the Gulf of Mexico.*

This action calls for state-level nutrient reduction strategies by 2013. The strategies are intended to be collaborative, support both current and new nutrient reduction efforts, identify available funding, and specify funding needs (Mississippi River/Gulf of Mexico Watershed Nutrient Task Force 2008). EPA has provided funding and assistance to many of the states to help develop these strategies, including Minnesota. The NRS applies to the entire state, a large part of which includes the basins flowing into the Mississippi River.

EPA Memo on State Nutrients Framework

A *memo* issued by EPA on March 16, 2011, urged states to accelerate nutrient reduction and provided "Recommended Elements of a State Nutrients Framework" to help guide state planning activities related to nutrient reduction. Framework elements include:

1. Prioritize watersheds on a statewide basis for nitrogen and phosphorus loading reductions
2. Set watershed load reduction goals based upon best available information
3. Ensure effectiveness of National Pollutant Discharge Elimination System (NPDES) point source permits in targeted/priority subwatersheds
4. Agricultural areas
5. Stormwater and septic systems
6. Accountability and verification measures
7. Annual public reporting of implementation activities and biannual reporting of load reductions and environmental impacts associated with each management activity in a targeted watershed
8. Develop a work plan and schedule for numeric criteria development

This NRS strives to address each of the framework elements.

In-State Surface and Groundwater Water Quality Issues

Excessive levels of phosphorus and nitrogen present a substantial threat to Minnesota's lakes and rivers, as well as downstream water bodies. These threats are not only to the environment, but also to drinking water and public health. Minnesota promulgated lake and reservoir eutrophication standards in 2008 and is in the process of promulgating proposed *river and stream eutrophication standards* in 2014. Both sets of standards include phosphorus as the cause variable along with response variables that demonstrate that phosphorus has manifested as excess algal levels. Based on the 2012 Impaired Waters List, almost 20 percent of Minnesota lakes and river segments have been assessed as impaired due to excess nutrients or nutrient-related parameters (see Chapter 2). These water bodies will be the subject of TMDL studies and individual restoration plans designed to help achieve state water quality standards. These listings do not reflect the proposed river eutrophication standards; therefore, many more streams and rivers are anticipated to be added to future impaired waters lists.

The Minnesota Pollution Control Agency (MPCA) has assessed many Minnesota lakes and categorized them as impaired for excess nutrients (e.g., phosphorus). Sixty-five percent of the state of Minnesota is located upstream of a lake impaired by excess nutrients. As a result, MPCA is developing individual restoration plans that are designed to bring local waters into compliance with state water quality standards.

Nitrate concentrations in Minnesota groundwater also present a threat to safe drinking water supplies. Groundwater supplies drinking water to about 75 percent of all Minnesotans and almost all of the water used to irrigate the state's crops. The inflow of groundwater also is important to maintain the water level, pollution assimilative capacity, and temperature in Minnesota's streams, lakes, and wetlands. Central and southern Minnesota has the highest groundwater nitrate concentrations, predominantly in areas of karst as well as shallow sand and gravel aquifers. Minnesota is currently developing nitrate toxicity standards to protect aquatic life in surface waters of the state. The state is working toward adoption of these standards in about 2015.

Confluence of Dry Weather Creek and Chippewa River Photo Credit: MPCA

Clean Water Land and Legacy Amendment

On November 4, 2008, Minnesota voters approved the *Clean Water, Land and Legacy Amendment* (Amendment) to the constitution to protect drinking water sources; to protect, enhance and restore wetlands, prairies, and forests, as well as fish, game, and wildlife habitat; to preserve arts and cultural heritage; to support parks and trails; and to protect, enhance and restore lakes, rivers, streams, and groundwater. The Amendment increased the sales and use tax rate by three-eighths of one percent on taxable sales, starting July 1, 2009, continuing through 2034. Of those funds, approximately 33 percent are dedicated to a Clean Water Fund to protect, enhance, and restore water quality in lakes, rivers, streams, and groundwater, with at least 5 percent of the fund targeted to protect drinking water sources. Approximately $152 million was invested in the Clean Water Fund in the first 2 years for water management activities such as monitoring, planning, and on-the-ground restoration and protection activities.

Minnesota agencies that receive Clean Water Fund dollars have released *two collaborative reports*, most recently in 2014. Overall, the report shows the state is on track with its investments, though challenges remain. The 25 measures in the report provide a snapshot of how Clean Water Fund dollars are being spent and the progress being made. The measures are organized into three sections: investment, surface water quality, and drinking water protection. These are just some of the measures that will be used to consistently track and report clean water outcomes over the life of the Amendment. Each measure has a status ranking and trend information.

Minnesota's Clean Water Road Map was released in 2014 and is "a set of goals for protecting and restoring Minnesota's water resources during the 25-year life of the Clean Water, Land and Legacy Amendment. Clean Water Roadmap goals are based on currently available data and are intended to be ambitious, yet achievable. Progress in meeting these goals will require significant investment from the Clean Water Fund established by the Amendment, combined with historical water resource funding from other sources." Goals are provided for four high-level indicators that describe surface water quality, groundwater quality, and groundwater quantity.

Minnesota Water Management Framework – Watershed Approach to Protecting and Restoring Water Quality in Minnesota's Watersheds

The Minnesota Water Management Framework (Framework) lays out the state's plan to implement watershed-based planning efforts that will over the next 10 years result in locally-led water quality improvement plans. The Framework is a high-level, multi-agency, collaborative perspective on managing Minnesota's water resources.

Minnesota's water resource management efforts are tied to the goals of the 1972 Clean Water Act (CWA) for restoring and protecting the multiple beneficial uses, including recreation, drinking water, fish consumption, and ecological integrity of America's waters. The CWA requires states to do the following:

- Assign designated beneficial uses to waters and develop water quality standards to protect those uses.
- Monitor and assess their waters.
- List waters that do not meet water quality standards.
- Identify pollutant sources and reductions in pollution discharges needed to achieve standards.
- Develop a plan to implement water restoration and protection activities.

The passage of Minnesota's Clean Water Legacy Act (CWLA) in 2006 provided a policy framework and resources to state and local governments to accelerate efforts to monitor, assess, and restore impaired waters, and to protect unimpaired waters.

The CWLA and the recently established Clean Water Fund has changed how Minnesota approaches water quality, allowing a systematic approach in addressing impaired waters and protection efforts in unimpaired waters. Minnesota's watershed program has rapidly evolved from a singular focus on TMDLs to a watershed approach that will lead to comprehensive restoration and protection strategies for each of the state's major (HUC8) watersheds described in comprehensive watershed management plans (e.g., *One Watershed One Plan*). The Framework describes how Minnesota agencies aim to streamline water management by systematically and predictably delivering data, research, and analysis and empowering local action (Figure 1-3).

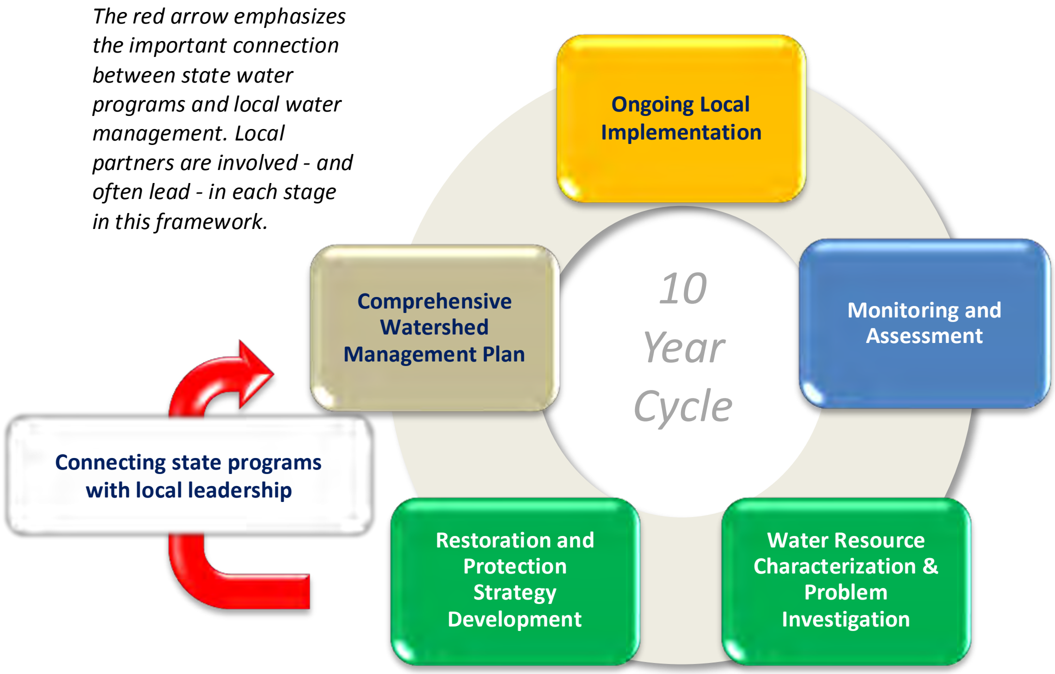


Figure 1-3. Minnesota Water Management Framework

Ongoing Local Implementation is at the heart of the state's overall strategy for clean water. Actions must be <u>prioritized, targeted, and measurable</u> in order to ensure limited resources are spent where they are needed most. The rest of the cycle supports effective implementation.

Monitoring and Assessment determines the condition of the state's ground and surface waters and informs future implementation actions. The state's "watershed approach" systematically assesses the condition of lakes and streams on a 10-year cycle. Groundwater monitoring and assessment is more varied in space and time.

Water Resource Characterization and Problem Investigation delves into the science to analyze and synthesize data so that key interactions, stressors, and threats are understood. In this step, watershed and groundwater models and maps are developed to help inform strategies.

<u>W</u>atershed <u>R</u>estoration <u>a</u>nd <u>P</u>rotection <u>S</u>trategies (WRAPS) and Groundwater Restoration and Protection Strategies include the development of strategies and high level plans, "packaged" at the 8-digit HUC scale (81 major watersheds in Minnesota). These strategies identify priorities in each major watershed and inform local planning.

The **Comprehensive Watershed Management Plan** is where information comes together in a local commitment for prioritized, targeted, and measurable action. Local priorities and knowledge are used to refine the broad-scale WRAPS and other assessments into locally based strategies for clean and sustainable water.

The NRS provides recognition that many of the watershed nutrients manifest as problems downstream of the HUC8 watersheds in regional lakes, reservoirs, national waters and international waters. It is important, therefore, that comprehensive watershed management plans address the contribution of nutrients to waters within their HUC8 watershed as well as downstream waters.

What is a Watershed Restoration and Protection Strategy (WRAPS)?

MN Statute 114D.15, Sec. 12, Subd. 13 defines a WRAPS as:

[A] document summarizing scientific studies of a major watershed no larger than a hydrologic unit code 8 including the physical, chemical, and biological assessment of the water quality of the watershed; identification of impairments and water bodies in need of protection; identification of biotic stressors and sources of pollution, both point and nonpoint; TMDLs for the impairments; and an implementation table containing strategies and actions designed to achieve and maintain water quality standards and goals.

Groundwater Protection and the Nitrogen Fertilizer Management Plan

The Comprehensive Groundwater Protection Act of 1989 (Minnesota Statute § 103H) provided direction and authority for water resource protection in Minnesota and especially with regard to nitrogen fertilizer management in Minnesota. This was a result of three separate but related components of the Act: (1) development of a groundwater protection goal; (2) enhanced regulatory authority for fertilizer practices within the Minnesota Department of Agriculture (MDA); and (3) development of a *Nitrogen Fertilizer Management Plan* (NFMP) by MDA.

The NFMP is the state's blueprint for prevention or minimization of the impacts of nitrogen fertilizer on groundwater. The plan must include both voluntary components and provisions for the development of nitrogen fertilizer use restrictions if the implementation of BMPs proves to be ineffective.

Many aspects of the NFMP have been implemented since the adoption of the original NFMP in 1990. In 2010 the MDA began a process to revise the plan to reflect current activities and interagency water protection planning and implementation work, and to better align it with current water resource conditions and program resources.

The following are excerpts from the Draft Plan's Executive Summary written by MDA (2013):

> *The intent of the Nitrogen Fertilizer Management Plan is to prevent, evaluate, and mitigate nonpoint source pollution from nitrogen fertilizer in groundwater. The plan must include components promoting prevention and developing appropriate responses to the detection of nitrogen fertilizer in groundwater. The strategies in the NFMP are based on voluntary BMPs, intended to engage local communities in protecting groundwater from nitrate contamination.*
>
> *The general approach to addressing nitrate in groundwater in Minnesota is to: (1) promote nitrogen fertilizer BMPs to protect groundwater with greater efforts in vulnerable areas to prevent groundwater problems from occurring (ongoing); (2) monitor private wells on a township scale over a 10-year period or use existing monitoring data to identify areas with nitrate concerns; (3) conduct a detailed assessment of water quality in these areas to determine the severity and priority of the problem; and, 4) conduct mitigation actions in high-priority areas using a phased approach starting with voluntary actions and progressing to regulatory actions if necessary.*
>
> *Prevention is significantly emphasized because once groundwater is contaminated; it can be extremely difficult, expensive, and very slow to remediate. Prevention activities within the NFMP are ongoing regardless of the status of mitigation for nitrate in groundwater. A variety of activities can be utilized in order to achieve the NFMP prevention goal including BMPs, alternative management tools, wellhead protection, education and promotion, and local water plans. A Nitrogen Fertilizer Education and Promotion Team will be developed to assist MDA with the coordination of prevention activities and programs.*
>
> *The goal of mitigation is to minimize the source of pollution to the greatest extent practicable and, at a minimum, to reduce nitrate contamination to below the drinking water standard (10 milligrams per liter or 10 mg/L) so the groundwater is not restricted for human consumption. The mitigation strategy is based on the prevention strategy, but implemented over a defined area and at a higher level of effort and intensity. It is intended to have significant local involvement and leadership, especially through the participation of local farmers.*

Red River and Lake Winnipeg Nutrient Strategy

The International Red River Board (IRRB) recognized that excessive nutrients such as phosphorus and nitrogen are one of the greatest water quality issues facing the international Red River watershed and Lake Winnipeg. While all jurisdictions within the watershed have various regulatory frameworks, plans, and approaches in place to reduce the contribution of nutrients to water, the development of an enhanced, coordinated, and systematic strategy across jurisdictional boundaries is desirable. Working with the Red River Basin Commission (RRBC), the IRRB has convened a group to coordinate development of a nutrient strategy that encompasses the three jurisdictions that cover the majority of the Red River basin: Minnesota, North Dakota and Manitoba. The goal is to attain water quality in the Red River that meets the needs of all of the jurisdictions. Implementation of the strategy will be done separately in each jurisdiction, but coordinated through the IRRB and the RRBC. Implementation in Minnesota will be guided by the NRS. Communication between those working on Minnesota's NRS and those working on the IRRB's strategy has ensured compatibility between the two efforts. Communication and coordination will continue as the strategies are implemented within the basin.

Red River at Fargo/Moorhead Photo Credit: MPCA

1.2 Collaborative Process

Interagency Coordination Team

Successful implementation of the NRS will require broad agency support, coordination, and collaboration. An interagency coordination team (ICT) supported development of the NRS and is expected to support its implementation. The ICT consists of representatives from various agencies and organizations that administer key nutrient reduction programs or implement programs that support decisions affecting nutrient loads. The ICT structure includes a high-level Steering Committee composed of senior agency managers and a work group composed of agency program managers. Two sector-specific focus groups were also formed to provide input and direction on NRS development. The Agricultural Sector group includes representation from MDA, Natural Resource Conservation Service (NRCS), Board of Water and Soil Resources (BWSR), MPCA, and University of Minnesota. The Point Source Sector group includes representation from MPCA and Metropolitan Council. Each of these groups met twice to identify potential strategies for nutrient reduction.

ICT Representation

- Minnesota Pollution Control Agency
- Minnesota Department of Agriculture
- Minnesota Department of Natural Resources
- Minnesota Department of Health
- Minnesota Department of Employment and Economic Development
- Board of Water and Soil Resources
- Natural Resource Conservation Service and Farm Service Agency
- United States Geological Survey
- University of Minnesota
- Metropolitan Council

Public Involvement

Public input on the draft NRS was obtained through a formal public comment period which began on October 7, 2013 and extended through December 18, 2013. Outreach activities included draft NRS availability through the *project website* along with summary facts sheets, a series of open houses, presentations, question and answer sessions, and one-on-one discussions. Hundreds of interested residents, agency and other governmental staff, elected officials, and advisors attended over 25 different events during the public comment period which provided the opportunity to learn about the NRS and provide input. A total of 85 comment letters were submitted by individuals or organizations. Many changes were made to update the NRS based on input by commenters.

1.3 Building Blocks

This NRS was developed from several existing foundational efforts which estimated the river nutrient loads, nutrient sources, and effectiveness of BMPs for nutrient reductions. Below are some of these key technical building blocks:

- Phosphorus Source Assessment
- Nitrogen in Minnesota Surface Waters, Conditions, Trends, Sources, and Reductions Report
- Spatially Referenced Regressions on Watershed (SPARROW) Modeling
- Conservation Effects Assessment Project
- Major Watershed Load Monitoring Network
- Major River Monitoring by Metropolitan Council Environmental Services, Manitoba and U. S. Geological Survey (USGS)
- BMP Effectiveness Manuals and Models

Phosphorus Source Assessment

In 2003 concerns about the phosphorus content of automatic dishwashing detergents prompted the passage of legislation requiring a *comprehensive study* of all of the sources and amounts of phosphorus entering publicly owned treatment works and, ultimately, Minnesota surface waters. The assessment conducted for the MPCA by Barr Engineering (2004), with assistance from the University of Minnesota and others, estimated how much phosphorus enters Minnesota's lakes, wetlands, rivers and streams, and where it comes from in each of the state's 10 basins.

The detailed assessment of phosphorus sources report, along with two updates to the study, was used for certain parts of NRS development. In 2007 the phosphorus atmospheric deposition amounts were updated (Barr Engineering 2007), and in 2012 the MPCA updated the phosphorus wastewater point source discharge amounts based on wastewater discharge monitoring reports.

Nitrogen in Minnesota Surface Waters Report

In 2013 the MPCA released *Nitrogen in Minnesota Surface Waters, Conditions, Trends, Sources, and Reductions* describing the nitrogen conditions in Minnesota's surface waters, along with the sources, pathways, trends, and potential ways to reduce nitrogen in waters (MPCA 2013a). The report was developed in response to concerns about nitrogen in Minnesota's surface waters, including: (1) toxic effects of nitrate on aquatic life, (2) increasing nitrogen concentrations in the Mississippi River combined with nitrogen's role in causing the hypoxic zone in the Gulf of Mexico, and (3) the discovery that some Minnesota streams exceed the 10 milligrams per liter (mg/l) standard established to protect potential drinking water sources. The report was developed by the MPCA, University of Minnesota, and USGS. Several parts of the report were used in the NRS, including the nitrogen sources to surface waters assessment, river nitrogen load based on monitoring and modeling, and practices to reduce nitrogen in waters.

SPARROW Modeling

Results from the SPARROW model, which the USGS developed and maintained, was used for this study to estimate nitrogen and phosphorus loads and to estimate nutrient contributions from different sources in Minnesota. The *Nitrogen in Minnesota Surface Waters, Conditions, Trends, Sources, and Reductions* report (MPCA 2013a) contains a chapter on SPARROW modeling for nitrogen in Minnesota.

The SPARROW model integrates water monitoring data with landscape information to predict long-term average constituent loads that are delivered to downstream receiving waters. The SPARROW models are designed to provide information that describes the spatial distribution of water quality throughout a regional network of stream reaches. SPARROW also tracks the attenuation of nutrients during their downstream transport from each source. Models are developed by statistically relating measured stream nutrient loads with geographic characteristics observed in the watershed.

Nutrient estimates for Minnesota were based upon the SPARROW Major River Basin 3 (MRB3) model that Robertson and Saad (2011) developed. The authors used water quality data from 1970 to 2007 to estimate representative loads expected in 2002 at each site. The SPARROW model for the Upper Midwest (Robertson and Saad 2011) incorporates five different nutrient sources, five climatic and landscape factors that influence delivery to streams, and nutrient removal in streams and reservoirs.

SPARROW results were used in certain parts of the NRS to provide comparable watershed nutrient yield and loading data, inform sources of nutrients, and estimate loading in the Lake Superior and Rainy River watersheds.

Conservation Effects Assessment Project

The U. S. Department of Agriculture NRCS Conservation Effects Assessment Project (CEAP) estimated the benefits of the 2002 Farm Bill's increase in conservation funding at a national, regional, and watershed scale. The Upper Mississippi River Basin was one of 13 basins studied in the CEAP. Total nitrogen and phosphorus loading values were estimated for five scenarios: background (no cultivated land), current conditions (2003–2006), no conservation practices, treatment of critical undertreated cropland, and treatment of all undertreated cropland conditions. The latter two scenarios dealt with increasing treatment for undertreated areas and, more specifically, simulated the effects of structural conservation practices, residue and tillage management, and nutrient management.

The recommendations from the CEAP analysis help to inform the general approach to the NRS. Compared to current conditions (based on a 2003 to 2006 operator survey), the study recommends a greater focus on applying conserving practices to undertreated land. The study also recommends complete and consistent use of nutrient management, including appropriate rate, form, timing, and method of application, especially for nitrogen loss in subsurface flows (USDA 2012a).

Watershed Pollutant Load Monitoring Network

The *Watershed Pollutant Load Monitoring Network* (WPLMN) is a multi-agency effort led by the MPCA to measure and compare regional differences and long-term trends in water quality among Minnesota's major rivers including the Red, Rainy, St. Croix, Minnesota, and Mississippi and the outlets of major HUC8 tributaries draining to these rivers. The network was established in 2007. Site-specific streamflow data from USGS and Minnesota Department of Natural Resources (DNR) flow gauging stations is combined with water quality data that the Metropolitan Council Environmental Services, local monitoring organizations, and MPCA staff collected to compute annual pollutant loads at river monitoring sites across Minnesota.

The WPLMN has been collecting water quality at an increasing number of locations since 2007, reaching 79 monitoring sites by 2010. The design scale is focused toward, but not limited to, monitoring HUC8 watershed outlets within the state. Strategic major river mainstem sites are included to determine basin loads and assist with statewide mass balance calculations. Annual water quality and daily average discharge data were coupled in the Flux32 pollutant load model, which Dr. Bill Walker originally developed and the U.S. Army Corps of Engineers and MPCA recently upgraded, to create concentration/flow regression equations to estimate pollutant concentrations and loads on days when samples were not collected. Primary output includes annual and daily pollutant loads and flow weighted mean concentrations (pollutant load/total flow volume). Loads and flow weighted mean concentrations are calculated annually for total suspended solids (TSS), phosphorus, dissolved orthophosphate , nitrate plus nitrite nitrogen (NO3+NO2-N) and total Kjeldahl nitrogen (TKN). The NO3+NO2-N is added to TKN to represent total nitrogen.

These data were compared to SPARROW model results, but were not used directly in NRS development. These data will be critical to future iterations of the NRS as long-term monitoring data become available for the majority of HUC8 major watersheds.

Major River Monitoring by Metropolitan Council Environmental Services, Manitoba, and USGS

Long-term monitoring of nutrients in rivers by three agencies was used for calculating nutrient loads. Table 1-1 summarizes these long-term monitoring efforts. Chapter 3 summarizes these data. Each of these efforts continues to collect data, and therefore newer data are available than presented in the NRS.

Table 1-1. Major river monitoring efforts

Monitoring program	Lead agency	Watershed/stream locations	Years	Load estimation methods
Long-term Resource Monitoring Program	USGS	Mississippi River Upstream and Downstream of Lake Pepin; Mississippi River near Iowa at Lock and Dams 7 and 8	1991–2010	MPCA used multiple year regressions in Flux32.
Metropolitan Council Major Rivers Monitoring Program	Metropolitan Council Environmental Services	Mississippi River at Anoka and Prescott; Minnesota River at Jordan; St. Croix River at Stillwater	1980–2010	Met Council used 1-year concentration/flow data and a single year's flow to calculate loads in Flux32.
Red River	Manitoba Conservation and Water Stewardship and Environment Canada (CWSEC)	Emerson Manitoba	1994–2007	Manitoba CWSEC used monthly water quality and flow data (average of daily) for full period to estimate monthly and annual loads.

Mississippi River at St. Cloud Photo Credit: MPCA

Best Management Practices for Nutrient Reduction

The effectiveness of BMPs and conservation practices for reducing nutrient loads to surface waters was evaluated from several sources. Three key sources of information for agricultural BMPs included: (1) Minnesota AgBMP Handbook; (2) Iowa State University literature review; and (3) University of Minnesota Nitrogen Best Management Practice watershed planning tool (NBMP).

MDA's Clean Water Research Program funded the *Minnesota AgBMP Handbook* (Miller et al. 2012). The handbook describes different BMPs and associated research findings concerning the effect that individual BMPs can be expected to have on reducing pollutants to surface waters, including nutrients.

Iowa recently completed an extensive review of Upper Midwest studies on the effectiveness of nitrogen removal when using various individual and collective BMPs (Iowa State University 2013). This report, part of the *Iowa Nutrient Reduction Strategy*, was developed by a team of scientists led by Iowa State University.

The University of Minnesota developed the *NBMP tool* to enable water resource planners developing either state-level or watershed-level nitrogen reduction strategies to gauge the potential for reducing nitrogen loads to surface waters from cropland, and to assess the potential costs of achieving various reduction goals. The tool merges information on nitrogen reduction with landscape adoption limitations and economics. The tool allows water resource managers and planners to approximate the percent reduction of nitrogen entering surface waters when either a single BMP is applied across the watershed or a suite of BMPs is adopted at specified levels across the watershed. The tool also enables the user to identify which BMPs will be most cost-effective for achieving nitrogen reductions. The spreadsheet was not designed for individual land owner decisions, but rather for large-scale watershed or state-level assessments.

Chapter 2

Setting Goals and Milestones

The *Minnesota Nutrient Reduction Strategy* (NRS) includes goals and milestones for nutrient reduction at multiple scales including supporting goals and objectives for protecting and restoring nutrient sensitive waters within the state, and expected outcomes at the major basin (e.g., Mississippi River Major Basin at the state line) and major watershed (e.g., 8-digit hydrologic unit code [HUC8] watershed) outlets. Progress toward goals and milestones can be tracked over time to determine if strategies are successful and where additional work is needed. The following definitions apply throughout the NRS document:

- **Goal** – Ultimate nutrient reduction desired for water quality improvement, expressed as a percent reduction in load. Goals are expected to be updated as new information becomes available in the various major basins.
- **Milestone** – An interim goal to be achieved, expressed in terms of load reduction. Milestones are used in this NRS to define loading reductions that represent environmental progress.
- **Baseline** – Represents initial time period against which goals are compared and trends in water quality and programmatic implementation are evaluated.

Identifying and integrating downstream needs and objectives with nutrient reduction goals at various watershed scales is an important part of the NRS intended to create a win-win approach for water quality improvement and protection. Downstream needs include total maximum daily loads (TMDLs) for phosphorus-impacted in-state rivers, regional lakes and reservoirs, along with both nitrogen and phosphorus reduction needs for the Gulf of Mexico, Lake Winnipeg, and other out-of-state waters.

2.1 Major Basin-Wide Goals and Milestones

Several existing efforts establish nutrient reduction targets for large drainages within Minnesota and provide a suitable framework for load reduction goals. Individual nutrient reduction goals (phosphorus and nitrogen) in this NRS are included for the following three major river basins (Figure 2-1):

- Mississippi River Major Basin (including the Missouri River, Cedar River, and Des Moines River basins)
- Lake Superior Major Basin
- Lake Winnipeg Major Basin (including the Red River and Rainy River basins)

In addition, a groundwater/source water protection goal is included to address groundwater as a drinking water source. Nutrient reduction needed to improve in-state rivers, lakes, and reservoirs is described in Section 2.2.

Figure 2-1. Minnesota's major basins and basins.

The NRS is based on load reduction goals that have previously been stated in applicable plans or policies. Goals are expressed as a percent reduction from loads during a baseline time period. Table 2-1 presents the goals, which are derived from existing planning goals as found in the following references:

- **Lake Superior** – Great Lakes Water Quality Agreement of 1978, amended by a protocol signed November 18, 1987.
- **Lake Winnipeg** – The Manitoba Water Stewardship Division developed the Lake Winnipeg Action Plan in 2003. The International Red River Board is currently working on developing nutrient reduction goals, expected to be completed in 2014 or 2015. Goals associated with the 2003 reference are included as provisional goals and are expected to be higher as a result of the International Red River Board plan.

NRS Goals

NRS goals for reductions to Major Basin Waters such as the Mississippi Basin/Gulf of Mexico are based on load reduction goals or water quality targets that have previously been stated in plans or policies.

- **Mississippi River (Gulf of Mexico)** – The Mississippi River/Gulf of Mexico Watershed Nutrient Task Force developed the 2008 Gulf Hypoxia Action Plan. Minnesota has assumed a nutrient reduction goal that is proportional to the load reductions needed in the Gulf of Mexico drainage area as a whole, as a percentage of baseline loads. In the future, it is possible that states could be allocated a nutrient load to meet the Gulf of Mexico goals. In the meantime, Minnesota will strive to reduce nutrient loads applying an equitable "fair-share" approach using a proportional reduction of the baseline load. Goals associated with this reference are included as provisional goals since the authorities for downstream waters may adjust the overall goals at some time in the future. Other states are concurrently developing their goals and strategies. It is the mission of the Hypoxia Task Force to coordinate these strategies.
- **Statewide Groundwater/Source Water** – Minnesota Groundwater Protection Act. The 1989 Act's degradation prevention goal states, "It is the goal of the state that groundwater be maintained in its natural condition, free from any degradation caused by human activities. It is recognized that for some human activities, this degradation prevention goal cannot be practicably achieved. However, where prevention is practicable, it is intended that it be achieved. Where it is not currently practicable, the development of methods and technology that will make prevention practical is encouraged."

Table 2-1. Major basin-wide nutrient reduction goals

Major basin	Phosphorus reduction goal	Nitrogen reduction goal
Lake Superior [a]	Maintain 1979 conditions	Qualitative – continued implementation of specific nutrient management programs
Lake Winnipeg [b]	10% reduction from 2003 conditions	13% reduction from 2003 conditions
Mississippi River [c]	45% reduction from average 1980–1996 conditions	45% reduction from average 1980–1996 conditions
Statewide Groundwater/ Source Water	Not applicable	Meet the degradation prevention goal of the Minnesota Groundwater Protection Act

a. Great Lakes Water Quality Agreement of 1978, amended by a protocol signed November 18, 1987.
b. 2003 Lake Winnipeg Action Plan; Provisional goal, milestones to be revised upon completion of the Red River/Lake Winnipeg strategy. Lake Winnipeg Goals are expected to change in the near future, resulting in additional load reduction needs which could approach a 50 percent reduction.
c. 2008 Gulf Hypoxia Action Plan; Provisional goal; Also includes drainage associated with Missouri, Des Moines, and Cedar rivers.

In addition to goals, milestones serve as interim measures of progress and were developed as part of the NRS. Milestones provide a step-wise approach to meeting major basin goals for nutrient reduction and can adapt to the changing landscape, regulatory environment, and suitability of available BMPs.

Milestones are an important component of the NRS because of a variety of factors, including the following:

- The adoption of future water quality standards will drive point source reductions in some watersheds; the timing of standards adoption is critical to long-term planning.
- Additional research and successful pilot demonstrations are required for several types of point and nonpoint source BMPs before widespread adoption.
- Effective nitrogen reductions at wastewater treatment facilities require several years of planning.

Milestone Foundation

The basis for milestone selection is the balancing of meaningful environmental outcomes with achievable actions working together across all sectors. Achieving milestones represents progress toward the goals for nutrient reduction.

Milestones are phased over time, depending on parameter and major basin. One milestone is included in the NRS to address nitrogen reductions in the Mississippi River Major Basin. Milestones for the Lake Winnipeg Major Basin are anticipated in future revisions of the NRS along with higher reduction goals being developed as part of a Red River/Lake Winnipeg strategy to reduce nutrient loading. The International Red River Basin Water Quality Committee has suggested that revised goals for the Red River may be as high as a 50 percent nutrient reduction (IIRB Water Quality Committee meeting June 23, 2014).

Mississippi Nitrogen Milestone–While progress can be made with existing BMPs for nitrogen reduction, achieving nitrogen goals for the Mississippi River will also require research and development of new BMPs and adjustment to some current BMPs to make them more widely applicable. As a result, a longer timeframe is proposed for nitrogen reduction implementation. In addition, nitrate standards for aquatic life that are currently being considered will require several years for approval and implementation. For nitrogen in the Mississippi River Major Basin, a milestone reduction of 20 percent is established with a target date of 2025. Future milestones for nitrogen reduction will be established based on progress toward the milestone, along with adaptations that integrate new knowledge and needs for continued improvement. The timeframe for achieving the provisional goal is likely between 2035 and 2045 and will be refined after the success of future BMP research is evaluated, and as the Gulf of Mexico Hypoxia Task Force further considers timeframes for reaching goals. For now, a projected target date for achieving the NRS provisional goal of 45 percent reduction is 2040.

Table 2-2 presents the target dates for goals and milestones, which are based on reducing major basin outlet loads. Strategies and target dates for goals and milestones will be adjusted through an adaptive management process.

Table 2-2. Timeline for reaching goals and milestones

Major basin	Pollutant	2010 - 2025	2025 - 2040
Mississippi River (Includes the Cedar, Des Moines, and Missouri Rivers)	Phosphorus	Achieve 45% reduction goal	Work on remaining reduction needs to meet water quality standards
	Nitrogen	Achieve 20% reduction from baseline	Achieve 45% reduction from baseline
Lake Winnipeg [a] (Red River Only)	Phosphorus	Achieve 10% reduction goal	Achieve any additional needed reductions identified through international joint efforts with Canada and in-state water quality standards
	Nitrogen	Achieve 13% reduction goal	
Lake Superior	Phosphorus	Maintain goals, no net increase	
	Nitrogen	Maintain protection	
Statewide Groundwater/ Source Water	Nitrogen	Meet the goals of the 1989 Groundwater Protection Act	

a. Timeline and reduction goals to be revised upon completion of the Red River/Lake Winnipeg strategy.

To track progress toward goals and milestones, a series of action and outcome metrics will be needed to maintain appropriate management and adaptation during the implementation of this *Path to Progress* strategy. The Clean Water Accountability Act of 2013 will guide tracking efforts, and might include programmatic annual or biennial reporting. Chapter 7 describes the NRS's adaptive management process in greater detail and highlights reporting on and evaluating progress toward goals and milestones.

2.2 Watershed Load Reductions

Major basin-wide goals are further refined for waters within Minnesota based on meeting state water quality standards. The specific load reductions that are needed at the basin and major watershed scale will be determined by existing or future TMDLs and as part of watershed planning activities (e.g., watershed restoration and protection strategy [WRAPS] and One Watershed One Plans) that will help to focus nutrient reduction activities at the major watershed level. While the NRS is not assigning required load objectives to the HUC8s within Minnesota, local planning that is consistent with the NRS is a key to achieving the goals for waters at the HUC8 outlets and downstream. The NRS includes two guides to determine appropriate HUC8 outlet nutrient reductions that are considered consistent with the NRS goals and milestones. One guide is based on proportional reductions applied across all major watersheds. Another guide adjusts possible reductions for BMP land suitability. Detailed HUC8 reductions are discussed further in Chapter 6.

For many of the Mississippi River Major Basin major watersheds, downstream impacts mean meeting goals at regional waters such as Lake Pepin or Lake St Croix. In the case of Lake Pepin, upstream major watersheds will need to integrate local and downstream reduction needs of lakes and streams undergoing eutrophication and also consider meeting their part of the reduction needs of Lake Pepin at their outlets. These local and regional goals need to be met in addition to meeting the major basin goals and milestones. Comparing phosphorus percent reductions needed at each local resource to downstream goals is beyond the scope of this document. General comparisons of percent reductions are made in Section 2.3.

Water quality standards are used to do the following:

1. Protect beneficial uses, such as healthy fish, invertebrates (bugs), and plant communities, swimming and other water recreation, and human consumption of fish.
2. Evaluate water monitoring data used to assess the quality of the state's water resources.
3. Identify waters that are polluted, impaired, or in need of additional protection.
4. Set effluent limits and treatment requirements for discharge permits and cleanup activities.
5. Serve as the target for TMDLs designed to reduce pollution from all sources to meet designated uses of a given water resource.

Rush River, Tributary to Minnesota River Photo Credit: MPCA

The federal Clean Water Act (CWA) requires states to designate beneficial uses for all waters and develop water quality standards to protect each use. Water quality standards include the following:

- **Beneficial uses** — identification of how people, aquatic communities, and wildlife use our waters.
- **Numeric standards** — allowable concentrations of specific pollutants in a water body, established to protect the beneficial uses.
- **Narrative standards** — statements of unacceptable conditions in and on the water.
- **Nondegradation** — extra protection for high-quality or unique waters and existing uses.

Explicit in the CWA is the presumption that a water body should attain healthy aquatic life and recreation uses unless proven unachievable. Minnesota's rules provide a framework that broadly protects aquatic life and recreation, as well as the following additional uses: drinking water (domestic consumption), industry, agriculture, navigation, and aesthetic enjoyment. Waters not meeting the minimal aquatic life uses are known as *limited resource value waters*, and might have modified standards, but are still protected for the multiple beneficial uses above.

Water quality standards including the beneficial uses of waters, the numeric and narrative criteria to protect beneficial uses, and antidegradation provisions, are included in Minnesota Rules Chapters 7050 and 7052. These water quality standards serve as the basis for wastewater treatment effluent limits to protect receiving water quality. Federal Regulations and Minnesota Rules Chapter 7053 serve as the basis for minimum wastewater treatment requirements and technology-based effluent limits. This NRS only refers to use of the term *water quality standard* as it applies to the conditions of the water resources.

A water body is impaired if it fails to meet one or more water quality standards. Impaired waters are addressed through TMDL studies that set pollutant reduction goals needed to restore those waters.

Relationship Between State Standards and Downstream Goals

Minnesota's existing and forthcoming eutrophication and aquatic toxicity nitrate water quality standards will lead to a reduced load of nutrients to downstream waters, including the Gulf of Mexico. Minnesota is not proposing additional nutrient water quality standards specifically for meeting suggested goals in the Gulf of Mexico. Where water quality standards are established, the standards development process is an independent effort that is not affected by this strategy's analysis. Restoring and protecting the Gulf of Mexico requires a multi-state approach. Minnesota is committed to participating in setting the appropriate targets and loads necessary to meet the hypoxia objectives in the Gulf of Mexico. Rather than iterate specific targets that must be met within Minnesota in relationship to the Gulf of Mexico, this NRS identifies planning goals for downstream waters and shows how progress can be made in reducing nutrient delivery to downstream waters.

The question sometimes arises, "Once we meet all Minnesota water quality standards, will we also be fully addressing the downstream needs in the Gulf of Mexico and Lake Winnipeg?" In-state reductions of phosphorus will be substantial to meet in-state eutrophication and turbidity/total suspended solids standards, and these reductions might be sufficient to meet downstream targets for the Mississippi River. The reduction requirements to meet future in-state nitrogen aquatic life standards are less certain.

Nitrate and eutrophication water quality standards for protection of Minnesota's water resources are important components of the NRS. Both the existing lake and pending river eutrophication standards in Minnesota include phosphorus, but they do not include nitrogen. Eutrophication standards were promulgated for lakes in 2008 and river eutrophication standards are expected to be finalized in 2014. Nitrate toxicity standards to protect aquatic life in surface waters are under development and expected in the next few years.

Phosphorus loading is often directly related to total suspended solids (TSS) in rivers, especially during moderate to high flow events. Minnesota has existing standards for turbidity and plans to replace the turbidity standards with TSS standards. Current TMDLs for turbidity have a TSS surrogate to facilitate the calculation of load allocations.

Promulgation of numeric water quality standards will provide more tools to protect and restore Minnesota's waters and make progress toward meeting goals to reduce Minnesota's contribution of nutrients into downstream waters such as the Gulf of Mexico and Lake Winnipeg. Minnesota's NRS takes into consideration the state-level programs, efforts, and goals which can aid local governmental units in addressing nutrients and thereby achieve these multipurpose goals.

Addressing the mutually beneficial goals of meeting state standards and protection and downstream goals will strengthen local, regional, state, and federal partnerships. This will in turn bring more resources to solving the problems. Additionally, motivation for adopting nutrient reduction measures could increase when these improvements are viewed as benefiting both local and downstream waters.

Reducing nutrient loads in all watersheds, regardless of localized impairments or eutrophication issues, will be necessary to protect many of our in-state and out-of-state downstream waters. Cumulative reductions, if limited to only those changes needed to meet local TMDLs (e.g., at the HUC8 scale) will often not be sufficient to meet regional and downstream needs (e.g., Lake Pepin, Gulf of Mexico).

The following sections describe the potential broad scale nutrient load reductions that can be expected from the following standards:

- Current Drinking Water Nitrate Standards
- Future Aquatic Life Nitrate Toxicity Standards
- Lake Eutrophication Standards
- River Eutrophication Standards
- Turbidity/TSS Standards

2.2.1 Current Drinking Water Nitrate Standards

Streams

Reductions in nitrate loads to achieve surface water drinking waters standards will be needed in a relatively small portion of Minnesota's surface waters. The 10 mg/l drinking water standard applies to cold-water streams (trout streams) in Minnesota. The overall stream miles covered by the existing standard are a relatively minor portion of the total stream miles in Minnesota (Figure 2-2). Several streams in the karst region of southeast Minnesota need nitrate reductions to meet the 10 mg/l standard.

Few streams have been listed on the State's Impaired Waters List for exceeding the 10 mg/l nitrate threshold (Figure 2-2). In 2011 the Impaired Waters List noted 15 cold-water streams in Minnesota as not meeting the 10 mg/l nitrate water quality standard established to protect potential drinking water supplies. Twelve of the fifteen were in southeastern Minnesota. Because nitrate-impaired watersheds are of limited geographic extent, nitrate reduction measures implemented to meet these standards are not expected to result in substantial annual nitrogen load reductions to the Mississippi River.

Surface waters are important drinking water sources for many Minnesotans, including the citizens of Minneapolis and St. Paul. Roughly 23 percent of Minnesotans get their drinking water from surface water supplies, primarily the Mississippi River. Fortunately, nitrate levels in the Mississippi River near the direct or indirect intakes for these cities are approximately 1 mg/l or less, so reductions are not currently needed to protect human health. However, protection of surface waters for nitrate is still important to ensure safe supplies of drinking water into the future.

Groundwater

Seventy-seven percent of Minnesota's population gets its drinking water from groundwater. Groundwater is an important source of drinking water throughout most of Minnesota, including many areas where aquifers have nitrate that exceeds the drinking water standard of 10 mg/l. Nitrate in groundwater used as a drinking water source is a concern in several areas in Minnesota that are susceptible to contamination (Figure 2-3).

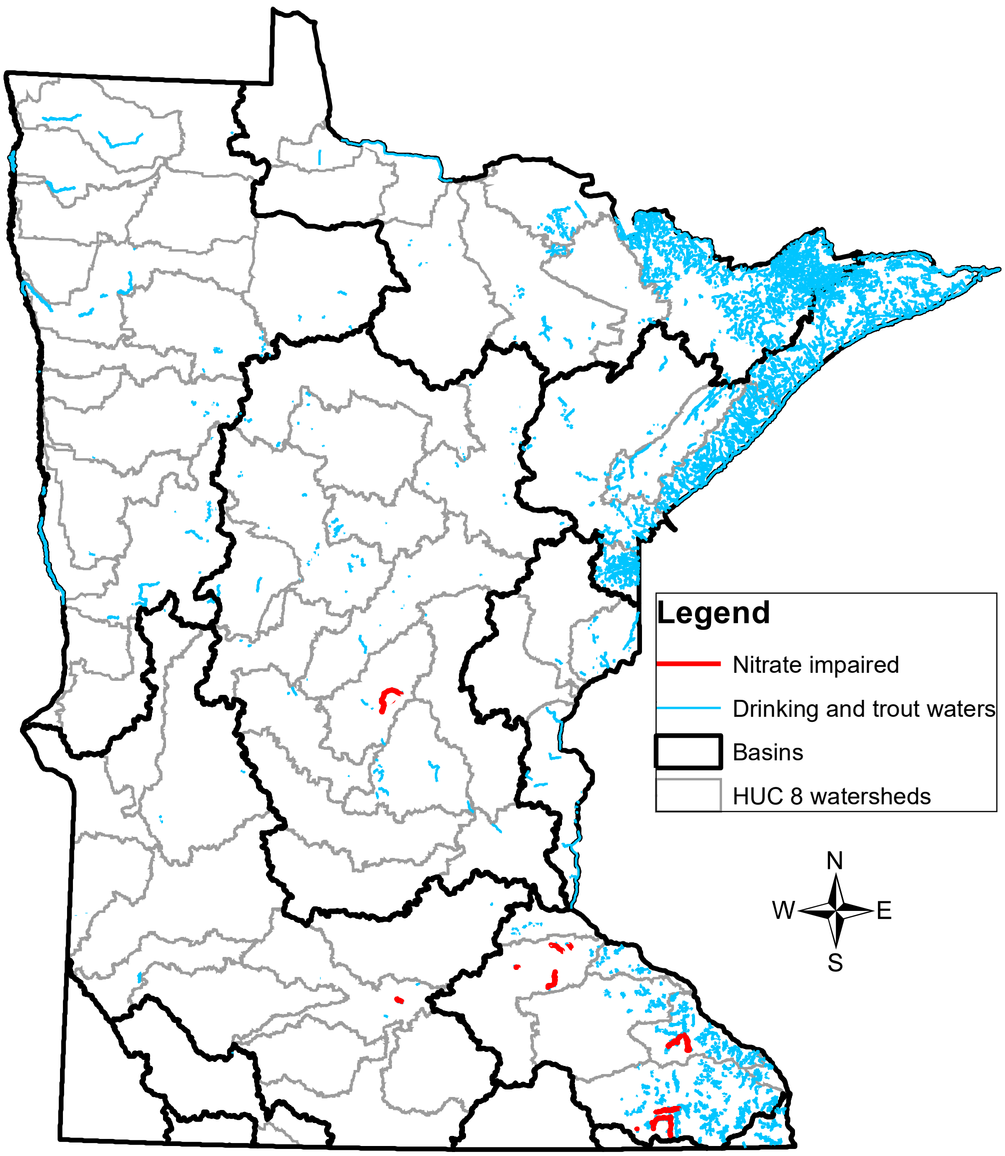


Figure 2-2. River and stream reaches protected as drinking water sources, including cold-water streams. The blue waters have a 10 mg/l nitrate drinking water standard and the red waters have a nitrate impairment based on exceedances of the drinking water standard.

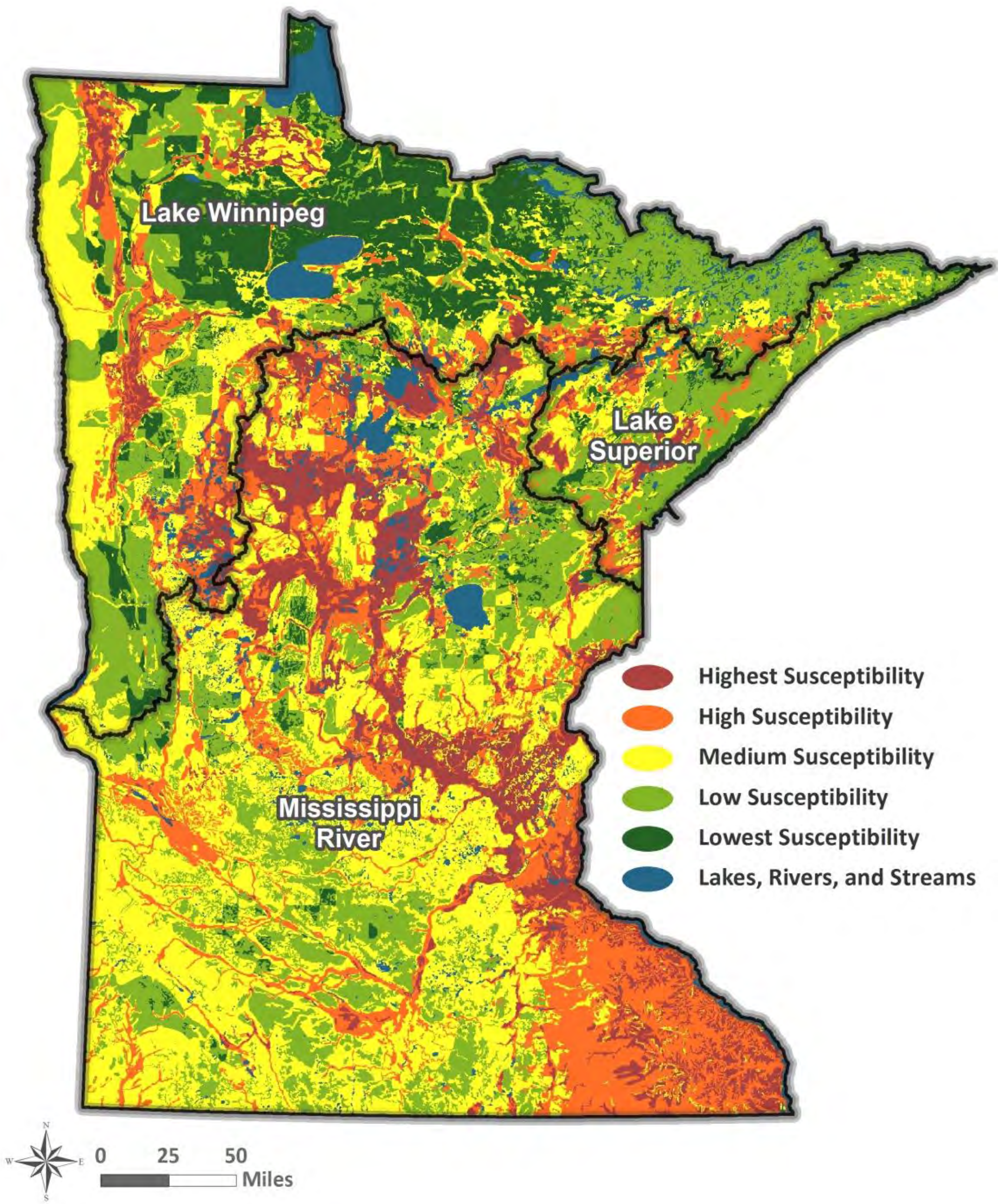


Figure 2-3. Groundwater susceptibility to contamination (MPCA 1989).

2.2.2 Future Aquatic Life Nitrate Toxicity Standard

Toxicity studies to determine safe levels of nitrate for aquatic life will inform the nitrate aquatic life standard rule-making process. Future aquatic life nitrate toxicity standards will be developed based on protecting designated uses of surface waters. The nitrate standard development process is independent from the NRS. Analyses conducted for this strategy will not be used to establish numeric nitrate standards.

Future Aquatic Life Nitrate Toxicity Standard and the NRS

Aquatic life nitrate toxicity standards will be developed based on protecting designated uses of Minnesota's surface waters.

Since ambient stream conditions have higher nitrate levels in the southern part of the state, it is anticipated that a nitrate aquatic life standard might have a larger influence in this area. In the Minnesota River Basin, nitrate levels are generally highest in May and June when flow is elevated. If the state standard for nitrate is exceeded during this high loading period, then reduction strategies to meet state standards will combine with the state-level *Path to Progress* strategy to reduce downstream loads. The potential for downstream reductions due to the forthcoming standard is not known at this time, since the nitrate standard for warm-water streams (Class 2B) has not been established. A standard as low as 5 mg/l nitrate would require reductions in annual loading of roughly 50 percent throughout much of southern Minnesota, whereas a standard greater than 15 mg/l would require only minor reductions over much smaller geographic areas. Much of the northern half of the state would not need to reduce nitrate levels, even for a nitrate standard set as low as 5 mg/l. Wastewater reductions required by a new standard will also depend on the concentration of the standard. Preventing elevated nitrate in watersheds where nitrate is generally low currently should be a point of emphasis in addition to reducing downstream loads.

2.2.3 Lake Eutrophication Standards

With lake eutrophication standards in place and river eutrophication standards are pending final approval, Minnesota is better positioned to evaluate the relationship between in-state phosphorus reduction needs and corresponding downstream phosphorus reduction potential. Both lake and river eutrophication standards in Minnesota include phosphorus, but they do not include nitrogen. Direct comparisons of phosphorus reduction needs for distant downstream water resources can be challenging due to the timing of peak phosphorus loads and temporal responses to phosphorus loading in resources being compared. Fortunately, modeling results exist for high phosphorus-loading areas such as the Minnesota River Basin.

Currently, 520 lakes (including bays of lakes) and reservoirs are listed as impaired due to eutrophication based on the standards in Table 2-3. While most of the drainage areas for lakes are quite small, there are reservoirs, flowages and regional lakes such as Lake Pepin with very large watersheds. These waterbodies have watersheds that receive water from more than 70 percent of Minnesota's land area (Figure 2-4). The spatial, seasonal, and annual distribution of phosphorus loadings within these watersheds is variable. Individual or watershed TMDLs will identify where phosphorus reductions are needed, sometimes at very large scales, within a watershed. Several TMDLs have been initiated or completed for lakes with the largest watersheds (Table 2-4).

The percent reductions for in-lake phosphorus concentration in impaired lakes needed to meet state-applicable standards varies throughout the state. The overall average percent reduction needed is 45 percent from 2002–2011 concentrations for the lakes with sufficient data (Figure 2-4 and Table 2-5). Lake Pepin, a flowage or riverine lake on the Mississippi River, requires an approximate 43 percent phosphorus load reduction compared to pre-2006 conditions to meet a proposed site-specific standard for the lake. Both of these reduction percentages are comparable to the 45 percent phosphorus reduction needed to meet long-term goals established for the Gulf of Mexico. However, the baseline period for measuring progress towards Gulf of Mexico hypoxia goals (1980–1996) is much earlier than the baseline for reductions for Lake Pepin (2006) and other in-state needs. Because progress was made toward achieving the goals after the Gulf of Mexico hypoxia baseline but before the Lake Pepin and other later baselines, there are some needed in-state reductions that are greater than the NRS goal for the Gulf of Mexico.

Table 2-3. Minnesota's lake eutrophication standards. A lake must exceed the cause variable (phosphorus) and one of the response variables chlorophyll-a (chl-a) or transparency (Secchi)) to be considered impaired.

Ecoregion (classification)	Phosphorus (ug/L)	Chl-a (ug/L)	Secchi (m)
NLF – Lake trout lakes	≤12	≤3	≥4.8
NLF – Stream trout lakes	≤20	≤6	≥2.5
NLF – Deep and shallow lakes	≤30	≤9	≥2.0
CHF – Stream trout lakes	≤20	≤6	≥2.5
CHF – Deep lakes	≤40	≤14	≥1.4
CHF – Shallow lakes	≤60	≤20	≥1.0
WCP & NGP – Deep lakes	≤65	≤22	≥0.9
WCP & NGP – Shallow lakes	≤90	≤30	≥0.7

Notes: Northern Lakes and Forest (NLF), Central Hardwood Forest (CHF), Western Cornbelt Plains (WCP) and Northern Glaciated Plains (NGP).

Lake Pepin Photo Credit: Guy Schmickle

Table 2-4. Key eutrophication-impaired lakes with large watersheds in Minnesota (phosphorus reductions)

Lake Pepin (48,634-square-mile watershed)

- Draft phosphorus reductions needed from contributing watersheds to meet standard in Lake Pepin
  - 50% in Minnesota River
  - 20% in St. Croix River
  - 20% in Upper Mississippi River
  - 50% in Cannon River
  - Reduced point source loads
- Hundreds of impaired lakes within Lake Pepin watershed
  - **Lake St. Croix** (contributing watershed: 7,674 square miles)
  - **Lake Byllesby** (contributing watershed: 1,116 square miles)

Lake of the Woods (Contributing watershed: 26,930-square-mile watershed)

- Approximately 10% reduction needed

Lake Zumbro (845-square-mile watershed)

- Approximately 40% reduction needed

South Heron Lake (467-square-mile watershed) and **Talcot Lake** (519-square-mile watershed)

- Approximately 80% reduction needed for both lakes

Table 2-5. Percent phosphorus reduction from average monitored condition (2003–2012) to meet applicable standards for impaired lakes with sufficient data to make calculations

Basin	Minimum	Average	Maximum	Count (number of lakes in dataset)
Cedar	48%	62%	73%	6
Des Moines	23%	47%	81%	13
Lower Mississippi	29%	67%	95%	36
Superior	11%	36%	90%	7
Minnesota	<5%	47%	95%	93
Missouri	20%	49%	73%	5
Red River	<5%	32%	71%	23
Rainy River	<5%	27%	55%	5
St. Croix	<5%	45%	88%	50
Upper Mississippi	<5%	42%	95%	195
Statewide average/total		**45%**		**433**

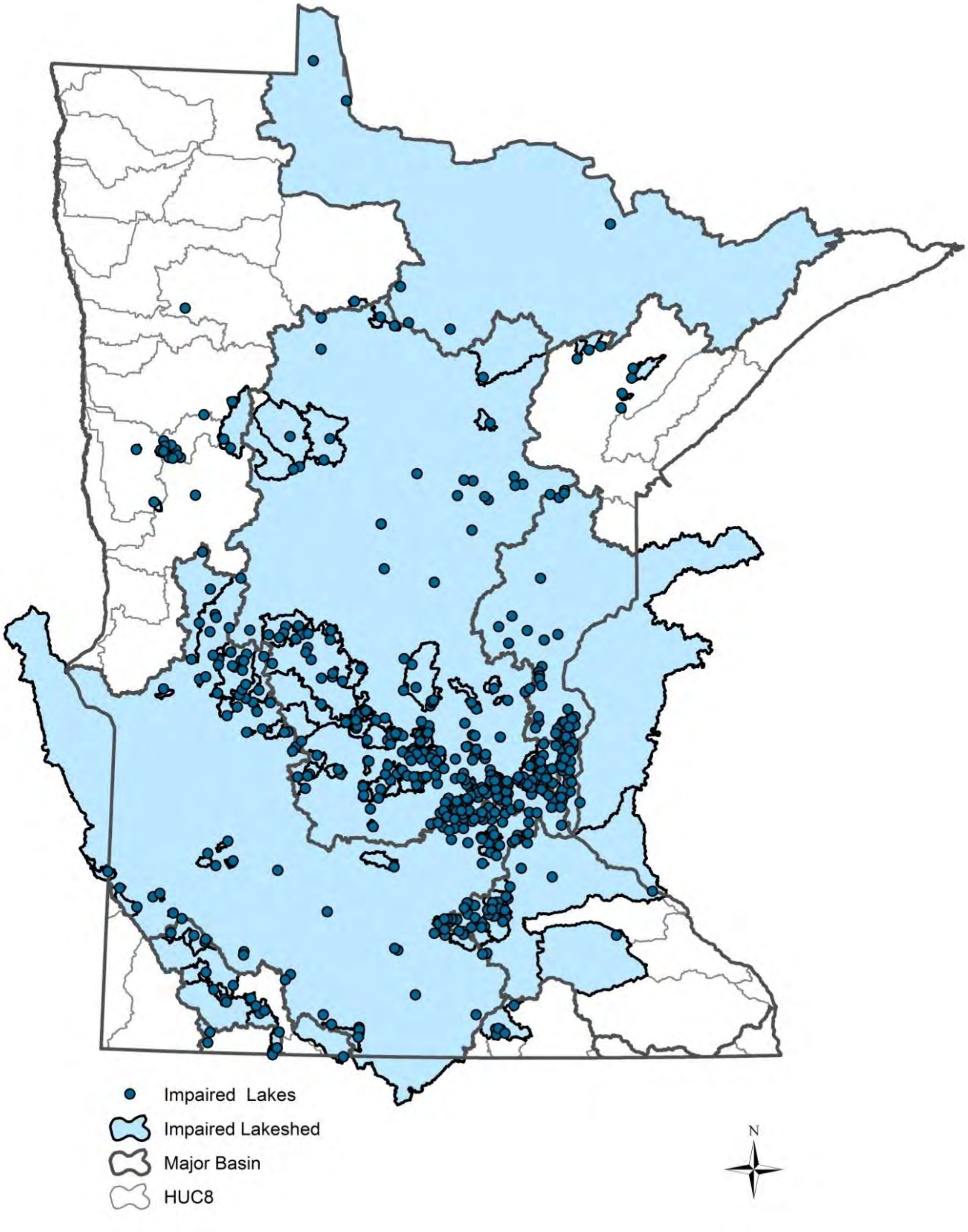


Figure 2-4. Contributing watersheds of lakes and reservoirs impaired due to eutrophication.

Note: Some watersheds of impaired lakes are very small and might not be visible on this graphic.

2.2.4 River Eutrophication Standards

Table 2-6 and Table 2-7 show Minnesota's pending river eutrophication standards, which are pending final approval at the time of this NRS. The phosphorus reductions needed to meet river eutrophication standards are highly variable throughout Minnesota based on data from the past 10 years. Only phosphorus and chlorophyll-a (chl-a) were assessed for the purposes of NRS development. Approximately 38 percent of streams and rivers in the state with 12 or more observations of both phosphorus and chl-a are meeting both the total phosphorus and response variable criteria as included in the pending river eutrophication standards (Figure 2-5). Eighteen percent of rivers with sufficient data exceed both the cause (phosphorus) and response (chl-a) variable of pending river eutrophication standards. These watersheds will need to reduce phosphorus loads to meet standards. The remaining 44 percent of rivers with sufficient data exceed the phosphorus variable of eutrophication standards, but do not exceed the chl-a response variable in the local reach. Some of these river reaches are upstream of other reaches impaired for river eutrophication standards or lake eutrophication standards. For example, the Minnesota River Basin has 21 reaches that are not locally impaired for river eutrophication standards, but would need reductions to meet standards at the Lower Minnesota River at Jordan, Minnesota (projected to be impaired for river eutrophication standards), and Lake Pepin (impaired for lake eutrophication standards). Other river reaches, such as several of those in the Red River of the North Basin, have elevated phosphorus, but specific eutrophication concerns have not been identified, except for the downstream Lake Winnipeg. Reduction targets from Minnesota rivers upstream of Lake Winnipeg are not well refined at this time, so it is difficult to project the load reduction needed.

The phosphorus load reductions from existing conditions needed to meet pending river eutrophication standards in the potentially impaired rivers average 41 percent for potentially impaired rivers (Table 2-8). These reductions are similar to both average phosphorus reductions needed to meet standards for lakes (45 percent) and Mississippi River (Gulf of Mexico) phosphorus reduction goals (45 percent from the baseline). While these phosphorus reduction needs are similar in percentage reduction, the process of crediting implementation activities towards progress will depend on when the actitivy occurred relative to the designated baseline period. All nutrient reduction activities that have occurred since the 1980-1996 baseline time period for the Mississippi River Major Basin goal can be used to show progress towards meeting that goal. However, those same activities may not be credited toward meeting pending river eutrophication standards or TMDLs that have been established more recently (much later than the 1980-96 baseline period for the Gulf of Mexico).

Table 2-6. Pending river eutrophication standards by river nutrient region for Minnesota

Region	Causal variable (nutrient)	Response variables		
	Phosphorus µg/L	Chlorophyll-a µg/L	Dissolved oxygen flux mg/l	5-day biochemical oxygen demand mg/l
North	≤50	≤7	≤3.0	≤1.5
Central	≤100	≤18	≤3.5	≤2.0
South	≤150	≤35	≤4.5	≤3.0

Table 2-7. Draft criteria for mainstem rivers, Mississippi River pools, and Lake Pepin. Concentrations expressed as summer averages. Assumes aquatic recreational and aquatic life uses are maintained if phosphorus and chlorophyll-a are at or below criteria levels.

River/Pool	Site	Data source	Phosphorus µg/l	Chlorophyll-a µg/l
Rivers				
Mississippi River at Anoka[1]	UM-872	MCES	100	18
Lake St. Croix[3]	SC-0.3	MCES	40	14
Minnesota River at Jordan[1]	MI-39	MCES	150	35
Pools and Lake Pepin				
Pool 1[2]	UM-847	MCES	100	35
Pool 2[4]	UM-815	MCES	125	35
Pool 3[4]	UM-796	MCES	100	35
Pepin (Pool 4)[5]	Four fixed sites	LTRMP	100	28
Pools 5-8[6]	Near-dam	LTRMP	100	35

Notes: MCES - Metropolitan Council Environmental Services; LTRMP - Long-Term River Monitoring Program
1. River eutrophication criteria-based. Based on modeling UM-872 and MI-3.5 criteria will meet Pepin requirements.
2. Minimize frequency of severe blooms. Upstream criteria provide additional protection for Pool 1.
3. Minnesota lake eutrophication criteria-based. Based on modeling St. Croix outlet (SC-0.3) would meet Pepin requirements.
4. Minimize frequency of severe blooms and meet Pepin requirements.
5. Phosphorus consistent with Wisconsin standard. Lake Pepin criteria assessed based on mean from four monitoring sites.
6. Minimize frequency of severe blooms; upstream phosphorus requirements benefit lower pools. Wisconsin standard of100 µg/L could apply to Pools 5—8.

Table 2-8. Preliminary analysis of all available phosphorus and chl-a levels in river and stream reaches in Minnesota compared to pending river eutrophication standards. Monitoring data are from 2003–2012. Percent reduction is the average reduction to meet phosphorus variable of river eutrophication standards.

	Elevated phosphorus and chlorophyll-a		Meets standard		Elevated phosphorus only		Total stream reaches
Basin	Count	% phosphorus reduction	Count	% phosphorus reduction	Count	% phosphorus reduction	
Cedar	3	52%	2	NA	3 [a]	42%	8
Des Moines	2	39%	--	--	1 [a]	91%	3
Lower Mississippi	5	63%	9	NA	29 [a]	52%	43
Minnesota	20	35%	3	NA	21 [b]	42% [b]	44
Missouri River	--	--	--	--	2 [a]	42%	2
Rainy River	--	--	10	NA	8 [b]	12% [b]	18
Red River	2	62%	22	NA	18 [a]	36%	42
St. Croix	2	19%	2	NA	1 [b]	9% [b]	5
Superior	--	--	9	NA	--	--	9
Upper Mississippi	14	42%	43	NA	34 [b]	37% [b]	91
Grand Total	**48**	**41%**	**100**	**NA**	**117**	**40%**	**265**

Note – This chart is only for streams with sufficient phosphorus and chl-a data (minimum 12 observations each).

a. Downstream resources might be beyond state boundaries.

b. Stream reaches with elevated phosphorus will only need to reduce if a downstream water exceeds response variable.

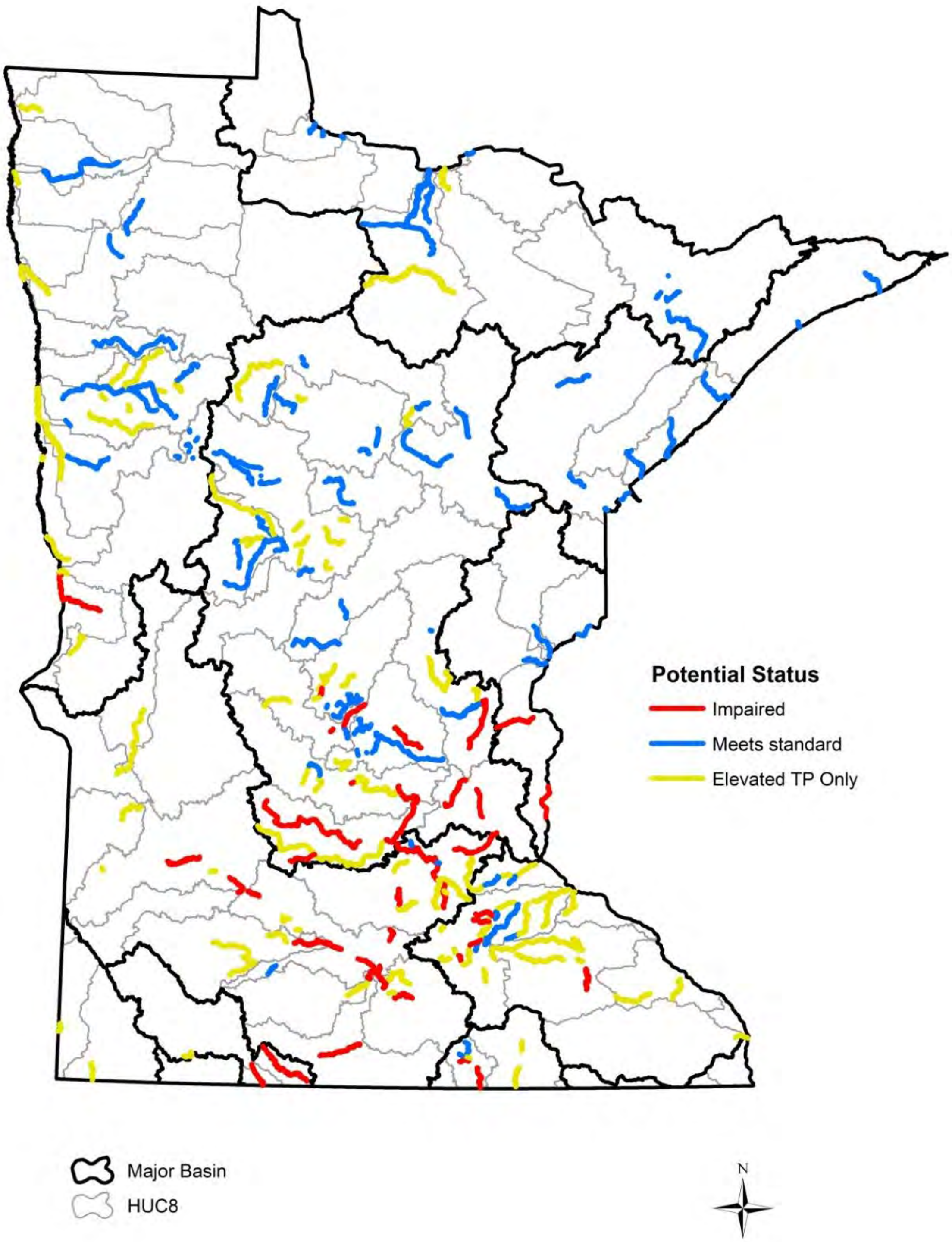


Figure 2-5. Projected status of assessed rivers potentially impaired by the pending river eutrophication standards (red) and rivers that exceed the phosphorus part of the standard, but do not also exceed the chl-a response variable (yellow).

2.2.5 Turbidity/TSS Standards

Phosphorus is typically attached to suspended particles in river systems. Minnesota has many streams and rivers listed on the Impaired Waters List due to excess turbidity (Figure 2-6). As previously noted, TSS is often used as a surrogate for turbidity to facilitate load calcuations for TMDLs. In some cases, high turbidity has resulted in diminished light penetration, making this a co-limiting factor for eutrophication. Increasing light penetration could increase the effect of phosphorus on eutrophication. It should be noted that suspended algae (measured via chlorophyll-a) need longer residence times and lower flow/velocity conditions to develop higher levels. Even though the TSS levels in many of the state's rivers are eleveated during high flows, TSS often drops during lower flows and algae levels can increase dramatically during low flows. The Minnesota River is an excellent example of a river with high TSS levels during higher flows and high algae levels during lower flows.

Reducing turbidity/TSS could result in lower phosphorus levels in streams, especially during high flows. Reductions in turbidity/TSS will be an important driver for phosphorus reductions in areas where response variables for lake and river eutrophication standards are not exceeded. For instance, there is limited algal growth in portions of the mainstem of the Red River of the North. Thus, nutrient reductions might not be needed for meeting lake or river eutrophication standards. In this river, reductions for turbidity and TSS may be the main driver for phosphorus reductions, along with eutrophication considerations for Lake Winnipeg.

The turbidity standard will also be important in rivers exceeding the pending river eutrophication standards, since river eutrophication standards only apply from June through September. There is substantial loading of phosphorus associated with TSS during March through May. This timeframe is extremely important to downstream loading and it can be the driver of internal loading in some downstream lakes. The proposed TSS standards will apply from April to September. The current turbidity standard applies to the entire year.

MPCA has extensive watershed modeling results for the Minnesota River Basin to demonstrate the impact of TSS (surrogate for turbidity) reductions on phosphorus concentration and loads. Multiple scenarios of various combinations of BMPs were simulated to determine if a given set of BMPs could meet TSS standards throughout the Minnesota River Basin. Results show that a 27 percent reduction in annual phosphorus load will be achieved in the lower Minnesota River if an aggressive set of sediment reduction BMPs were adopted throughout the Minnesota River Basin. Further reduction of TSS would still be required, and could be achieved through stabilization of streambanks, streambeds, and bluffs. Therefore, meeting the TSS standard will likely achieve a more than a 27 percent reduction in phosphorus.

In summary, reductions to meet turbidity and future TSS standards will result in reduced loads of phosphorus during moderate to high flows in rivers. Therefore phosphorus reductions will be realized through TSS reductions in streams which do not exceed river eutrophication standards, but which have elevated phosphorus and TSS. TSS and associated phosphorus reductions will be most important for downstream resources such as Lake Pepin and the Gulf of Mexico. Lake and river eutrophication standards will be important for limiting phosphorus at average to low flows during the summer, when algal production in rivers and lakes is most problematic.

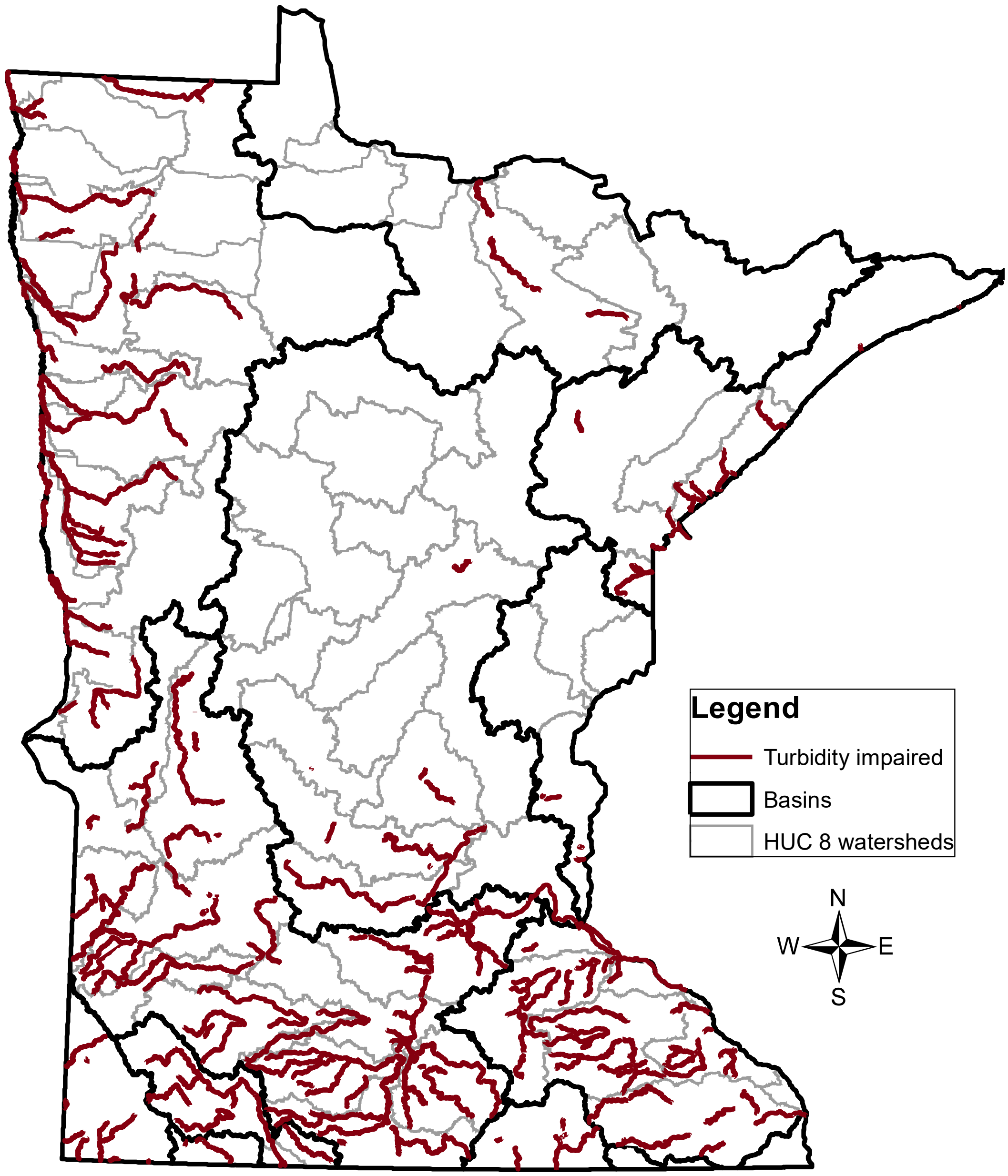


Figure 2-6. Turbidity-impaired streams included on 2012 Impaired Waters List.

The Lower Minnesota River Dissolved Oxygen TMDL

In addition to impaired lakes, streams and rivers can also be impaired due to nutrients, even without river eutrophication standards. For example, a river can be impaired due to low dissolved oxygen (DO) and a TMDL is developed to reduce phosphorus and achieve the DO criterion. The largest and most relevant example in the state is the Minnesota River.

The Lower Minnesota River Dissolved Oxygen TMDL established a phosphorus loading capacity during the 61-day critical low flow period (MPCA 2004). This loading capacity represents a reduction of 29,751 pounds from the "current day" loading estimate of 75,620 pounds (1988 critical low flow period with 1999–2000 land use and point source loading), which is a 39 percent reduction in load within this time period. The Dissolved Oxygen TMDL has been very successful for reducing wastewater point source loads, which are a major factor during low flow periods.

2.3 Basin Scale Comparison of Local and Downstream Reductions Needs

Eutrophication and TSS impairments are a common issue in central and southern Minnesota (Figure 2-7). In this area of the state, both lakes and rivers need improvement. The north-central and northeastern areas of the state need less reduction of phosphorus. Moderate reductions are necessary in the northern portions of the Lake St. Croix and Lake Pepin watersheds. The Lake of the Woods watershed will also require some targeted reductions. Far fewer rivers and lakes in this area of the state have elevated phosphorus compared to proposed and existing standards.

As the following sections describe, a focus on state phosphorus-related standards and protection for major rivers and regional lakes and reservoirs will likely result in long-term, out-of-state downstream needs being met. Basin and major watershed planning activities (e.g., WRAPS and comprehensive watershed management plans) will help focus phosphorus reduction activities at the smaller watershed level. For nitrogen, the NRS focuses on downstream waters, since at this time existing local surface and groundwater standards will not sufficiently reduce nitrogen loads going to out-of-state waters. The following section discusses the downstream effects of meeting existing lake standards and proposed river standards in each individual basin.

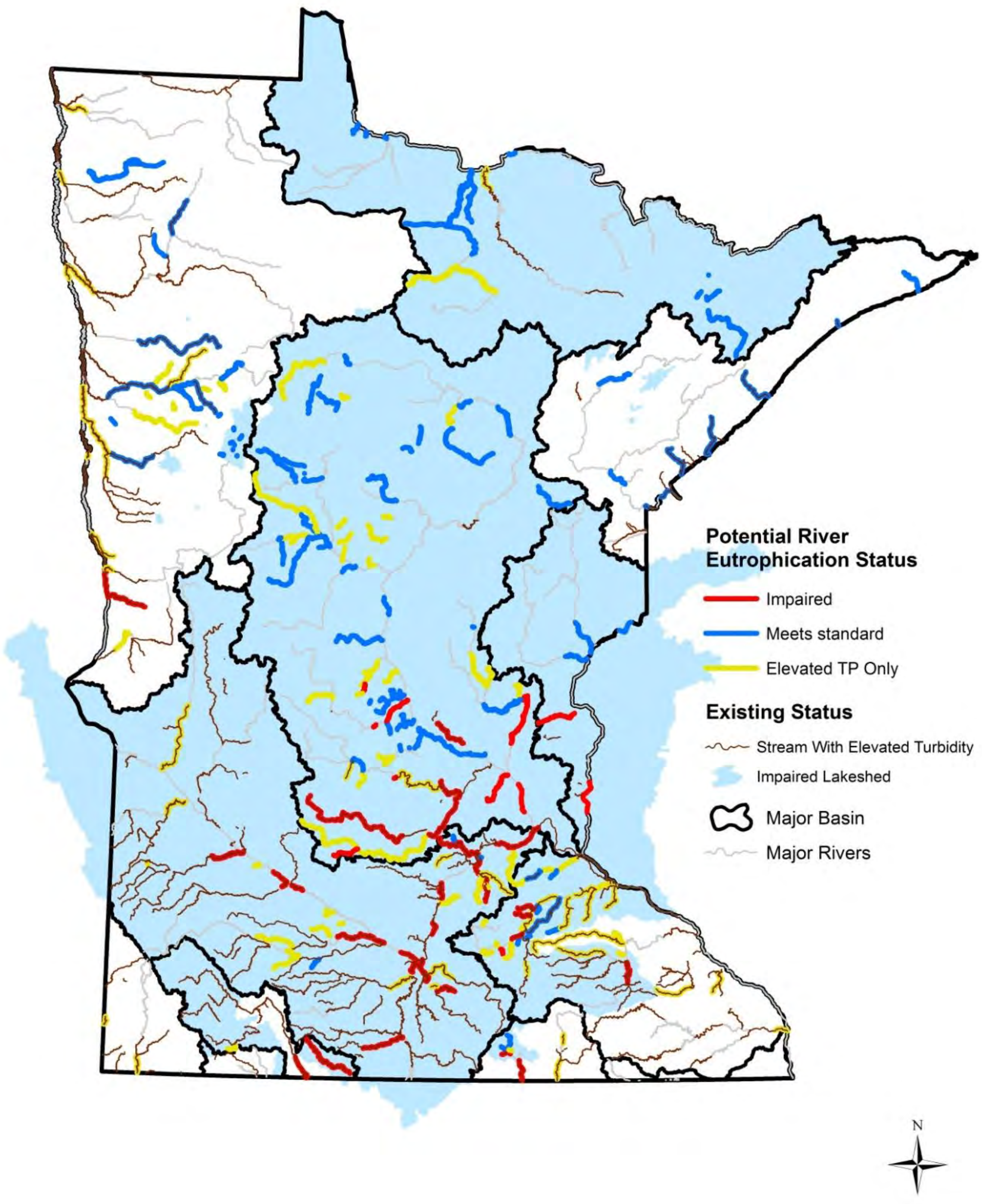


Figure 2-7. Summary of turbidity-impaired streams, streams with potential eutrophication impairments, and watersheds of eutrophication-impaired lakes in Minnesota. Note: Not all water resources in Minnesota have sufficient data to assess for eutrophication and turbidity.

2.3.1 Mississippi River/Gulf of Mexico Major Basin

Upper Mississippi River

The Upper Mississippi River Basin transitions from watersheds with limited eutrophication issues in the northern portion of the basin to watersheds with more eutrophication issues in the southern portion of the basin. Unlike the lower Minnesota River, which clearly exceeds the pending river eutrophication standards, the Mississippi River at Anoka is essentially at the pending river eutrophication standards. Therefore, the downstream driver for phosphorus reductions is Lake Pepin, which is outside the basin. Pool 2 of the Mississippi River is close to exceeding the proposed chl-a threshold. Key major watersheds for phosphorus reductions include the South Fork Crow River, North Fork Crow River, and Sauk River. As with the Minnesota River, management to meet phosphorus targets at the major watershed outlets could be an approach to meeting the target for the downstream resource.

Portions of this basin have high densities of lakes. This basin has the most eutrophication-impaired lakes in the state, including key lakes such as the Horseshoe Chain (near the outlet of Sauk River watershed), Big Sandy Lake, and several others. Management in the watersheds of these lakes will be important to both local and downstream eutrophication issues. The average percent reduction needed for eutrophication-impaired lakes in the basin is 42 percent.

Minnesota River

Forty-four reaches in the Minnesota River Basin had sufficient data to determine if a given stream reach would exceed the pending river eutrophication standards. These reaches included the majority of the major watershed outlets in the Minnesota River Basin. Of the 44 reaches in the Minnesota River Basin, 20 have chl-a levels above the pending river eutrophication standards. The average reduction to meet the local eutrophication standard (phosphorus equals 150 ug/L) for these waters is 35 percent. There are 21 additional reaches with elevated phosphorus, but these reaches do not exceed the chl-a variable of the pending river eutrophication standards. If it is assumed that these reaches need reductions to meet the local TP standard to protect downstream waters despite the lack of local response, then these reaches would need to be reduced by 44 percent. Of the 44 reaches, only 3 actually meet both the phosphorus variable and response variables of the pending river eutrophication standards. The downstream reach of the Minnesota River at Jordan and Lake Pepin have total phosphors (nutrient/cause variable) and chl-a (response/stressor) levels above the pending river eutrophication standards and existing lake standards, respectively, and therefore there are downstream needs to reduce phosphorus from the entire Minnesota River Basin. A proposed approach to managing phosphorus in the Minnesota River Basin would be to meet the 150 µg/l phosphorus target at the major watershed outlets (HUC8s) including the Lower Minnesota River major watershed. There are some additional considerations for the metropolitan portion of the Minnesota River such as the low dissolved oxygen TMDL and Lake Pepin, but these have/will be addressed in a basin-wide TMDL , such as the Lake Pepin TMDL.

Currently completed assessments show that there are also 112 lakes in the Minnesota River Basin that need in-lake concentrations reduced by an average of 47 percent from average phosphorus concentration monitored from 2003–2012 for each individual lake. While the number of lakes identified with phosphorus-based impairments is likely to increase, the watersheds for the smaller lakes are relatively small themselves, so the impact of meeting lake standards in the basin will not be nearly as large as meeting river standards. Reducing loads to lakes will be important to local watershed efforts and provide some load reductions at the major watershed scale.

Reductions needed throughout the Minnesota River Basin for turbidity/TSS impairments, lake eutrophication standards, and river eutrophication standards will conservatively result in loading reductions from 30 to 50 percent. Annual phosphorus loads in the lower Minnesota River are projected to be reduced by greater than 27 percent from turbidity BMPs based on modeling runs. Improvements in wastewater point source loads have occurred throughout the basin due to a low DO TMDL, along with additional requirements for Lake Pepin. Key major watersheds that contribute to downstream loading include the Greater Blue Earth River and Lower Minnesota River. These major watersheds have greater water and phosphorus yields than the western portion of basin due to higher levels of precipitation.

Lower Mississippi River

There have been fewer studies of the Mississippi River in Minnesota downstream of Lake Pepin (Lower Mississippi River). Wisconsin has a 100 µg/l phosphorus standard for the Mississippi River downstream of Lake Pepin and Minnesota has proposed eutrophication standards of 100 µg/l phosphorus and 35 µg/l chl-a. The Lower Mississippi River currently exceeds 100 µg/l phosphorus, but it is uncertain if the chl-a target is exceeded at any of the Dams 5–-8. The water coming out of Lake Pepin plays a critical role in driving the concentration of the Lower Mississippi River, since it is approximately 74 percent of the drainage area of the Mississippi River at Lock and Dam 8. The phosphorus standards for the Wisconsin tributaries to the Lower Mississippi River are 100 µg/l phosphorus for larger rivers such as the Chippewa River and 75 µg/l for wadeable streams. Minnesota has proposed eutrophication standards of 100 µg/l phosphorus and 18 µg/l chl-a for the tributaries of the Lower Mississippi River.

Turbidity impairments are prevalent in the Lower Mississippi Basin. A large portion of the basin is in the driftless area ecoregion, which has steeper slopes that are vulnerable to erosion. Management of turbidity/TSS impairments throughout the basin will be critical to reducing phosphorus during high flows. Local turbidity protection will result in downstream phosphorus load reductions.

Key lakes in the Lower Mississippi Basin include Lake Pepin, Lake Byllesby in the Cannon River watershed, and Lake Zumbro. Reductions to meet lake eutrophication standards, along with reductions to meet river standards in Wisconsin will likely result in achieving the 100 µg/l phosphorus standard in the Lower Mississippi. The Root River watershed is one watershed that might not exceed the response variable of river eutrophication standards, and thus local reductions will not be necessary. Some streams in the Root River watershed do not exceed the phosphorus variable of the river eutrophication standards during summer. High levels of phosphorus in the Root River watershed are mostly linked to excess turbidity so reducing phosphorus will be linked to meeting the turbidity standard.

Cedar, Des Moines, and Missouri Rivers

The Cedar River Basin has both lake and river eutrophication drivers. Reductions needed in the Shell Rock River range from 36 to 69 percent. This is also one of the few basins where wastewater point sources of phosphorus have not been reduced in the past 10 years. The cities of Albert Lea and Austin represent large phosphorus sources in this basin.

The Des Moines Basin has both lake and river eutrophication drivers. Meeting all applicable lake eutrophication standards, river eutrophication standards, and turbidity/TSS standards will result in substantial reductions of downstream phosphorus loads. Key lakes draining over half of the basin are Heron Lake and Talcot Lake. Both of these lakes need 80 percent phosphorus reductions from current levels to meet lake eutrophication standards. Two potentially impaired river reaches will need a 39 percent reduction to meet river eutrophication standards. One of these river reaches is the outlet of the Des Moines River Basin.

Turbidity/TSS reductions will be the main driver in the Missouri River Basin to reduce downstream phosphorus loads. Rivers and streams in the basin are relatively small, which limits production of suspended algae.

St. Croix River

Lake St. Croix is located at the outlet of this basin. A TMDL has been completed for the lake, which requires a 20 percent reduction of phosphorus from levels observed over the past 10 years. This reduction, along with other proposed reductions in other basins, is sufficient to meet the reduction needed for the draft Lake Pepin TMDL. Reductions in select watersheds in the southern portion of the St. Croix River Basin to meet local lake and river eutrophication standards will be key to meeting standards in Lake St. Croix and Lake Pepin. The northern portion of the basin has fewer eutrophication and TSS impairments. Any slight reductions needed in the northern portion of the basin will have limited impact on downstream loading.

St. Croix River Photo Credit: MPCA

2.3.2 Winnipeg Major Basin

Red River

Phosphorus is high in the Red River Basin, but there are relatively few local impacts. There are some lake and river eutrophication issues in the headwaters of the basin. Once phosphorus loads enter the mainstem of the Red River, turbidity limits algal production. Reductions in TSS should help dramatically lower phosphorus loads, benefitting downstream Lake Winnipeg. Downstream goals for Minnesota that are needed to protect Lake Winnipeg are expected to change in the near future.

Rainy River

The Rainy River Basin generally meets the applicable lake and river eutrophication standards. The main driver for phosphorus reductions in this basin is Lake of the Woods, which is impaired due to eutrophication. None of the river reaches with adequate data exceed the chl-a variable of the pending river eutrophication standards. River reaches that exceed the proposed phosphorus variable of river eutrophication standards in the basin would need an average reduction of 12 percent. The Lake of the Woods TMDL will ultimately determine the best approach to reducing phosphorus loading in the basin.

2.3.3 Lake Superior Major Basin

Rivers and lakes in the Lake Superior Major Basin are also in relatively good condition concerning phosphorus levels. The phosphorus and nitrogen levels in Lake Superior are low, and the goal is to maintain these low levels while vigilantly monitoring nutrient source contributions as well as river and lake trends.

Chapter 3

Water Quality Evaluation

Water quality in the three major basins was evaluated to assess the sources of nutrients and to support implementation planning. This chapter begins with a discussion of factors that affect nutrient loads. The chapter continues with discussions of sources of nutrients, nutrients in groundwater, and nutrient concentration and load trends in major basins.

3.1 Environmental and Land Use Factors Affecting Nutrient Loading

Several factors influence nutrient loading to waters. Some key factors include climate, land use and management. Long-term trends reflect changes in these factors over time. An understanding of these factors provides important perspective on the causes and solutions to reduce loadings and interpreting observed changes in loading over time. The following sections briefly review statewide information on changes in climate, urban development, and agricultural practices, with a focus on large changes within the major basins.

3.1.1 Climate

Climate and its impact on precipitation, runoff, and streamflow plays an important role in evaluating pollutant loadings. A snapshot of water quality data from a certain time period may suggest a change in loading is due to a change in sources while examination of precipitation over that same period may show this trend to be due to an increased level of precipitation and streamflow. Figure 3-1 displays annual precipitation averaged for the entire state of Minnesota for the period 1890 to 2010. It suggests the following regarding the different baseline periods for each of the major basins:

- Lake Superior (1979): wet year (near the 75th percentile)
- Lake Winnipeg (2003): dry year (below the 25th percentile)
- Mississippi River (1980 to 1996): four dry years, five relatively average years, and eight wet years suggesting that, overall, this period may have been somewhat wetter than the long-term average

These findings should be kept in mind as one compares future years to the loads for these time periods, and is one reason that flow-adjusted approaches (i.e., flow weighted mean concentrations [FWMCs]) are proposed for tracking progress over time.

In addition to the natural impact that weather has on year-to-year variability in pollutant loads, the long-term climate records show higher precipitation in recent decades as compared to historical precipitation. In Minnesota, the last three decades have been the wettest in more than 100 years and the annual number of large storm events has doubled in the past century. Since the *Minnesota Nutrient Reduction Strategy* (NRS) was developed with data from the past three decades, the river flows and precipitation evaluations in the strategy reflect the more recent climate situation rather than the pre-1980 historical climate. Trends in nutrient loading for the last century are difficult to assess except for those observed in sediment core studies such as those on Lake Pepin (Engstrom et al. 2009). Reducing loads and discerning trends in the face of such large-scale changes are important challenges to be addressed as we evaluate environmental progress of this NRS and future iterations of the NRS. It should be noted that current flows are similar to or less than baseline flows (the flows recorded during the goal setting periods) in all three major basins. Predicting future trends in flow is beyond the scope of the NRS, but it is an active area of research and debate in Minnesota.

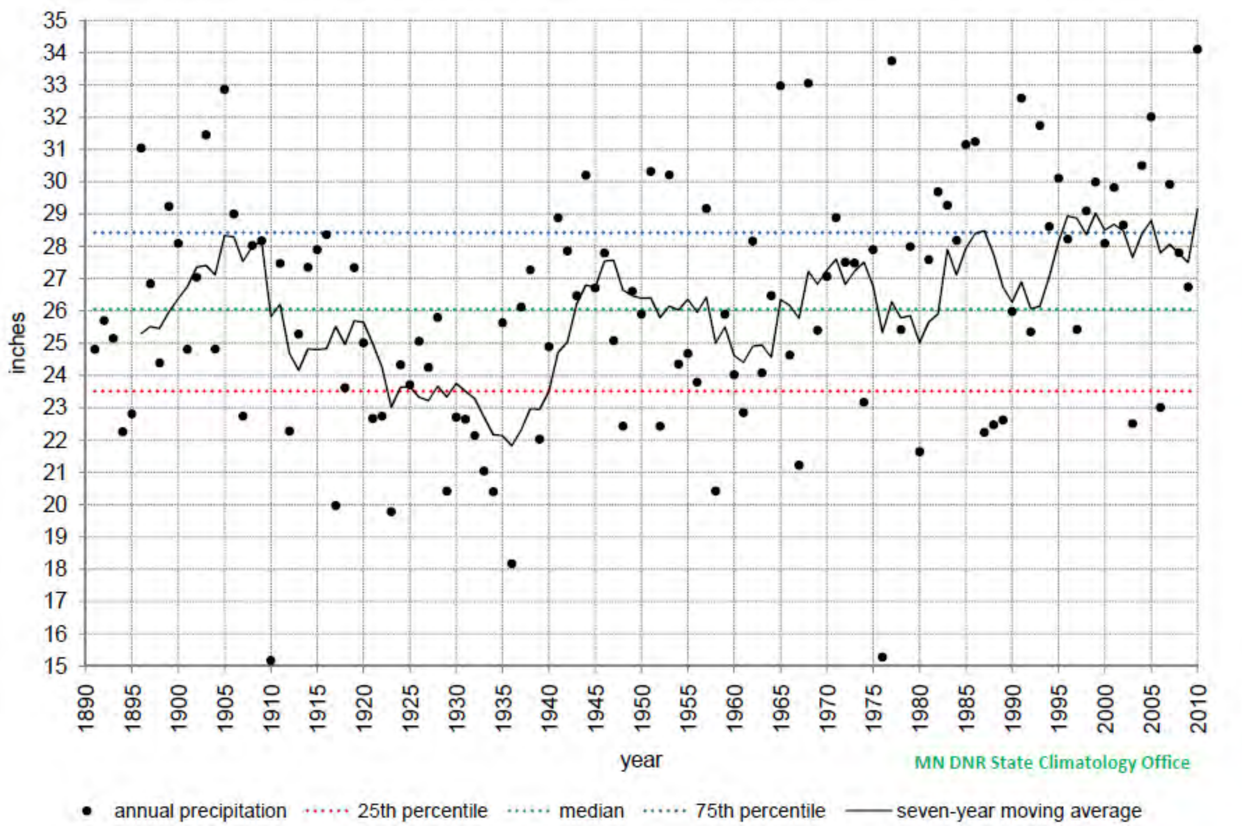


Figure 3-1. Minnesota state-averaged annual precipitation (Minnesota Climatology Working Group 2013).

3.1.2 Urban Development

Urban areas within Minnesota have grown over the past decade as the statewide population has increased from 4.9 million in the year 2000 to 5.3 million in the year 2010 (U.S. Census Bureau 2013). According to the National Land Cover Database, urban area in the state has increased from about 5.3 percent in 2001 to 5.4 percent in 2006 (the most recent year for which statewide data are available); similarly, impervious area has increased from about 1.0 to 1.1 percent. Figure 3-2 displays the population change by county between the 2000 and 2010 censuses. The greatest population increases by county occurred within the Mississippi River Major Basin, and all three major basins have experienced a consolidation in population from rural to more urban areas. The growth in land under urban development has increased the amount of stormwater runoff produced, although these increases are relatively small at the statewide level and have been mitigated, in part, by stormwater management and other nutrient reduction activities. Trends in wastewater flows are variable and have been reduced in some areas with improved collection systems that limit inflow and infiltration from groundwater into collection systems. A dramatic reduction in the statewide load of total phosphorus from wastewater has been achieved in the past 14 years (see Chapter 5). Loads of total nitrogen from wastewater have remained relatively stable.

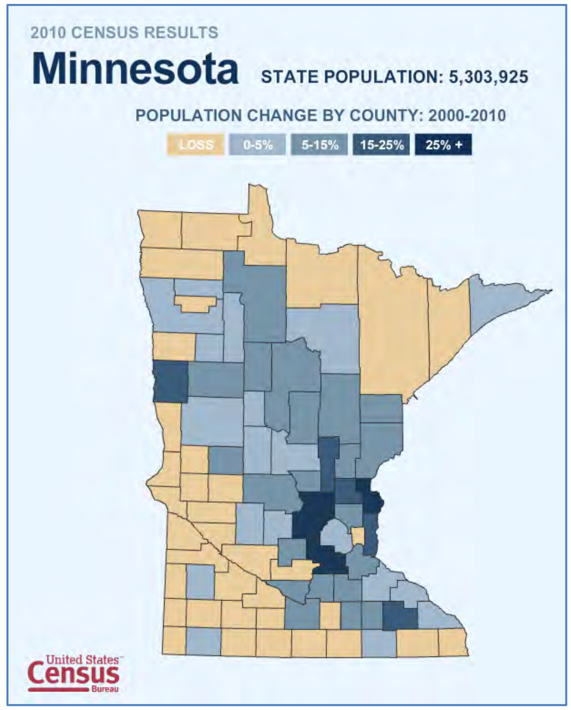


Figure 3-2. Population increase in Minnesota by county (Minnesota State Demographic Center 2013).

3.1.3 Agricultural Practices

Agricultural activities are expected to have a strong influence on nutrient loading in the Lake Winnipeg and Mississippi River major basins and less of an impact in the Lake Superior Major Basin. Across the entire state, about 50 percent of Minnesota's land is used for agriculture (USDA 2011). The greatest number of agricultural acres are used for our two most produced crops, corn and soybeans, although Minnesota is also known for its production of sugar beets, wheat, potatoes, dry beans, and other specialty crops. Agricultural practices in Minnesota began with corn and wheat production in the mid-1800s, and then wheat and small grain production began to shift to soybeans at the beginning of the 20th century (MDA 2008). Crop demands associated with World War I and World War II, as well as the

Great Depression and Dust Bowl, had significant impacts on Minnesota row crops; however, since the 1950s Minnesota's most valuable crops have been corn, soybeans, and wheat (MDA 2008).

Fluctuations and some marked changes in agricultural activities have occurred over the past few decades. From 1974 to 2002, the number of hogs and poultry raised within the state generally increased, while the number of cattle decreased. Livestock on farms has gone through a period of consolidation resulting in fewer livestock farms with larger livestock enterprises. Table 3-1 provides select historical acreages from the *Census of Agriculture* (USDA 2012b). Land enrolled in the Conservation Reserve, Wetlands Reserve, Farmable Wetlands, or Conservation Reserve Enhancement Programs dropped considerably between 2007 and 2012.

Table 3-1. Historical acreages from the Agricultural Census, Minnesota (USDA 2012b). See *http://agcensus.usda.gov/Publications/2012*.

Sector	Millions of acres			
	1997	2002	2007	2012
Land in farms	27.6	27.5	26.9	26.0
Harvested cropland	19.8	19.4	19.3	19.8
Permanent pasture	1.0	1.2	1.5	1.3
All pasture	2.9	2.6	2.7	1.9
Woodland used as pasture	0.8	0.6	0.5	0.4
Land enrolled in Conservation Reserve, Wetlands Reserve, Farmable Wetlands, or Conservation Reserve Enhancement Program	1.5	1.6	1.9	1.3

Recent Agricultural and Rural Land Changes

While statewide agricultural statistics capture overall trends, valuable insight can also be gained using satellite imagery for land use and land cover. Note, however, that statewide and large scale data summaries do not always reflect the changes occurring regionally or at the watershed level.

A shift from grassland to corn/soybean production is evident in a comparison of Cropland Data Layer from the U.S. Department of Agriculture (USDA) National Agricultural Statistics Service from 2006 to 2011 (Wright and Wimberly 2013). Grassland was converted to corn/soybean at a rate of 1.0 percent to 5.4 percent annually from 2006 through 2011 in the Western Corn Belt, which includes North Dakota, South Dakota, Nebraska, Iowa, and Minnesota; the conversion occurred as commodity prices and biofuel subsidies incentivized the switch from native grasslands and pasture to cultivated crops

(Wright and Wimberly 2013). For example, incentives for ethanol production began in the 1980s through the Minnesota Ethanol Program (MDA 2012).

The net loss of grassland to corn/soybean production in Minnesota from 2006 to 2011 was approximately 196,000 acres (Wright and Wimberly 2013). A summary of Conservation Reserve Program (CRP) data between 2007 and 2013 is available from the Farm Service Agency (FSA) (*CRP summary data*) and is summarized in Figure 3-3 and Figure 3-4. Statewide enrollment has been declining; the majority of CRP acres lost during 2012 and 2013 were in the Red River Valley. An additional 700,000 acres are expected to expire between 2014 and 2018. While the exact fates of the CRP-expired lands are unknown (i.e. converted to cropland or developed lands), based on the recent grassland-to-corn/soybean conversion rates it is likely that many CRP-expired lands will be converted into agricultural production. This has important implications for nutrient loading; since in general, cropland generates larger loads of phosphorus and nitrogen than grassland.

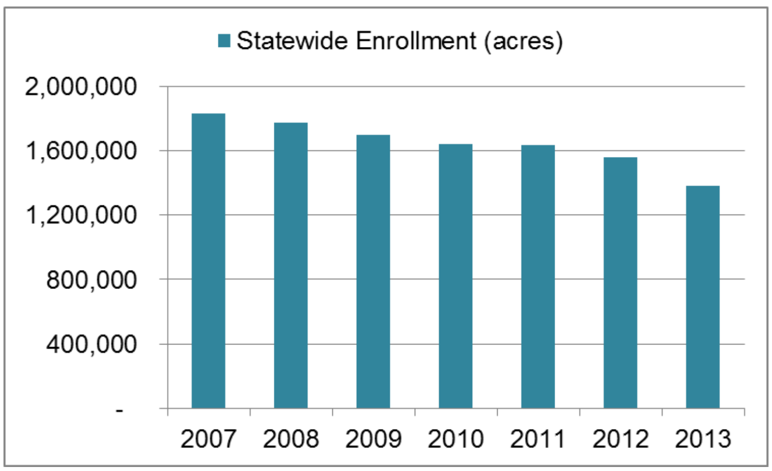


Figure 3-3. Total statewide enrollment in CRP.

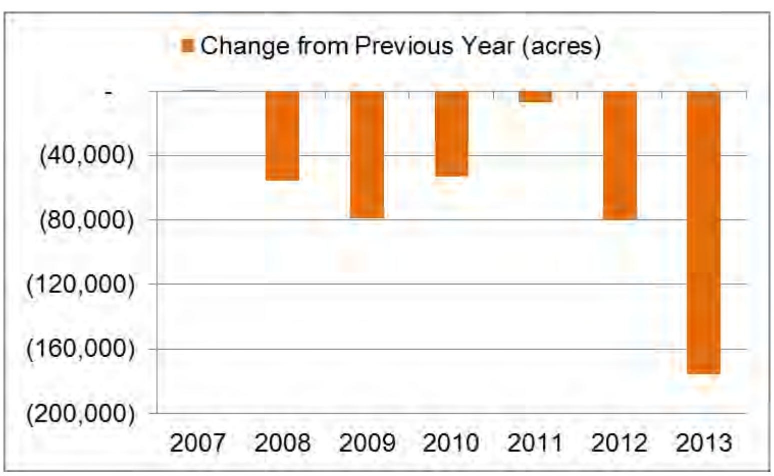


Figure 3-4. Annual net gain or loss of CRP acres.

Spring Corn Field in Minnesota Photo Credit: MPCA

Trends in crop genetics and in the use of agricultural drain tiles also have the potential to impact nutrient loads. Crop genetics has resulted in increased efficiency of corn and soybeans such that greater production has occurred per acre of farmland and per unit of fertilizer. The glacial processes that shaped the Upper Midwest left the area with highly productive but very poorly drained soils that require artificial drainage assistance to increase yields (Sands 2010). Tile drains were introduced to the American Midwest in the early- to mid-1800s, which supported the growth of corn and wheat production in Minnesota (Sands 2010). However, tile drains reduce surface runoff, increase subsurface runoff, and can expedite transport of soluble nutrients to waters, especially inorganic nitrogen. Inadequately designed or installed tile drain outlets are also sometimes associated with gully formation that erodes soil and contributes associated nutrients. In Minnesota it is estimated that about 20 to 30 percent of agricultural soil is tile-drained (Sands 2010). In some areas, such as the eastern portion of the Minnesota River Basin, a high percentage of row crop agriculture uses tile drains. Controlling nutrient loads from tile-drained lands will be a critical aspect of meeting the NRS's goals.

3.2 Sources and Pathways of Nutrients in Minnesota Waters

Sources of nutrients to Minnesota waters have been studied in depth over the past 15 years. Efforts have been made to quantify the nutrient loads associated with different sectors and activities, as well as to quantify nutrient loads spatially throughout the state. These efforts form the basis of this source assessment. Specific source loading information is not available for all evaluation time periods. The source data presented in this section represent research compiled since 2000 and land use information is generally from 2009 to 2010.

The phosphorus source assessment summary is based on the *Detailed Assessment of Phosphorus Sources to Minnesota Watersheds* (Barr Engineering 2004) and associated updates for wastewater point sources and atmospheric contributions. Atmospheric deposition loads were updated in 2007 and wastewater data have been updated to reflect 2011 conditions. The loadings do not represent the sources of phosphorus reaching the major basin outlets, but rather the sources of phosphorus to waters in each major basin. Atmospheric deposition values were further adjusted in 2012 by subtracting the phosphorus load directly to wetlands due to uncertainty about releases to downstream waters and to provide comparable results with the nitrogen source assessment.

The following are sources of phosphorus to surface waters (Table 3-2):

- Cropland and pasture runoff
- Atmosphere (including redeposited sediment from wind erosion)
- National Pollutant Discharge Elimination System (NPDES) permitted wastewater discharges
- Streambank erosion
- Urban runoff
- Nonagricultural rural runoff
- Individual sewage treatment systems
- Agricultural tile drainage
- Feedlots
- Roadway deicing chemicals

Historical phosphorus accumulations in Minnesota lakes are an important factor affecting water quality. Phosphorus that was historically deposisted in lake sediments can be released into the water column for decades through physical processes such as wind and wave action and as a result of anoxic conditions (lack of oxygen). In addition, bottom-feeding fish such as carp and bullhead can also cause suspension of sediment and subsequent release of phosphorus into the water column. Aquatic plants such as curly-leaf pondweed (*Potamogeton crispus*) can also contribute to phosphorus levels in lakes, especially in shallow lakes. Generally, internal loading is most important to local resources during July and August and a lesser source during higher flow periods from mid-March through June. In-lake treatment of legacy phosphorus and internal loading with alum has been effective in some lakes of Minnesota. Fish removal and aquatic vegetation management has also been effective in some lakes in

Minnesota. In-lake management techniques improve conditions during the summer for the local resource, but will not likely result in large downstream load reductions.

The Minnesota Pollution Control Agency (MPCA) has completed a *Nitrogen Study* (MPCA 2013a) that comprehensively assesses the science concerning nitrogen in Minnesota waters and characterizing nitrogen loading to Minnesota's surface waters by assessing conditions, trends, sources, pathways, and potential ways to reduce nitrogen loads. The nitrogen study is the basis for the nitrogen source assessment summary.

The following are sources of nitrogen to Minnesota waters (Table 3-2):

- Agricultural cropland via tile drainage
- Agricultural cropland via groundwater (nitrogen leached to groundwater beneath cropland, which later reaches surface waters through groundwater baseflow)
- Agricultural cropland via runoff over the soil surface
- NPDES permitted wastewater discharges
- Atmospheric deposition into lakes, rivers, and streams
- Forest runoff
- Individual sewage treatment systems
- Urban runoff and leaching
- Feedlot runoff (manure spreading to cropland is part of the cropland/agricultural categories.)

Within each major basin, the distribution of nutrient sources is unique. Table 3-2 provides a summary of the sources from Minnesota major basins associated with both phosphorus and nitrogen; the table is color coded to indicate the higher loading sources relative to other sources in the same major basin (green) and sources that contribute smaller load percentages (yellow). Each source will potentially require a different set of implementation activities to achieve reductions.

Table 3-2. Minnesota phosphorus and nitrogen sources by major basin, average conditions [a]

Nutrient source	Mississippi River		Lake Superior		Lake Winnipeg	
	P	N	P	N	P	N
Cropland runoff	35%	5%	6%	2%	42%	11%
Atmospheric [b]	8%	6%	7%	10%	18%	21%
NPDES permitted wastewater discharges [c]	18%	9%	24%	31%	11%	6%
Streambank erosion	17%	--	15%	--	6%	--
Urban runoff and leaching	7%	1%	10%	1%	2%	0%
Nonagricultural rural runoff [d]	4%	--	32%	--	15%	--
Individual sewage treatment systems	5%	2%	3%	4%	3%	2%
Agricultural tile drainage	3%	43%	0%	5%	0%	7%
Feedlot runoff	2%	0%	0.1%	0%	0.3%	0%
Roadway deicing	1%	--	2%	--	2%	--
Cropland groundwater [e]	--	31%	--	9%	--	35%
Forest runoff	--	4%	--	38%	--	19%

Notes: P = phosphorus; N = nitrogen

a. Source estimates are based on Barr Engineering (2004) with more recent MPCA updated wastewater (2011 conditions) and atmospheric deposition sources (2007). Source percentages do not represent what is delivered to the major basin outlets, but what is delivered to local waters.

b. Atmospheric deposition is to lakes and rivers (atmospheric deposition to wetlands is not reflected in this table).

c. Nutrient loads in the Lake Superior Major Basin are lower than other major basins in the state and therefore wastewater is a larger portion of the overall sources. Western Lake Superior Sanitary District (Duluth area) accounts for more than 50 percent of the wastewater phosphorus load in the major basin.

d. Includes natural land cover types (forests, grasslands, and shrublands) and developed land uses that are outside the boundaries of incorporated urban areas.

e. Refers to nitrogen leaching into groundwater from cropland land uses.

Scale:	Low				High

Phosphorus findings:

- The primary sources of phosphorus transported to surface waters are cropland runoff, atmospheric deposition, permitted wastewater, and streambank erosion. These four sources combined are 71 percent, 76 percent, and 83 percent of the statewide phosphorus load under dry, average, and wet years, respectively.

- During dry conditions, NPDES permitted wastewater discharges and atmospheric deposition become more prominent sources of phosphorus. Under wet conditions, streambank erosion becomes the most significant source of phosphorus in the state.

- The most significant phosphorus sources by major basin during an average precipitation year include cropland runoff, wastewater point sources, and streambank erosion in the Mississippi River Major Basin; streambank erosion, nonagricultural rural runoff, and wastewater point sources in the Lake Superior Major Basin; and cropland runoff, atmospheric deposition, and nonagricultural runoff in the Lake Winnipeg Major Basin. These sources do not necessarily represent the proportion of nutrient sources at the major basin outlets.

Nitrogen findings:

- Cropland nitrogen losses through agricultural tile drainage and agricultural groundwater make up the majority of nitrogen sources, contributing 51 percent, 68 percent, and 73 percent of the nitrogen load under dry, average, and wet years, respectively.
- During wet years, cropland nitrogen losses through tile drainage in the Minnesota River Basin have the single highest contribution to nitrogen loading.
- The most significant nitrogen sources by major basin include agricultural tile drainage and cropland groundwater in the Mississippi River Major Basin; forest and wastewater point sources in the Lake Superior Major Basin; and cropland groundwater, forest, and atmospheric deposition and in the Lake Winnipeg Major Basin. These sources do not necessarily represent the proportion of nutrient sources at the major basin outlets.

3.3 Nitrogen in Groundwater

Groundwater is monitored in Minnesota by a number of agencies and organizations. The MPCA maintains an Ambient Groundwater Monitoring Network that monitors the aquifers that are most likely to be polluted with nonagricultural chemicals. The Minnesota Department of Agriculture (MDA) monitors aquifers that agricultural chemicals are likely to impact. In southeastern Minnesota, a large amount of groundwater quality data has been collected by a Volunteer Nitrate Monitoring Network. The MPCA recently authored a report entitled *The Condition of Minnesota's Groundwater, 2007–2011* (MPCA 2013b), which includes a summary of nitrogen monitoring data. Figure 3-5 presents the nitrate concentrations in groundwater. It is important to note that these data represent many different aquifers and depths of wells. The Minnesota Department of Health also monitors the condition of groundwater in public water supply wells, however these data were not included in the MPCA's (2013b) report.

The following excerpt summarizes the key findings from the 2013 MPCA report:

> *The groundwater in the shallow sand and gravel aquifers in selected parts of Minnesota continues to be impacted by high nitrate concentrations. The shallow sand and gravel aquifers contained the highest median nitrate concentrations compared to all of the other aquifers assessed in this report. The highest nitrate concentrations occurred in the aquifers in Central and southwestern Minnesota. In Central Minnesota, about 40 percent of the shallow sand and gravel aquifer wells contained water with nitrate*

concentrations that were greater than the Maximum Contaminant Level (MCL) of 10 milligrams per liter (mg/L) set by the U.S. Environmental Protection Agency (USEPA) for drinking water. The limited available data in southwestern Minnesota showed that about 20 percent of the shallow sand and gravel aquifer wells contained water with nitrate concentrations that exceeded the MCL of 10 mg/L.

Some wells installed in the uppermost bedrock aquifers in southeastern Minnesota had nitrate concentrations that exceeded the MCL of 10 mg/L. These high concentrations occurred in selected wells in the Upper Carbonate, St. Peter, Prairie du Chien, and Jordan aquifers, and all occurred in areas where the aquifers are naturally susceptible to contamination.

Nitrate concentrations in the sand and gravel aquifers varied with land use and depth. The groundwater underlying both agricultural and urban lands contained higher nitrate concentrations compared to the groundwater underlying undeveloped land. The highest nitrate concentrations observed in this investigation typically were in the shallow groundwater underlying agricultural lands. The median concentration in the shallow groundwater underlying agricultural areas was about 9 mg/L; whereas, the median concentration in the groundwater underlying a variety of urban land uses ranged from 2-3 mg/L. Data from the MDA suggested the high nitrate concentrations in the state's sand and gravel aquifers may be restricted to the uppermost parts. In deeper parts of the sand and gravel aquifers, the nitrate may be removed by a natural, microbially-mediated processed called denitrification, or the groundwater in these parts of the sand and gravel aquifers may be so old that nitrate contamination that originated from the land surface has not yet percolated down to these depths.

The amount of nitrate contamination in Minnesota's groundwater generally has not changed over the last 15 years. There was sufficient data to quantify trends from about 90 wells, which primarily were sampled from 1997-2011. Nitrate concentrations did not significantly change in the majority of the wells.

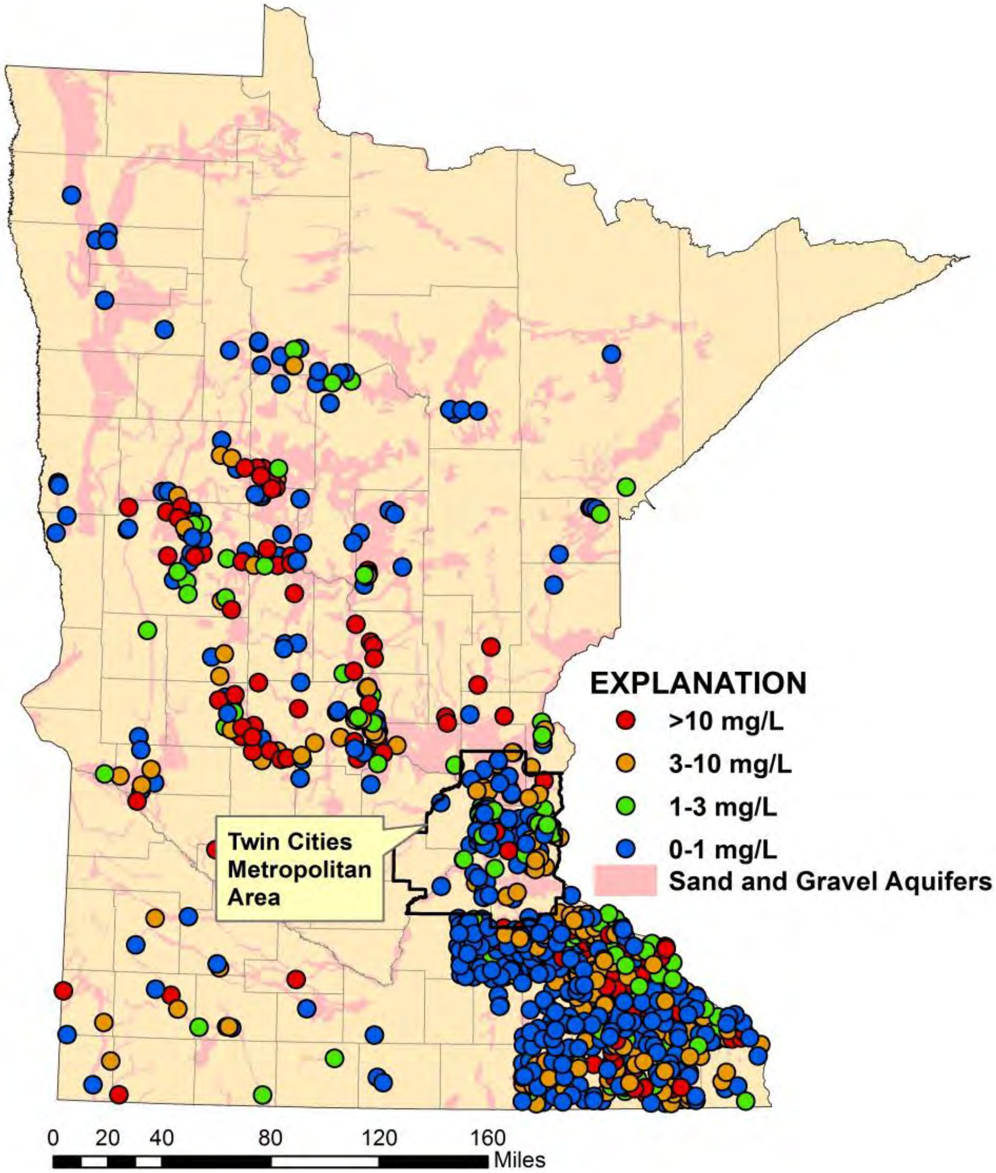


Figure 3-5. Nitrate concentrations in Minnesota's ambient groundwater, 2007–2011 (MPCA 2013b).

3.4 Surface Water Loading Analysis

Information on historic loading, water quality, and program implementation data were evaluated to inform changes in conditions since the baseline period. The purpose of this analysis was to assess potential trends in conditions that could have important implications on the NRS.

Potential trends were evaluated in four different ways:

- **Loads[1].** Nutrient loads were calculated as 5-year rolling averages of annual phosphorus and nitrogen loads using available flow and water quality data. These averages represent the arithmetic mean of the calculated annual loads for 5 consecutive years; for example, a 5-year rolling average of 1993 is the arithmetic mean of the annual loads from 1989, 1990, 1991, 1992, and 1993. Five-year rolling averages were used to smooth large variations in annual loads caused by flow variability, although flow still has an important impact on the load calculations.

- **Flow weighted mean concentrations (FWMC).** A FWMC is simply the annual load divided by the annual flow. Flow normalized values like FWMC provide a useful evaluation of long-term trends by removing variability in flow from annual averages of load. It is a good estimate of average concentration during moderate to high flows which dominate the annual load.

- **Program quantification of BMPs.** Quantification of BMP adoption and management change as represented in select program data and surveys is intended to provide an assessment of the recent progress achieved through implementation of best management practices (BMPs) and wastewater treatment. This metric, often referred to in the NRS as "program quantification," relies on inventorying the activities that have occurred over a period of time to reduce nutrient loads, and then estimating the reduced load using known information on the effectiveness of each practice (e.g., cover crops are reported to reduce phosphorus loading by 29 percent [Iowa State University 2013]).

- **Flow.** Trends in flow were not statistically analyzed in this effort, but this important variable was graphed for visual inspection since it is a fundamental driver to loads (Load = FWMC x Flow).

Careful examination of all four variables collectively will be needed to assess trends in each major basin. Loads measure the amount of nutrients delivered to a downstream water body, and as such provide a direct measure of the goals. However, trends in loads are difficult to determine because of a variety of factors, including variability in flows; insufficient data; lag times between BMP implementation and water quality response; and the impact of in-stream settling, resuspension, sediment release, etc. FWMCs are an in-stream measure and help to address the issue of flow variability, but determining trends can still be difficult if there are inadequate data, lag times, multi-year precipitation departures, and in-stream transformations. Program quantification provides a

[1] The most appropriate data to represent the major basin outlets were selected for evaluation. The available data varied, ranging from both annual and monthly loads for both nitrogen and phosphorus, to only annual loads for phosphorus or nitrogen. Limited data were available for the Lake Winnipeg Major Basin; data at Emerson in Manitoba generally represent the in-stream load in the Red River at the U.S.-Canada border. Except for SPARROW loading data, no known loading data were available that provided annual estimates based on observed data for the Lake Superior Major Basin or the Rainy River portion of the Lake Winnipeg Major Basin. Considerable nutrient processing occurs after the Rainy River flows into Lake of the Woods, which makes it difficult to assess the ultimate impact of the Rainy River on Lake Winnipeg.

simplified picture of BMP implementation and associated load reductions using available program data. However, it also relies on adequate data, is not a measure of actual in-stream conditions, and is subject to the uncertainties associated with quantifying the effectiveness of different practices. The approach to program quantification also does not account for BMPs that are adopted independent of state and federal programs and does not incorporate the effects of land use and management changes which can occur independent of BMP implementation (i.e., changing crops or tile drainage).

The following sections discuss the results of the loading and FWMC analysis, and Section 4.4 presents the program quantification analysis. In some cases, the results from each measure generally agree, whereas in other cases they do not. As discussed in Chapter 7, no one measure is considered the best and the NRS will ultimately be successful when they are all moving in the same direction.

3.4.1 Statewide SPARROW Results

The Spatially Referenced Regressions on Watershed (SPARROW) model integrates water monitoring data with landscape information to reflect long-term average constituent loads that are delivered to downstream receiving waters. The model also approximates nonpoint source loading for the 2000–2002 period. Loads reflect the wastewater point source update, which incorporates updated wastewater data from MPCA (updated for 2005–2006 for nitrogen and 2005–2009 for phosphorus) and is assumed to approximate current wastewater point source loading.

Results are independent of year-to-year variability in flow. SPARROW utilizes a mass-balance approach with a spatially detailed digital network of streams and reservoirs to track the attenuation of nutrients during their downstream transport from each source. Robertson and Saad (2011) developed the Major River Basin 3 (MRB3) SPARROW model for use in simulated nutrient loading in Minnesota. A primary advantage of the SPARROW model is that it provides statewide estimates of nitrogen and phosphorus for the same time periods and based on one methodology. Results from the Watershed Pollutant Load Monitoring Network (WPLMN) can be used to describe nutrient loads between 2007 and 2011 for many major watersheds. However, because long-term monitoring averages are not available at this time for all 8-digit hydrologic unit code major watersheds, analyses for NRS relied more heavily on SPARROW model outputs. Future revisions to the NRS should incorporate the WPLMN generated load data.

Estimates of transported phosphorus load in MRB3 depend on the following:

- Point source loads (excluding regulated stormwater)
- Manure production
- Fertilizer use on farms
- Forest area
- Urban area
- Soil permeability
- Tile density
- Travel time in stream
- Presence of lakes or reservoirs in stream network

Transported nitrogen load estimates depend on similar factors, with the addition of the following:

- Atmospheric nitrogen deposition rates
- Average annual precipitation
- Air temperature
- Clay content of soil
- Area of watershed in agricultural land use, as a proxy for other agricultural sources
- Presence of lakes or reservoirs in stream network

Use of these factors provides reasonable estimates of average annual load, but the model does not address a number of other factors. Notably, there are no measures of soil erodibility. There is also no correction for the extent of adoption of agricultural management practices. Therefore, the agricultural nonpoint load estimates are essentially a function of agricultural area, fertilizer use, and manure production. Given these conditions, the precision of the model is limited and used within the NRS primarily to assess the relative difference in loads by source categories and spatial differences in total loads across the state's watersheds.

Figure 3-6 and Figure 3-7 show the modeled yields by major watershed. Yields are used to understand the relative differences in loading between the major watersheds and are a product of land cover, land use, precipitation, and flow conditions.

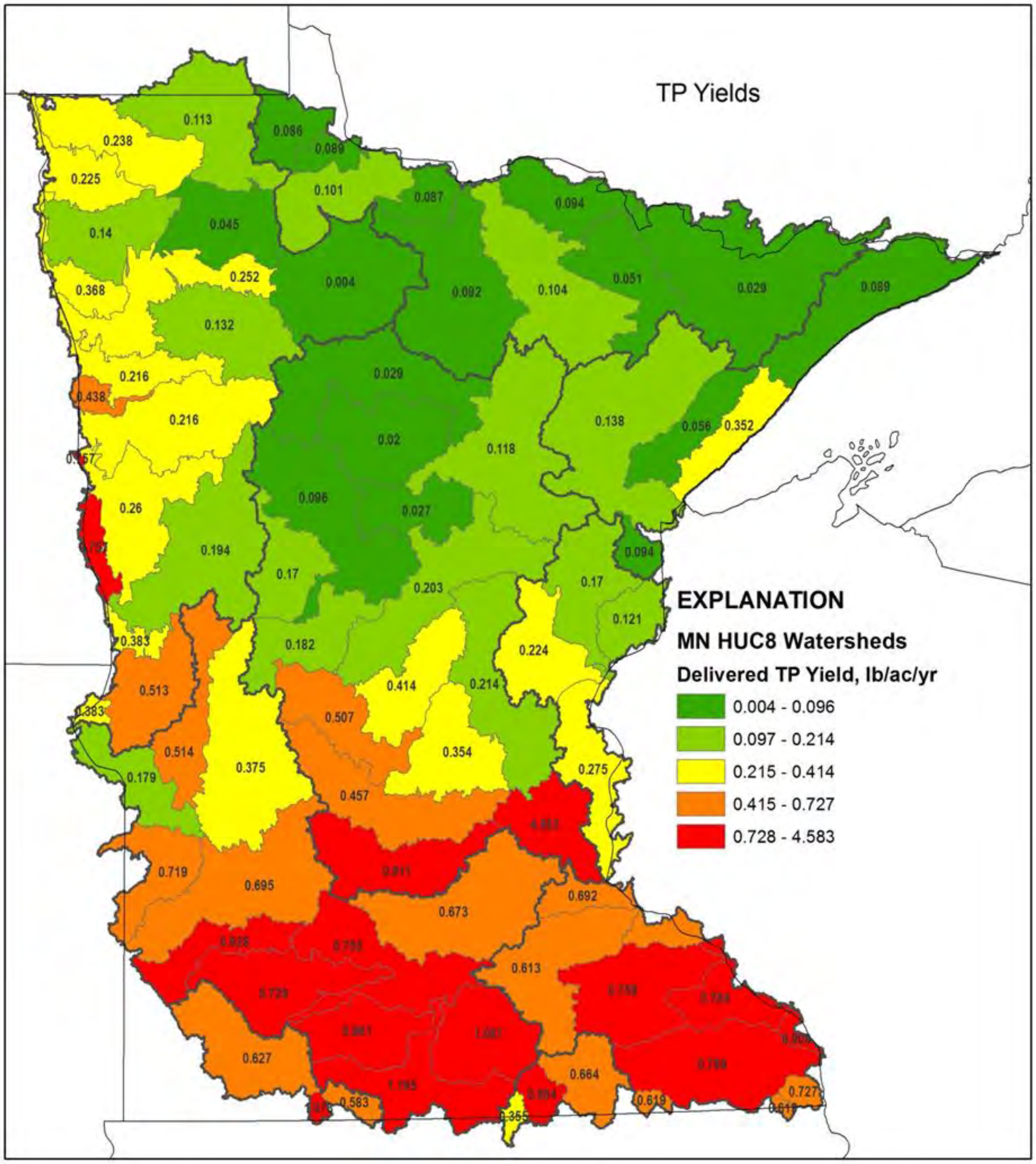


Figure 3-6. Annual phosphorus yield delivered to major watershed outlets in pounds/acre/year (Robertson and Saad 2011).

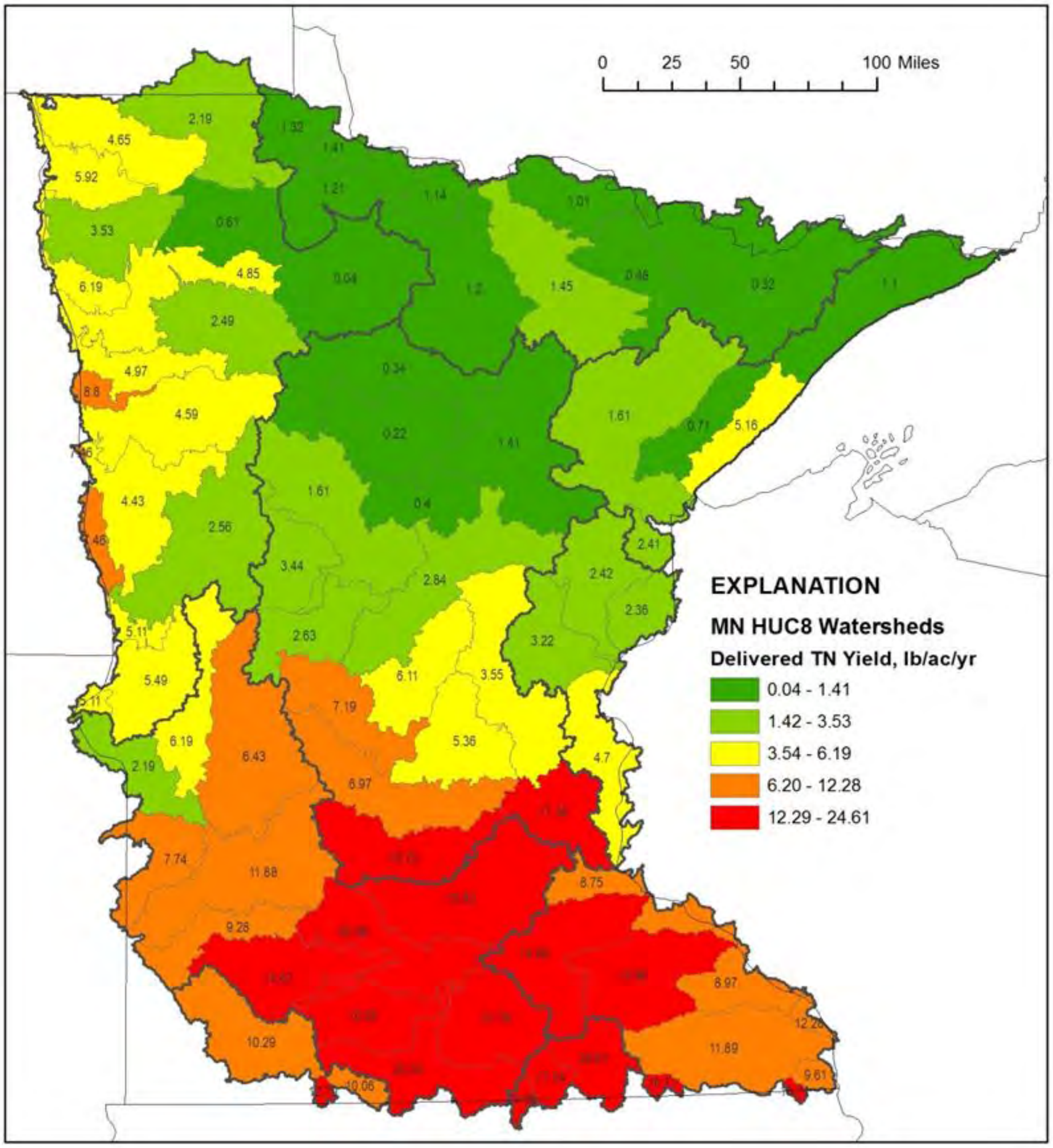


Figure 3-7. Annual nitrogen yield delivered to major watershed outlets in pounds/acre/year (Robertson and Saad 2011).

3.4.2 Lake Superior Major Basin

The Lake Superior Major Basin in northeastern Minnesota is approximately 6,200 square miles. Major watersheds include the Cloquet, Nemadji, and St. Louis River systems, as well as the North Shore tributaries to Lake Superior. Over 93 percent of the major basin is forest, wetlands, and open water. Duluth and the surrounding area comprise the majority of the urban development in this major basin.

Open-pit mining is common along the major basin divide between Hibbing and Virginia. Many high-quality streams and large forested areas, along with Lake Superior, provide significant recreational opportunities.

Excess nutrients within this major basin are primarily derived from anthropogenic sources in the developed areas, including wastewater from both municipal treatment systems and individual sewage treatment systems and runoff. Industry within the major basin may also contribute to excess nutrients.

Phosphorus bound to sediment is also an important source in North Shore streams. The University of Minnesota completed a study in 2013 *Lake Superior Stream Sediment Assessment: Phase 1* that begins work to study the major causes of erosion and sediment transport, excessive turbidity levels and their impacts on North Shore streams (Lahti et al. 2013). Anthropogenic stressors and natural variables were evaluated. Roads were identified as the most widespread anthropogenic stressor and areas along the channel mainstems have the greatest potential to impact water quality. Channel stability and the potential for channel erosion were also evaluated.

In-stream monitoring was insufficient for this major basin during the baseline timeframe (1979) to quantify nutrient loads to Lake Superior. Therefore, the 2002 USGS SPARROW modeling results were used to evaluate nutrient loading. Because land uses in this major basin have not changed substantially since the late 1970s and early 1980s, SPARROW results were determined to adequately approximate loads during the 1979 baseline condition in this basin. The SPARROW results with wastewater point sources updated in 2011 were used for the current conditions load. Table 3-3 provides phosphorus loading results for the Lake Superior Major Basin.

An approximate goal of 248 metric tons/year of phosphorus is proposed to represent "holding the line" at 1979 conditions. No new reductions are proposed based on the modeled current condition, the difference between the modeled baseline and current condition is within the range of uncertainty regarding the actual load. The nitrogen loading goal for the Lake Superior Major Basin is qualitative (no specific load reductions identified) and, therefore, nitrogen loading was not evaluated.

Table 3-3. Phosphorus loading results, Lake Superior (metric tons/year)

Data set	Modeled baseline ~1979	Goal load (no increase in 1979 loads)	Modeled current conditions 2006-2010 [a]	Notes
SPARROW Model Results	248	248	255	Minnesota drainage area only; delivered to lake

Current conditions in the Lake Superior Major Basin are represented by SPARROW as updated with wastewater point source data in 2011.

NPDES wastewater sources contribute the majority of anthropogenic phosphorus and nitrogen to the Lake Superior Major Basin. Thus, controlling wastewater sources is important to prevent load increases to Lake Superior. In addition, stormwater runoff and streambank erosion are important sources due to the developed nature of Duluth and surrounding areas, as well as flashy flows common in North Shore streams. Management needs to address all flow regimes.

3.4.3 Lake Winnipeg Major Basin

The Lake Winnipeg Major Basin includes both the Red River of the North Basin and the Rainy River Basin. The Minnesota portion of the Red River Basin covers about 37,100 square miles in northwestern Minnesota in all or part of 21 counties and flows to Lake Winnipeg. It is home to about 17,842 miles of streams and 668,098 acres of lakes including Upper and Lower Red Lakes. This basin is characterized by intensive agricultural land uses within the flat topography east of the river, rolling uplands full of trees and lakes in the east-central portion of the basin, and extensive wetlands in the northeast. The Rainy River Basin is home to some of the state's finest forest and water resources and flows to the Winnipeg River in Canada, which discharges into Lake Winnipeg. The Minnesota portion of the basin includes approximately 11,000 square miles and consists predominantly of forests, wetlands, and lakes, including Lake of the Woods. Voyageurs National Park and the Boundary Waters Canoe Area Wilderness are located within the Rainy River Basin, as are several of Minnesota's most famous walleye fisheries and many high-quality trout streams. Other prominent uses of natural resources in the basin are forestry, mining, and various forms of recreation.

Excess nutrients within this basin are primarily derived from agricultural activities and wastewater point sources within the Red River Basin. In-stream loading estimates were not available for the Rainy River Basin, and because there are limited anthropogenic sources of nutrients in this basin and likely substantial nutrient losses in Lake of the Woods, loading analysis concentrated on the Red River. Lake of the Woods is impaired due to eutrophication therefore reductions upstream of this valuable resource will be more important to an in-state water than Lake Winnipeg.

In-stream monitoring data collected in Emerson, Manitoba, and loading analysis provided by Manitoba Conservation and Water Stewardship and Environment Canada (CWSEC) were used to evaluate the flow trends, load (using 5-year rolling average), and FWMC in the Red River. For phosphorus, Figure 3-8 compares in-stream load, FWMC, and flow in the Red River near Emerson, Manitoba. Despite the lower flows, phosphorus loads in the Red River have not decreased since 2000. While the phosphorus 5-year rolling average load is relatively stable, the FWMC has been gradually increasing, indicating that progress toward long-term load reduction has not been achieved. The FWMCs show a smooth curve for phosphorus, with the exception of a high value in the low flow year of 2003, which may reflect a strong influence of wastewater point sources under low flow conditions.

To illustrate progress needed to achieve the load reduction goal, the dashed lines in Figure 3-8 represent the estimated outcome of a 10 percent provisional reduction in baseline conditions load. While the in-stream loading goal is achieved during 2 years with lower flows, on average, the goal based on the FWMC is not achieved during the entire period of record. If loading conditions remain similar to current conditions, high flow years are likely to show loading above the in-stream load goal.

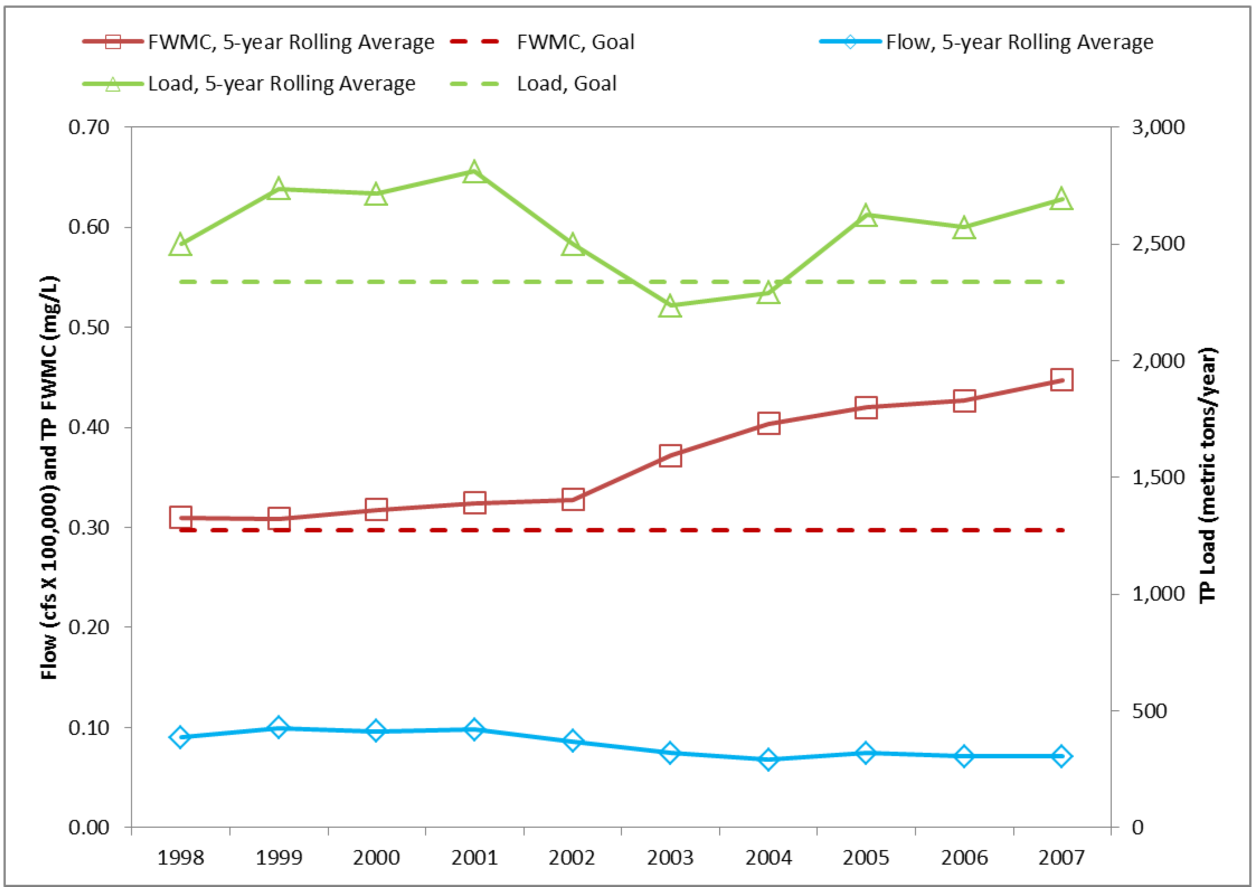


Figure 3-8. Phosphorus loading analysis, Red River near Emerson, Manitoba.

Data are the result of in-stream monitoring, and include out-of-state drainage area.

Table 3-4 presents the available phosphorus annual average load and FWMC estimates, summarized by time period. The goal load of 2,340 tons of phosphorus per year and the FWMC of 0.30 mg/l phosphorus correspond to the goals for the Lake Winnipeg Major Basin. An 11 percent reduction from current conditions would be required to achieve the loading goal, and a 32 percent reduction would be required to achieve the FWMC goal. When only in-stream loads from the Minnesota drainage area are considered, the load goal is 1,123 tons of phosphorus per year.

Table 3-4. Phosphorus loading results, Lake Winnipeg (concentration in mg/l; loads in metric tons/year)

Data set	Baseline 1999–2003	Goal (10% reduction from baseline)	Current conditions 2006–2010	Notes
FWMC (Red River only)	0.33	0.30	0.44	Based on in-stream loads; includes out-of-state drainage area
In-stream Loads[a] (Red River only)	2,600	2,340	2,633	In-stream loads; includes out-of-state drainage area
Total Minnesota Load to the Red River	1,248	1,123	1,264	An estimated 48% of River loads are from in-state (MN) watersheds

a. Calculated as the average of the 5-year rolling averages across the time period.

Figure 3-9 compares nitrogen in-stream load, FWMC, and flow in the Red River near Emerson. Nitrogen load has decreased since 2001. However, flow has also decreased during that same time period. The FWMC has remained relatively stable over time, possibly with a slight increase as flows have decreased. This suggests that apparent improvements in loading since 2001 are mostly due to lower flows rather than a true reduction in loads from nitrogen sources.

To illustrate progress needed to achieve the load reduction goal, the dashed lines represent the estimated outcome of a provisional 13 percent reduction in nitrogen from baseline conditions. Although some 5-year rolling average loads are less than the goal, both the in-stream load and FWMC measures indicate that the load reduction goal is not being met on an average basis.

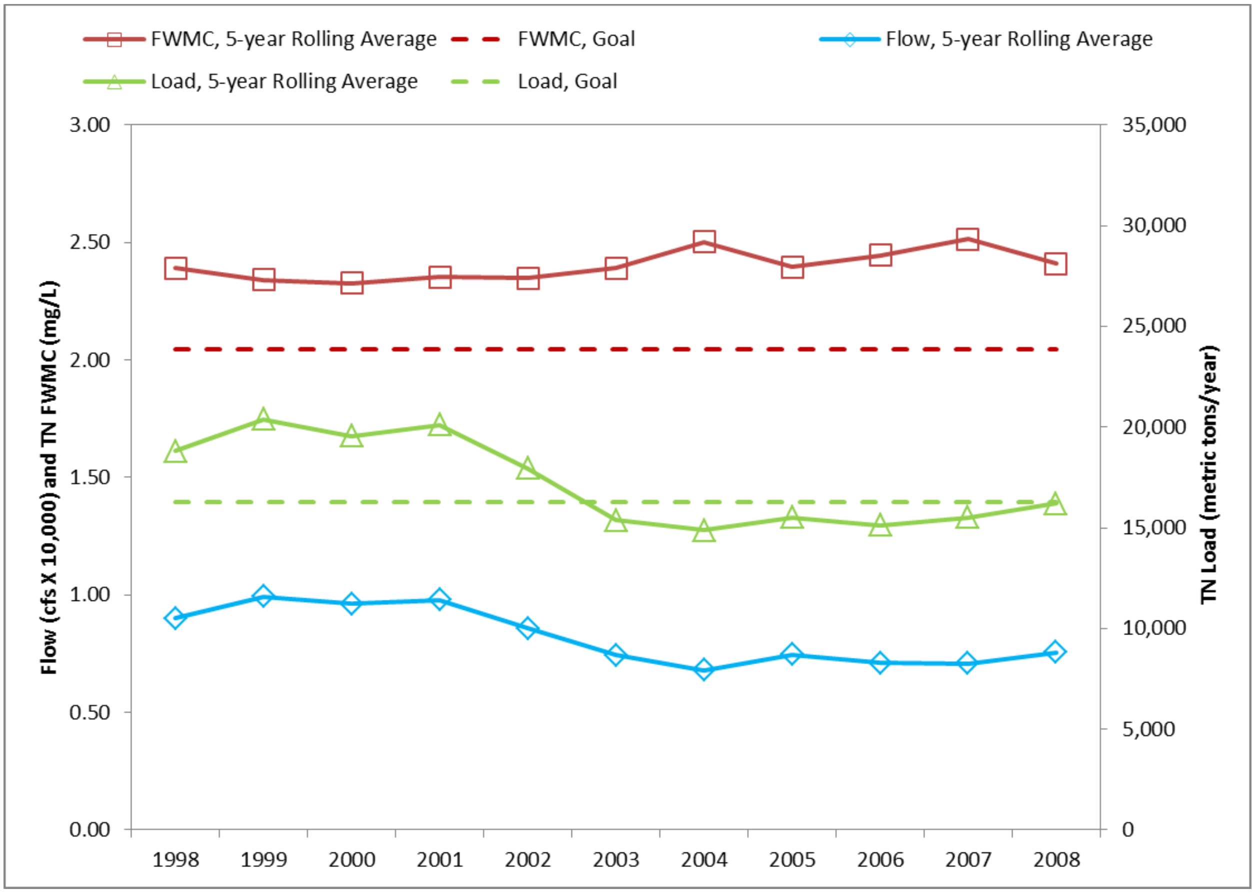


Figure 3-9. Nitrogen loading analysis, Red River near Emerson, Manitoba.
Data are the result of in-stream monitoring, and include out-of-state drainage area.

Table 3-5 presents the nitrogen FWMC and load estimates, summarized by time period. The proposed goals represent a 13 percent reduction from the baseline conditions. While the current conditions average load is less than the goal load, the analysis of flow trends indicates that this is likely due to lower flows under current conditions compared to baseline conditions. Future monitoring can confirm the status of nitrogen load across long-term conditions and not just within the current conditions time period. The FWMC goal represents a 17 percent reduction from current conditions. The goal load of 16,258 metric tons of nitrogen per year and the FWMC of 2.05 mg/l are the provisional nitrogen goals for the Lake Winnipeg major Basin. The goal load estimated for the Minnesota portion of the major basin can be used to assess reductions achieved within Minnesota as a secondary measure of achieving the loading goal. When only in-stream loads from the Minnesota drainage area are considered, the load goal is 7,804 tons of nitrogen per year.

Table 3-5. Nitrogen loading in the Red River near the Minnesota-Manitoba border (concentration in mg/l; loads in metric tons/year)

Data set	Baseline 1999–2003	Provisional Goal (13% reduction from baseline)	Current conditions 2006–2010	Notes
FWMC (Red River only)	2.35	2.05	2.46	Based on in-stream loads; includes out-of-state drainage area
In-stream Loads[a] (Red River only)	18,687	16,258	15,624	In-stream loads; includes out-of-state drainage area
Total Minnesota Load to the Red River	8,970	7,804	7,500	An estimated 48% of River loads are from in-state (MN) watersheds

a. Calculated as the average of the 5-year rolling averages across the time period.

3.4.4 Mississippi River Major Basin

The Mississippi River Major Basin covers 60 percent of the state and includes the following seven basins: Upper Mississippi River, Minnesota River, St. Croix River, Lower Mississippi River, Cedar River, Des Moines River, and Missouri River. The Upper Mississippi River Basin contains the headwaters to the Mississippi River near Itasca and includes a mixture of forest, prairie, agriculture, and urban land areas. The majority of the Twin Cities Metropolitan Area (Metro Area) is also located in this basin. The Minnesota River discharges to the Mississippi River near Fort Snelling and drains approximately 16,770 square miles. This basin contains very fertile soils and is predominantly agricultural upstream of the Metro Area. Sediment and nutrient reduction has been a focus in this basin for several decades and a phosphorus total maximum daily load (TMDL) was approved in 2012. The St. Croix River Basin is approximately 3,500 square miles in Minnesota and includes the state's only National Wild and Scenic River (St. Croix River). The basin is typically forested with lower intensity livestock agriculture in the upper portion and agriculture becoming more prominent in the lower portion. The Lower Mississippi River Basin is characterized by a mix of agriculture, bluffs, springs, caves, and many cold-water streams. Lake Pepin is a natural lake along the Mississippi River within this basin and has been the subject of many studies. A TMDL is being developed to address excessive nutrients (phosphorus) in Lake Pepin. Agriculture is the predominant land use in this basin. Agriculture accounts for 84 percent of land use in the combined Cedar River, Des Moines River, and Missouri River basins.

To evaluate major basin loading, loading data were obtained for a variety of locations (Table 3-6 and Figure 3-10). Data for the Mississippi River provide a reasonable span of years to cover most of the time periods. The most relevant data for goal setting were for sampling stations located at Lock and Dam 7 and 8, the most downstream locations in Figure 3-10. In addition, Lock and Dam 3 contains the longest period of record and is therefore also an important monitoring station. Its location upstream of Lake Pepin and many of the Wisconsin tributaries eliminates these complicating factors from annual loading evaluations. A review of average statewide precipitation indicates that the baseline period of 1980–1996 may have been wetter than the long-term average in Minnesota. However, the average annual load from this period is very similar to the average annual load from the 1998–2002 time period for both phosphorus and nitrogen.

Table 3-6. Mississippi River annual loading data

Location	Source agency	Nitrogen (annual loads available)	Phosphorus (annual loads available)
Mississippi River			
Above Lock and Dam 3 (UMR 796.9)	MCES	1980–2010[a]	1980–2010
Lake Pepin outlet (M764)	USGS/MPCA	1992–2008	1985–1996[c]
Gage 05378500, at Winona, Minnesota (60001)	USGS[b]	1975–1993	1975–1993
At Winona, Minnesota	MPCA	2009[a]	2009
Lock and Dam 7 (M701)	USGS/MPCA	1990–2010	1990–2010
Lock and Dam 7 + Root River	USGS/MPCA	--	1991–2010
downstream of Lock and Dam 7 (80009)	USGS[b]	1991–1997	1991–1997
Near Lock and Dam 8 (80011)	USGS/ MPCA	1990–2010	--
Near Lock and Dam 8	USGS[b]	1991–1997	1991–1997

Additional data available but are not included in the analysis below.
MCES = Metropolitan Council Environmental Services; USGS = United States Geological Survey.
a. Results are for total Kjeldahl nitrogen (TKN) and nitrate; the results are summed to represent nitrogen.
b. Upper Mississippi River Basin Loading Database (Sediment and Nutrients).
http://www.umesc.usgs.gov/data_library/sediment_nutrients/sediment_nutrient_page.html
c. Additional data are available for this site; however, loads were not available at the time of this report.

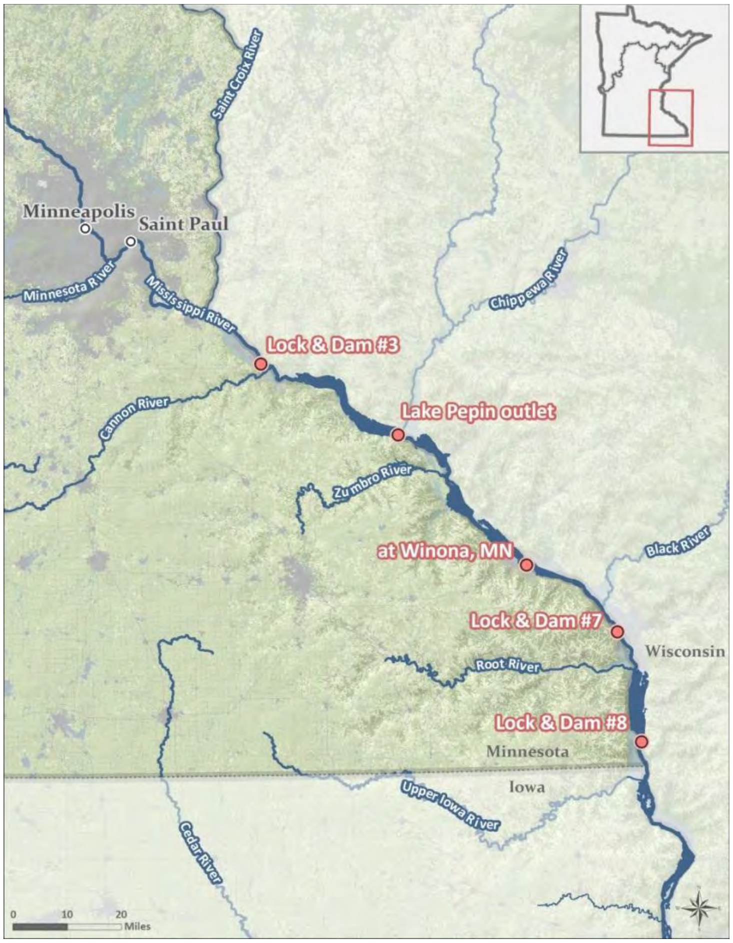


Figure 3-10. Monitored locations with available nutrient load estimates.

The loading analysis for the Mississippi River Major Basin involved evaluations of flow, load (using 5-year rolling average), and FWMC. Loading is estimated proportionally by area for the Cedar, Des Moines, and Missouri River basins from the Mississippi in-stream load associated with Minnesota.

Figure 3-11 compares in-stream load, FWMC, and flow in the Mississippi River near the state border. The dashed lines represent the estimated outcome of a 45 percent reduction in baseline conditions load. Analysis of load and flow for phosphorus indicate that phosphorus load reductions have been documented within the recent decade and between baseline and current conditions in the Mississippi River near the state border, with the exception of 2010 (a high flow year). While total load and flow have shown a decreasing trend, FWMC has remained fairly constant. These findings suggest that limited long-term progress has been made in reducing phosphorus loads to the Mississippi River near the state border. In contrast to this conclusion, substantial phosphorus reductions have been measured upstream of Lake Pepin at Lock and Dam 3, where additional monitoring data are available. Based on the results at Lock and Dam 3 and other more direct measurements, there is likely a lag time response at the state border for phosphorus. Lake Pepin, pools behind locks and dams, and backwaters of the Mississippi River likely affect the lag time.

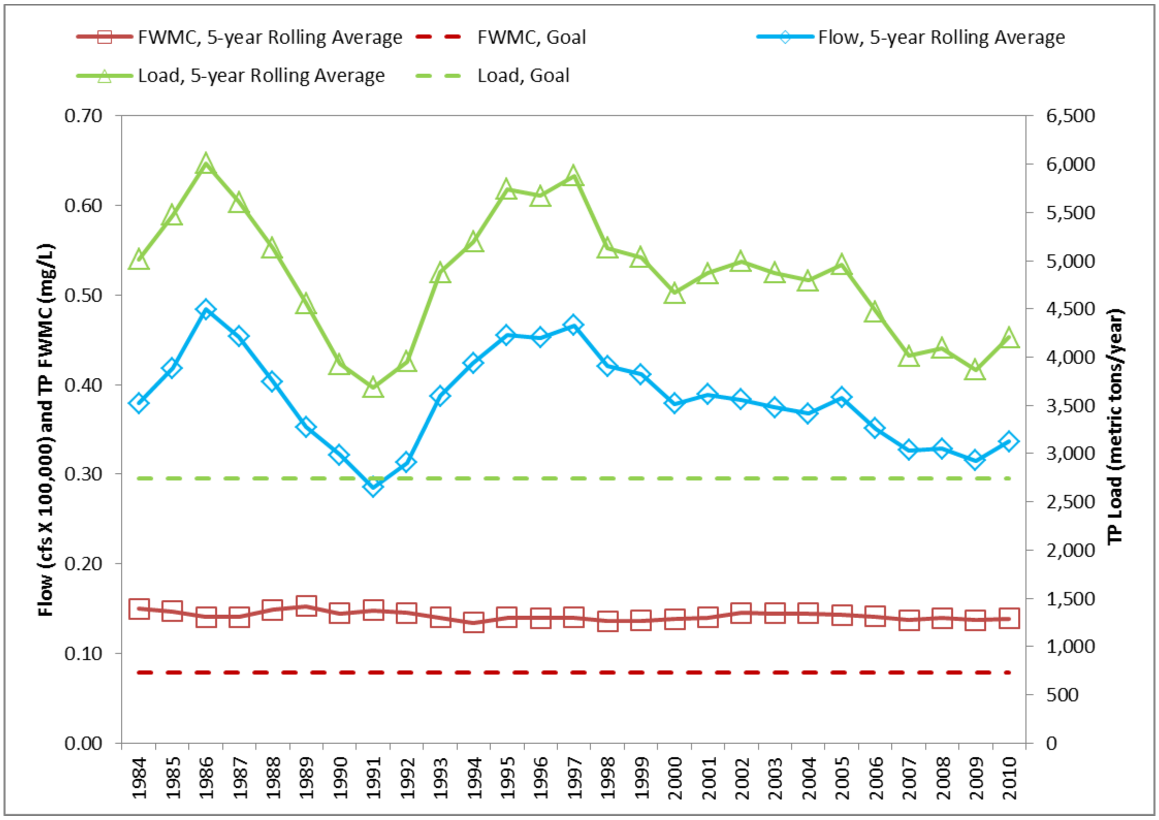


Figure 3-11. Phosphorus loading analysis, Mississippi River near the Minnesota border.

Data are the result of in-stream monitoring, and include out-of-state drainage area.

Table 3-7 presents the phosphorus load and FWMC estimates available at the state border, summarized by time period. The goals represent a 45 percent reduction in load from the baseline conditions. An in-stream load of 2,737 metric tons of phosphorus per year and a FWMC of 0.08 mg/l are proposed as the goals for the Mississippi River Major Basin. The goal load estimated for the Minnesota portion of the major basin (2,107 metric tons of phosphorus per year) can be used to assess reductions achieved within Minnesota as a secondary measure of achieving the loading goal. Since long-term annual loading data were not available for the Cedar, Des Moines, and Missouri River basins, the approximate load for these small basins was proportioned from the Mississippi in-stream loads (Minnesota portion which excludes areas in the Dakotas, Iowa, and Wisconsin as estimated using SPARROW). The goal load (437 metric tons of phosphorus per year) can serve as a nutrient reduction goal until more reliable loading data are available. When the load estimates for the Mississippi, Cedar, Des Moines, and Missouri Rivers are combined and only loads from the Minnesota drainage area are considered, the load goal is 2,544 tons of phosphorus per year.

As noted earlier and described in more detail later in this chapter, considerable progress has been made in reducing phosphorus loads to the Mississippi River, even though the monitoring-based load calculations at Lock and Dam 8 do not show the full extent of the reductions.

Table 3-7. Phosphorus loading results, Mississippi River (concentration in mg/l; loads in metric tons/year)

Data set	Baseline 1980–1996	Goal (45% reduction from baseline)	Current conditions 2006–2010	Notes
FWMC (Mississippi River near State Border)	0.14	0.08	0.14	Based on in-stream loads; includes out-of-state drainage area
In-stream Loads (Mississippi River near State Border)[a]	4,976	2,737	4,084	In-stream loads; includes out-of-state drainage area
In-stream Loads (Mississippi River near State Border, MN portion)	3,832	2,107	3,145	An estimated 77% of River loads are from in-state (MN) watersheds
Cedar, Des Moines, and Missouri River (proportional load based on Mississippi load, Minnesota portion)	795	437	658	MN drainage area only
Total Minnesota Load to the Mississippi River near State Border including the Cedar, Des Moines, and Missouri River loads	4,627	2,544	3,803	MN drainage area only

a. Calculated as the average of the 5-year rolling averages across the time period.

Figure 3-12 presents nitrogen in-stream load, FWMC, and flows for the Mississippi River near the state border. To illustrate reductions needed to achieve goals, the dashed lines represent the estimated outcome of a 45 percent reduction in baseline conditions load. The data indicate an overall decrease in nitrogen load within the past decade and between baseline and current conditions. The decrease can be mostly attributed to corresponding reductions in flow during this time period, with the exception of 2010 (a high flow year). FWMC has remained relatively constant, with a slight decrease over the period of record. Nitrogen loading appears to be strongly tied to flow, and future increases in flow would likely lead to increases in load, all other factors remaining constant.

Monitoring further upstream at Lock and Dam 3 has not shown nitrogen reductions when comparing baseline and recent periods during various flow conditions. This further substantiates that flow-adjusted nitrogen loads have not reduced appreciably in the Mississippi River since the baseline period.

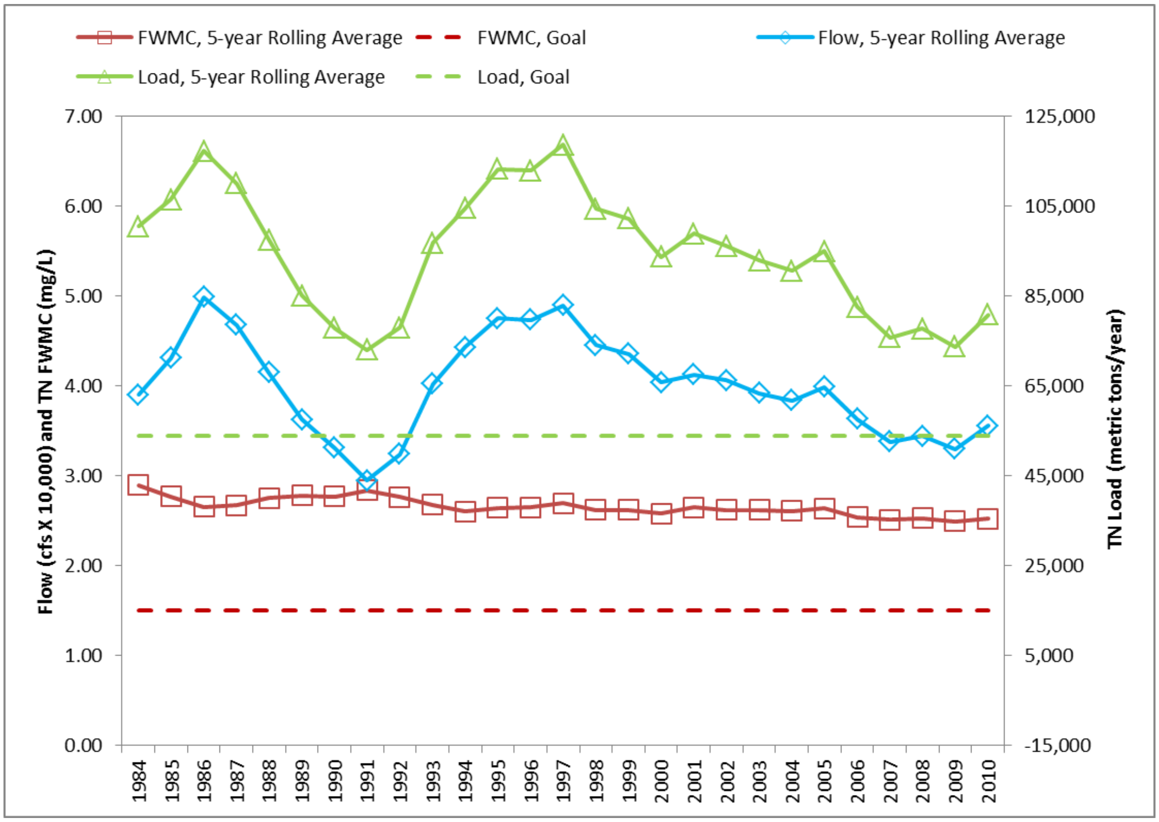


Figure 3-12. Water Quality Measures Comparison: Nitrogen, Mississippi River near the Minnesota border.

Data are the result of in-stream monitoring, and include out-of-state drainage area.

Table 3-8 presents the nitrogen load and FWMC estimates available, summarized by time period. The goals represent a 45 percent reduction in load from the baseline conditions. The goal load of 53,989 metric tons nitrogen per year and the FWMC of 1.5 mg/l are proposed as the goals for the Mississippi River Major Basin. The goal load estimated for the Minnesota portion of the major basin (41,502 metric tons of nitrogen per year) can be used to assess reductions achieved within Minnesota as a secondary measure of achieving the loading goal. The Cedar, Des Moines, and Missouri River basins' goal load (8,587 metric tons of nitrogen per year) can serve as a nutrient reduction goal until more reliable loading data are available. When the load estimates for the Mississippi, Cedar, Des Moines, and Missouri Rivers are combined and only loads from the Minnesota drainage area are considered, the load goal is 50,088 tons of nitrogen per year.

Table 3-8. Nitrogen loading results, Mississippi River (concentration in mg/l; loads in metric tons/year)

Data set	Baseline 1980–1996	Goal (45% reduction from baseline)	Current conditions 2006–2010	Notes
FWMC (Mississippi River near State Border)	2.73	1.50	2.58	Based on in-stream loads; includes out-of-state drainage area
In-stream Loads (Mississippi River near State Border)[a]	97,996	53,898	78,211	In-stream loads; includes out-of-state drainage area
In-stream Loads (Mississippi River near State Border, MN portion)	75,457	41,502	60,223	An estimated 77% of River loads are from in-state (MN) watersheds
Cedar, Des Moines, and Missouri River (proportional load based on Mississippi load)	15,612	8,587	12,460	MN drainage area only
Total Minnesota Load to the Mississippi River near State Border including the Cedar, Des Moines, and Missouri River loads	91,069	50,088	72,682	MN drainage area only

a. Calculated as the average of the 5-year rolling averages across the time period.

Headwaters to the Mississippi River Photo Credit: MPCA

Nutrient Reductions Upstream of Lake Pepin - A Closer Look at Lock and Dam 3

Data at Lock and Dam 3 show different results than Lock and Dam 8, likely due to its location which is upstream of Lake Pepin (impaired for eutrophication), several pools and backwaters of the Mississippi River, and several tributaries from Wisconsin. Recent (2009–2011) monitoring data from the Mississippi River at Lock and Dam 3 indicates that the average flow normalized phosphorus load has been reduced 31 percent from the 1980–1996 baseline level. Data from the recent period was used to calibrate the FLUX loading model developed by the U.S. Army Corps of Engineers, and this calibration was applied to historical flows. This technique was used to normalize flow since short-term variability in weather may impact average load when examining short periods of record such as the recent period.

Phosphorus concentrations at Lock and Dam 3 in recent (2009–2011) years are lower than the baseline period (1980–1996) (Figure 3-13). This is especially true during lower flows when wastewater point sources generally have the most impact on phosphorus concentration. Major wastewater reductions upstream of this station started in 2003 and stabilized from 2009–2011. Between 2000 and 2010, phosphorus loads from wastewater point sources upstream of Lock and Dam 3 reduced from 1,653 to 445 metric tons per year. Monitored nitrogen concentrations at Lock and Dam 3 also show a decrease under low flows (Figure 3-14). Two load estimates were compared to determine if the concentration changes in the recent period would result in lower loads if flows were identical to the baseline conditions (Figure 3-15 and Figure 3-16). Loading estimates were calculated by calibrating flow verses concentration relations during monitored dates and applying the calibration for all dates of interest to estimate the load for a given time period. The baseline loads are derived from monitored data collected between 1980 and 1996.

The recent calibration applied to the baseline flows predicts that average annual phosphorus load at Lock and Dam 3 would be 31 percent less than the baseline load. This analysis indicates that progress toward the NRS phosphorus goals has been made on a portion of the Mississippi River mostly due to phosphorus reductions in Minnesota. The baseline nitrogen loads are similar to the loads based on a 2002–2011 calibration applied to the baseline flows.

This analysis is a more effective method of removing flow bias than the flow-weighted mean or load estimation techniques used elsewhere in the NRS. Unfortunately, water quality data sets needed to similarly evaluate these trends are not available at the outlets of the state’s three major basins.

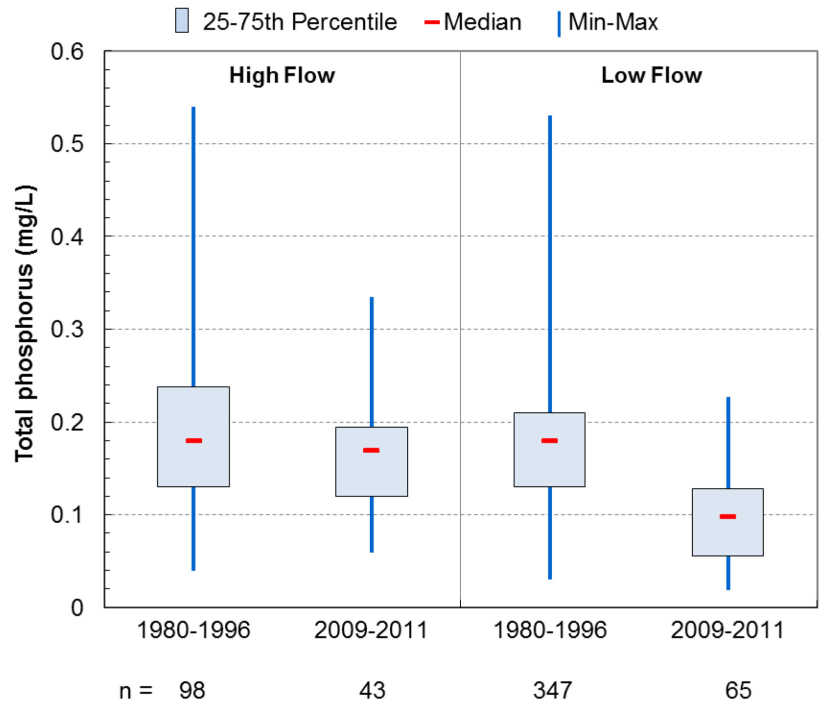


Figure 3-13. Monitored phosphorus concentration at Lock and Dam 3 during baseline (1980–1996) and recent conditions (2009–2011) for three flow conditions. *High Flow* represents flows that are exceeded from 0–20 percent of the time; *Low Flow* represents flows that are exceeded 21–100 percent of the time.

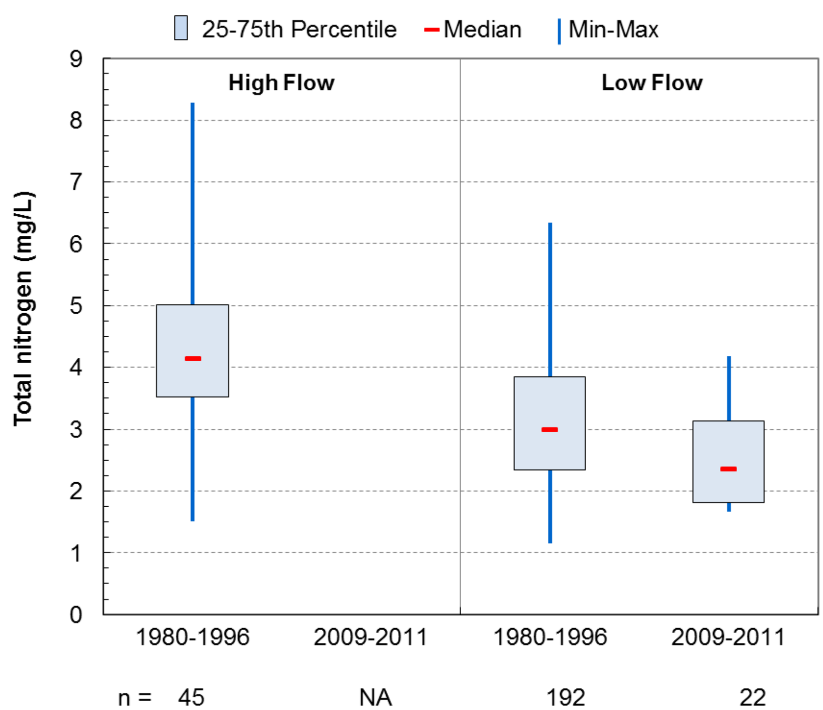


Figure 3-14. Monitored nitrogen concentration at Lock and Dam 3 during baseline (1980–1996) and recent conditions (2009–2011). *High Flow* represents flows that are exceeded from 0–20 percent of the time; *Low Flow* represents flows that are exceeded 21–100 percent of the time.

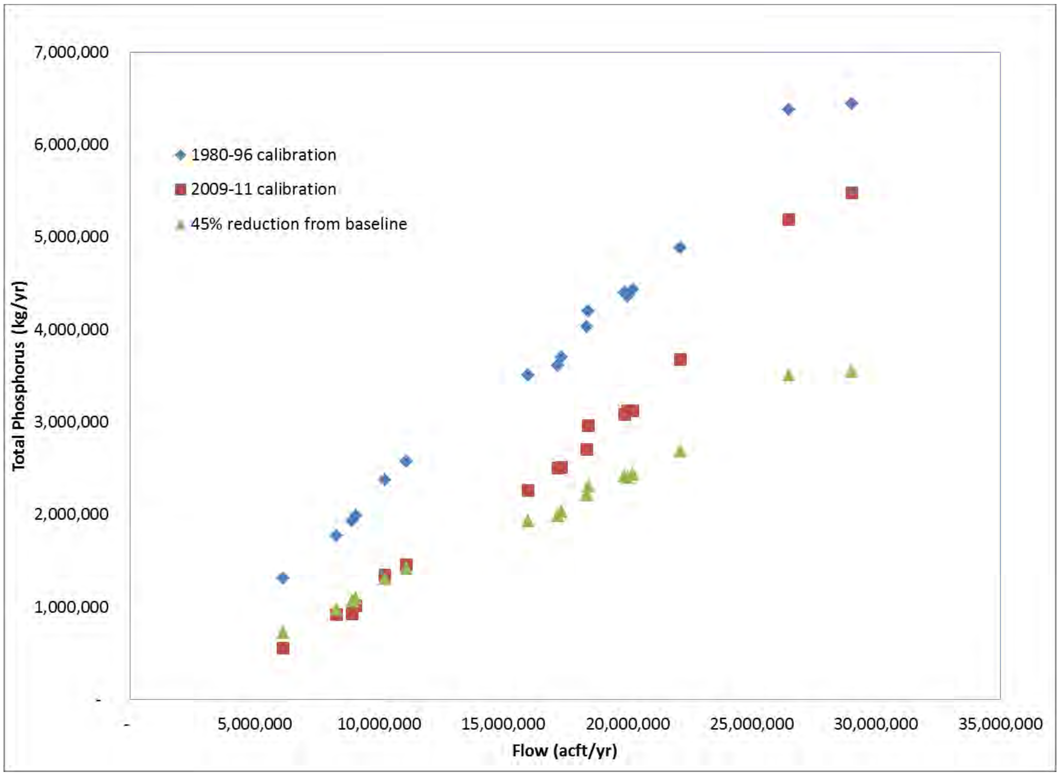


Figure 3-15. Estimated annual phosphorus loads for baseline years based on baseline and recent calibration verses observed flow.

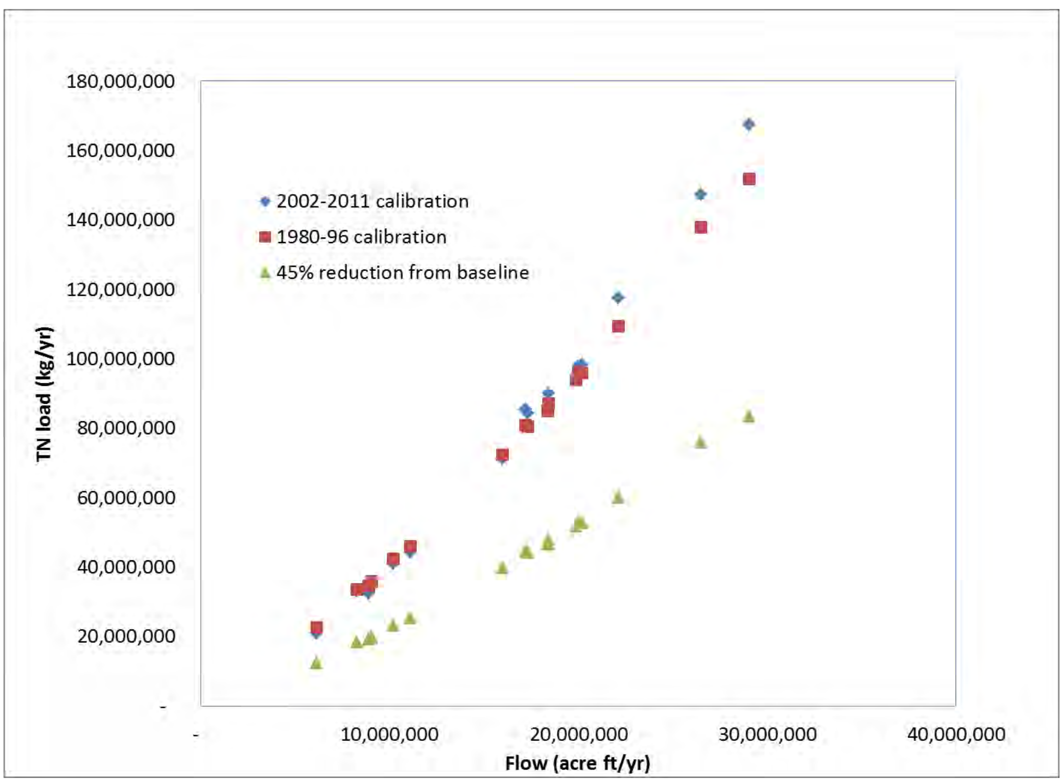


Figure 3-16. Estimated annual nitrogen loads for baseline years based on baseline and recent calibration verses observed flow.

3.4.5 Load Reduction Summary

Table 3-9 and Table 3-10 summarize the proposed water quality targets needed to meet goals (see Chapter 2). Future monitoring efforts will track changes in load, FWMC, and flow. These three variables are not independent and fluctuate annually. Achieving the ultimate goals in this NRS will be based on long-term evaluations that account for changes in river flow conditions.

Table 3-9. Summary of proposed in-stream FWMC targets (mg/l)

Major basin	Goal	FWMC target		Notes
		P	N	
Lake Winnipeg (Red River Only)	10% and 13% reductions from 2003 conditions for phosphorus and nitrogen, respectively	0.30	2.05	In-stream loads; includes out-of-state drainage area
Mississippi River near State Border	45% from average 1980–1996 conditions	0.08	1.50	In-stream loads; includes out-of-state drainage area

Note: P = phosphorus, N = nitrogen

Table 3-10. Summary of proposed in-stream load targets (metric tons per year)

Major basin	Goal	Load target		Notes
		P	N	
Lake Superior	Maintain loading at 1979 conditions	248	NA	MN drainage area only; delivered to lake
Lake Winnipeg (Red River Only)	10% and 13% reductions from 2003 conditions for phosphorus and nitrogen, respectively	2,340	16,258	In-stream loads; includes out-of-state drainage area
		1,123	7,804	In-stream loads; MN drainage area only
Mississippi River near State Border	45% from average 1980–1996 conditions	2,737	53,898	In-stream loads; includes out-of-state drainage area
		2,107	41,502	In-stream loads; MN drainage area only
Cedar, Des Moines, and Missouri River (sum of loads to state border)	45% from average 1980–1996 conditions	437	8,587	MN drainage area only
Total Minnesota Load to the Mississippi River near State Border including Cedar, Des Moines, and Missouri Rivers	45% from average 1980–1996 conditions	2,544	50,088	MN drainage area only

Note: P = phosphorus, N = nitrogen

Chapter 4 provides further analysis to determine reductions needed to meet milestones that take into consideration recent progress from known BMP implementation in the state. BMP implementation data, which are supported by upstream in-stream measurements, are used to quantify recent progress due to the limitations of current in-stream data at the Iowa border. However, in order to achieve milestones, all three measures (FWMC, in-stream loading, and BMP implementation) should be considered when evaluating progress toward milestones and goals.

Chapter 4

Management Priorities and Recent Progress

A function of the *Minnesota Nutrient Reduction Strategy* (NRS) is to identify the nutrient reduction goals and milestones and provide a path to achieve those reductions over time. Accomplishing the goals in an effective and efficient manner requires an understanding of the priority geographic areas within the state where nutrient reductions are most needed, priority nutrient sources, and key programs for delivering those reductions. This chapter describes the NRS's watershed prioritization process and presents a list of key regional, state, and federal nutrient reduction programs to address key nutrient sources. This chapter also presents the results of a program quantification analysis to assess recent progress in nitrogen and phosphorus source load reduction. Ultimately, the NRS should provide the information necessary to align priority major watersheds and priority programs to help programmatic staff at the local, state, and federal levels to better target key program resources.

4.1 Major Watershed Priorities

Comparing watershed nitrogen yields (i.e., lbs/acre of nitrogen and phosphorus) using the Spatially Referenced Regressions on Watershed (SPARROW) model provided the basis for major watershed nitrogen priorities. SPARROW modeling, which has been widely used to compare watershed nutrient loads throughout the country, is further described in Chapter 5. SPARROW modeled yields along with a comparison of available data to the pending river eutrophication standards, serve as the foundation for major watershed phosphorus prioritization. SPARROW reports an 8-digit hydrologic unit code (HUC8) yield as delivered to the state border, which takes into account attenuation of that load as it moves downstream from HUC8 pour point to the state border. This yield is used to determine which HUC8s have the highest nutrient loading per acre that ultimately reaches the state border. Major watersheds (HUC8s) with higher nutrient loading per acre are considered higher priority over lower yielding major watersheds. It is important to recognize that, while prioritization is a beneficial management tool for directing limited resources, significant reduction targets to meet the goals of the NRS—especially in the Mississippi River Major Basin and the Lake Winnipeg Major Basin—cannot be achieved through implementation in a limited number of high-priority major watersheds.

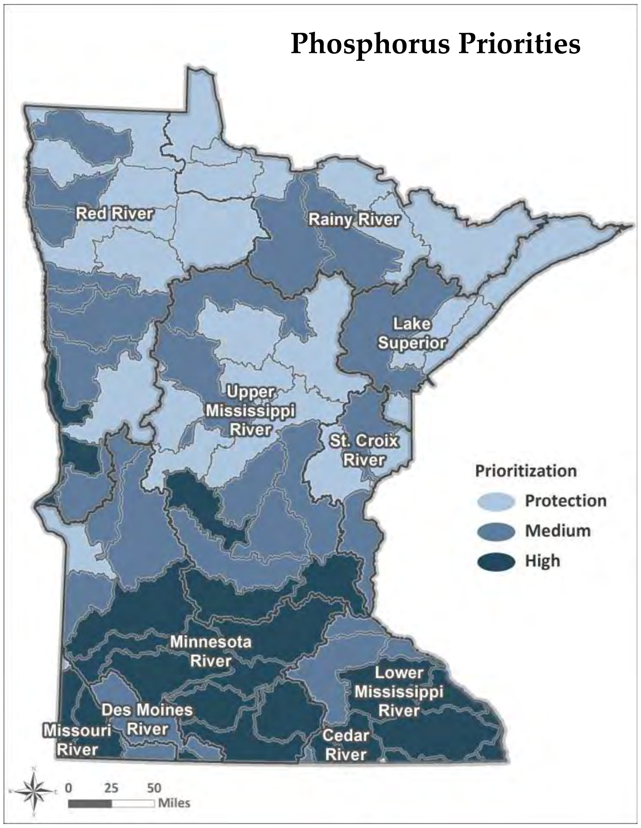
In addition to the SPARROW yield data, an analysis of available monitoring data (minimum 12 samples per reach) was used to determine which stream reaches would be likely determined impaired if the pending river eutrophication standards were in place. While the river eutrophication standards require both the phosphorus concentration and a response variable to exceed the pending water quality criteria for eutrophication in streams, the prioritization process assigns a high-priority ranking to major watersheds that have phosphorus concentrations higher than the pending river eutrophication standards, even when the eutrophication response variable may not be exceeded. This is because even where local waters are not sensitive to high nitrogen or phosphorus loads, downstream waters can still be sensitive to the added nutrients. For those major watersheds without monitoring data, prioritization is based on the SPARROW-modeled yields alone.

The prioritization process occurs at a state level so as to help state programs identify the largest loading major watersheds. A hierarchy of nutrient contributions can be identified for managers within the three major basins. Since priority rankings are assigned to major watersheds with the highest yields statewide, most of the priorities are located in the Mississippi River Major Basin. Table 4-1 summarizes the prioritization criteria and Figure 4-1 presents the results based on phosphorus and nitrogen.

Table 4-1. Major watershed prioritization criteria

<table>
<tr><th colspan="2">Nutrient yield</th><th>Anticipated exceedance of river eutrophication standards</th><th>Prioritization</th></tr>
<tr><td>Highest (upper 25%) yielding nitrogen or phosphorus HUC8s</td><td rowspan="2">OR</td><td>Phosphorus priorities only - HUC8s with greater than or equal to 50% of the monitored reaches estimated as not meeting pending river eutrophication standards.</td><td>High</td></tr>
<tr><td>HUC8s with high (25%–50%) yielding nitrogen or phosphorus</td><td>Phosphorus priorities only - Of the remaining HUC8s with monitoring data (those not already prioritized as High), greater than or equal to 50% of the reaches have elevated phosphorus levels (no elevated response variable).</td><td>Medium</td></tr>
<tr><td colspan="3">All remaining HUC8 major watersheds</td><td>Protection</td></tr>
</table>

Note: Based on additional review from Minnesota Pollution Control Agency (MPCA) technical staff, the following changes were made to the systematic screening approach to prioritization: Lower Minnesota from Medium to High and Lower St. Croix from High to Medium.



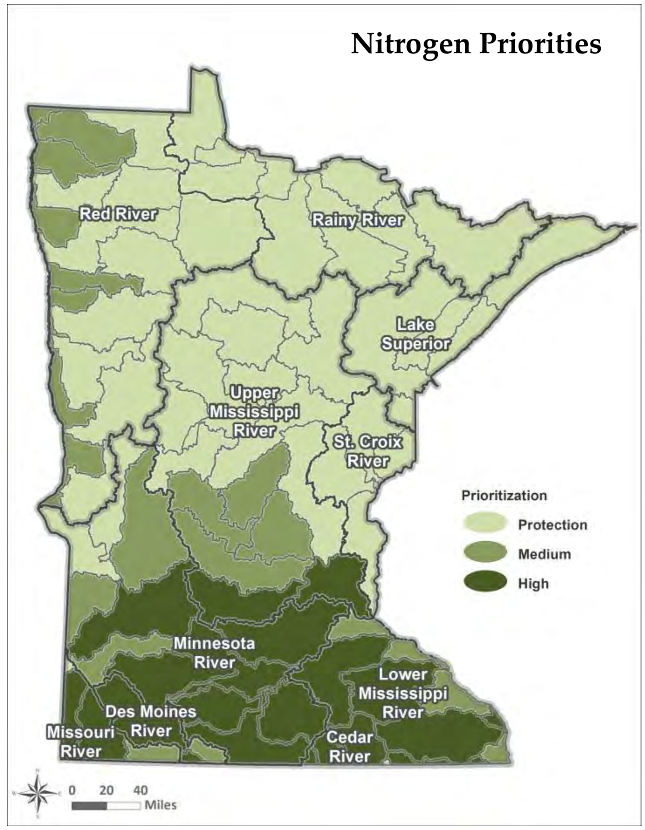


Figure 4-1. HUC8 major watershed priorities for phosphorus loading (left) and nitrogen loading (right).

Areas with a higher vulnerability for groundwater nitrate pollution are shown in Figure 4-2. Townships identified as vulnerable to groundwater contamination have a combination of greater than 20 percent row crops and a high geologic vulnerability. In 2013, groundwater supplies in 22 vulnerable townships were sampled under the leadership of Minnesota Department of Agriculture (MDA). In 18 of those townships at least 10 percent or more of the sampled wells were greater than or equal to 10 mg/l nitrate, which is the nitrate drinking water standard. Many areas of the state that are vulnerable for groundwater nitrate are located in areas with a lower priority for surface water nitrogen. Therefore prioritization efforts to reduce nitrate leaching should consider both surface water and groundwater loads and vulnerability.

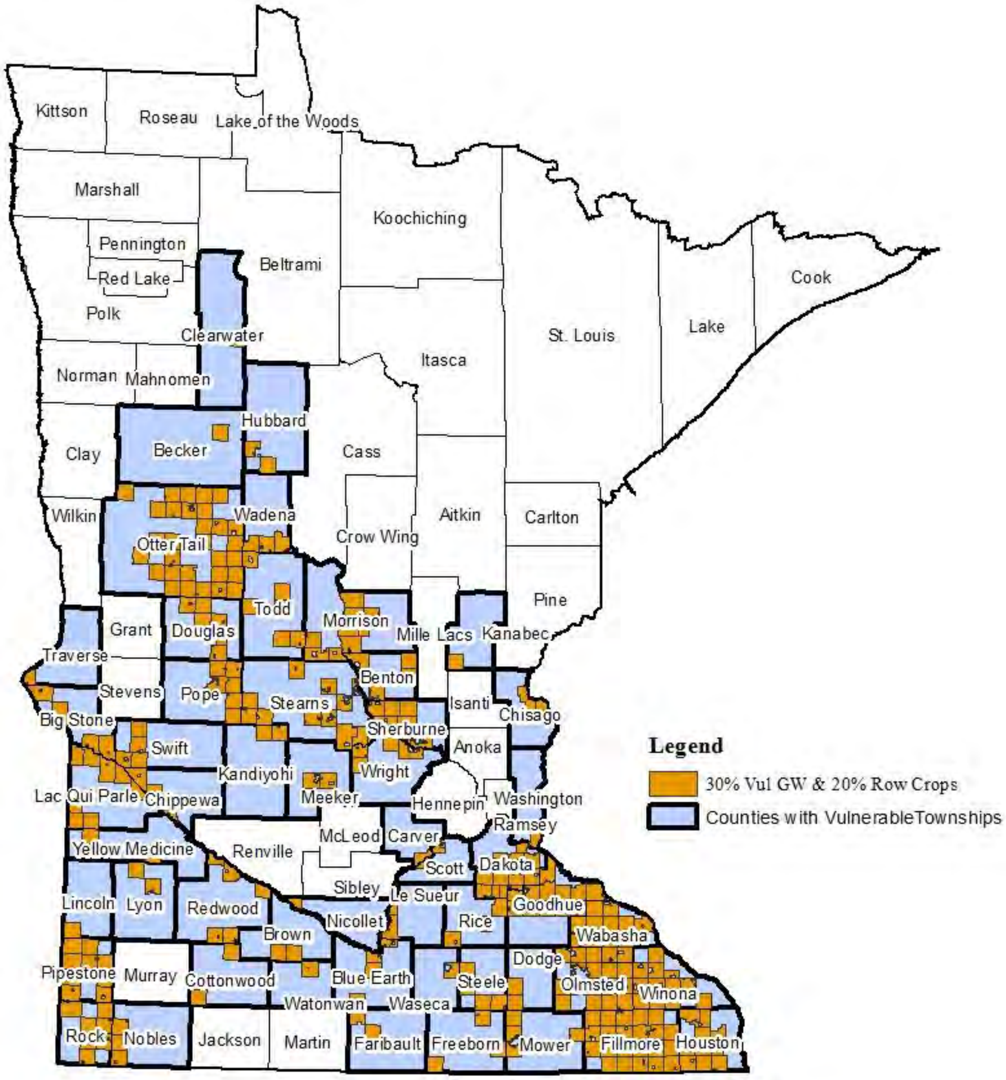


Figure 4-2. Priority groundwater areas (map provided by MDA).

The surface water analysis focuses mostly on priorities based on contributions to downstream loads, considering also potential river eutrophication standards impairments. The priority areas for groundwater protection from nitrate pollution are somewhat different compared to surface water protection priorities since the groundwater priorities are affected by areas of sandy soils which can create high nitrate levels in drinking water wells, but are not dominant enough across the watershed to create high loadings in surface water. Additionally, priorities for protection of overall water quality may be different than nutrient reduction priorities, since many lakes and streams currently have relatively small nutrient loads, but are highly sensitive to new loads if not protected. Some major watersheds also have numerous individual lakes impaired by eutrophication, but they do not contribute appreciably to downstream nutrient loads. Such major watersheds may be a higher priority when considering lake protection and restoration at a smaller scale.

Prioritizing areas at a smaller watershed scale is deferred to development of Watershed Restoration and Protection Strategies (WRAPS) and comprehensive watershed management planning initiatives. WRAPS and watershed plans (e.g., One Watershed One Plan) are developed for each HUC8 in the state according to a rotating schedule. Lower priority HUC8 watersheds can still have subwatersheds with high nutrient yields and may be considered high priority in local water plans. The *Clean Water Legacy Act* (CWLA) requires that WRAPS summarize priority areas for targeting actions to improve water quality, identify point sources, and identify nonpoint sources of pollution with sufficient specificity to prioritize and geographically locate watershed restoration and protection actions. In addition, the CWLA requires including an implementation table of strategies and actions that are capable of cumulatively achieving needed pollution load reductions for point and nonpoint sources. Because many of the nonpoint source strategies provided in WRAPS rely on voluntary implementation by landowners, land users, and residents of the watershed, civic engagement is required as part of WRAPS development in order to create social capital (trust, networks, and positive relationships) with those who will be needed to voluntarily implement best management practices (BMPs).

4.2 Source Priorities

The source assessment presented in Chapter 3 identifies the most significant sources of reducible nutrients in Minnesota (Table 4-2). These sources generally reflect 2009-2011 nitrogen conditions and a hybrid timeframe for phosphorus consisting of 2003 conditions for nonpoint source phosphorus and 2011 phosphorus loads from treated wastewater (reflecting the large reductions in wastewater phosphorus accomplished since 2003). Priority sources are determined on the major basin scale, although it should be noted that different sources may be more or less important at the local scale. Priority sources at the HUC8 scale or smaller will be determined through watershed planning efforts. For example, individual sewage treatment systems are not identified as a significant source of nutrients at the major basin scale but can contribute to lake eutrophication, potentially resulting in water body impairment. Each source will require a different set of implementation activities to achieve nutrient reductions.

Table 4-2. Priority sources

Major basin	Priority phosphorus sources	Priority nitrogen sources
Mississippi River	Cropland, wastewater point sources, and streambank erosion	Agricultural tile drainage and cropland
Lake Superior	Nonagricultural rural runoff [a], wastewater point sources, and streambank erosion	Wastewater point sources
Lake Winnipeg	Cropland and nonagricultural rural runoff	Cropland

a. Includes natural land cover types (forests, grasslands, and shrub-lands) and developed land uses that are outside the boundaries of incorporated urban areas.

Priority sources may differ depending on the scale at which reductions are needed and may be adjusted through local and regional planning processes. There are also sources that cannot be reliably reduced by local or regional scale implementation activities, including atmospheric deposition and loads from forested areas. These sources are therefore not considered priorities in this NRS. It is possible with additional research that a portion of the atmospheric deposition phosphorus load will be attributed to local wind-blown particulates. In this case, implementation of activities aimed at reducing wind-blown sediment could potentially reduce the atmospheric deposition phosphorus load. At this time, research is not available to make this distinction.

4.3 Nutrient Reducing Programs

Nutrient management efforts have been ongoing for several decades. Within the past 15 years, these efforts have increased in number and scope. Table 4-3 provides an overview of key regional, state, and federal nutrient-reducing programs in Minnesota with the initial year of program operation and a brief description of program activities. Most of the nutrient reduction efforts are statewide in scope, although each program has specific eligibility or regulatory requirements that narrow the geographic scope.

Regional, state, and federal programs only account for a portion of the nutrient reduction activities in the state. For example, agricultural producers are implementing BMPs without participating in cost-share programs that allow for tracking of BMP implementation. These activities, likely privately funded, are not tracked or quantified at a statewide level. However, it is probable that there are a significant number of BMPs implemented in this manner that warrant inventorying with assistance from partners at the local level, such as Soil and Water Conservation Districts (SWCDs). For example, two studies recently completed in the Chesapeake Bay watershed identified BMP adoption rates 30 to 50 percent higher than those identified through tracking of BMPs adopted through government programs (Maryland Department of Agriculture 2011).

For certain BMPs, we have existing methods to track the influence of combined government and private actions. The MDA, in partnership with the National Agricultural Statistics Service (NASS) and University of Minnesota, conduct *surveys of nitrogen fertilizer practices* on a regional and statewide scale. Both of these surveys should reflect BMP adoption as influenced by both government and private sector.

In addition, analysis (see Appendix A) of land cover data within a 30-meter buffer zone of all streams in Minnesota reflects a combination of buffers from both government program-influenced and private action (30 meters is beyond most regulatory requirements, but was used to represent a highly protective BMP scenario). The analysis indicates that within the Red River and Minnesota River basins streams have perennial vegetation within 50 and 57 percent of the buffer area, respectively. Figure 4-3 summarizes the percent of buffer area within each HUC8 major watershed that is recorded as perennial vegetation in the 2012 Cropland Data Layer. This level of implementation is not reflected in the quantifiable BMPs tracked as part of existing databases and programs.

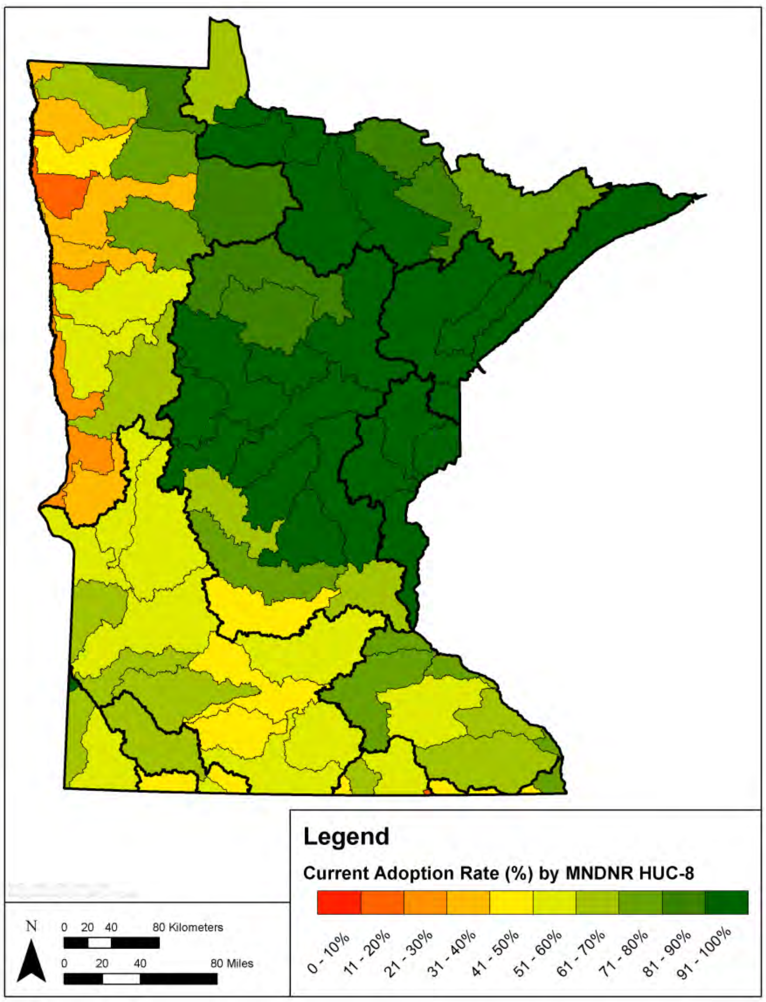


Figure 4-3. Statewide buffer analysis, percent of 30-meter riparian buffer (based on DNR 24K streams) in perennial vegetation.

Examples of some nongovernmental organization and industry-led initiatives include the fertilizer industry Four Rs Program for efficient fertilizer use, Minnesota Agricultural Water Resource Center Discovery Farms, Farm Bureau Green Farm Planning, Dairy Industry Livestock Environmental Quality Assurance, Pork Industry Quality Assurance, Farmland Trust, BMP Challenge, and many others. Nutrient planning is frequently provided through independent or cooperative crop advisors, and conservation tillage equipment advice is typically provided by equipment dealers in many cases without government program assistance. There are many other organizations that either help to support these programs or private advice networks (e.g., University of Minnesota Extension [*http://www1.extension.umn.edu/*]), or work to implement the program requirements and recommendations (e.g., counties, watershed districts [*www.mnwatershed.org*], and private industry). Water quality implementation work has also been occurring for the past three decades by cities, counties, and the Minnesota Department of Transportation, resulting in thousands of BMPs that help mitigate the effects of stormwater. Much of this work predates urban stormwater regulatory permits or programs at the state or federal levels. These entities are not specifically identified in the NRS; however, their actions are critical to implementation.

Nutrient Reduction in Action

Nitrate Reduction Efforts to Protect Groundwater

In response to elevated nitrate levels in its water, Cold Spring, Minnesota has been working with local landowners and others to reduce nitrogen fertilizer applications. In addition to area farmers, the central Minnesota city has partnered with the Minnesota Department of Health (MDH), the Minnesota Department of Agriculture, Minnesota Rural Water Association (MRWA), Stearns County, and the Natural Resource Conservation Service and has benefited from a grant from the Clean Water Fund.

After studying the issue, the wellhead protection team prioritized fields where recharge to public water supply wells was likely occurring and then worked with area farmers and landowners to reduce the nitrate levels. Cold Spring purchased nitrification-inhibitor products from the local co-op, which applied the products to farmers' fields to more efficiently use the nitrogen fertilizer that was being applied to the fields. As a result, farmers reduced their levels of fertilizer by 8 to 16 percent of their current application. The use of nitrification inhibitors, combined with the additional reduction in applied fertilizer, resulted in a decrease of 4,100 pounds of nitrogen applied on 277 acres.

Cold Spring also created a turf management demonstration project in a residential development near the public supply wells to demonstrate to landowners the proper rates and timing of nitrogen fertilizer applications. Beyond reducing the nitrogen fertilizer being applied, the partnership has increased the trust and cooperation between the city and local farmers and landowners, a relationship that had been strained in the past. The partnership, aided by funds from the Clean Water Fund, has improved vital relationships while making safer the water that Cold Spring is supplying to its 4,100 residents.

Monitoring wells have been installed to measure the effectiveness of the program and develop information about the source of contaminated groundwater now supplying the city's wells.

The City of Cold Spring was awarded the Source Water Protection Award by MRWA and MDH in 2013.

Other such efforts are described at:
http://www.mda.state.mn.us/en/protecting/waterprotection/drinkingwater.aspx

Table 4-3. Key regional, state, and federal nutrient-reducing programs

Program (date of program initiation)	Program activities
Metropolitan Council Environmental Services (MCES)	
Point Source Reduction Activities (1967)	MCES collects and treats wastewater at its seven regional treatment plants. It also develops plans to preserve and manage the region's water resources. Under the Point Source Program, MCES reduces nutrient loads through wastewater treatment plant (WWTP) technology upgrades and has phosphorus removal technologies at six of its seven plants that have greatly reduced contributions of phosphorus to the major receiving waters (Mississippi, Minnesota, and St. Croix). MCES develops monthly discharge monitoring reports, in response to permit requirements; WWTP load information available upon request. More information is available at *http://www.metrocouncil.org/environment/AboutMCES/index.htm*.
Nonpoint Source Pollution Management	To help achieve federal and state water quality standards, provide effective water pollution control, and help reduce unnecessary investments in advanced wastewater treatment, the MCES provides technical assistance to address nonpoint source pollution. These efforts include working with partners by providing the technical expertise and water quality and quantity information needed to develop TMDLs for several Metropolitan Area watersheds, conducting research and study on the control and prevention of water pollution (MN Statute 473.244), reviewing local surface water management plans (MN Statute 103B.231, Subd. 7), and providing technical assistance for local management of nonpoint source pollution control.
Water Quality Monitoring and Assessment (Streams – 1989; Rivers – 1930s; Lakes – 1980)	MCES supports several water monitoring programs that collect a variety of data for regional rivers, streams, lakes, WWTPs, and industrial dischargers. MCES is in the process of finalizing a comprehensive stream report that includes loading and trend information for the streams monitored in the metro area. Information on stream, river, and wastewater treatment loads are available on the Council's web site at *http://es.metc.state.mn.us/eims/index.asp* .
Minnesota Board of Water and Soil Resources (BWSR)	
Clean Water Land and Legacy Program (2008)	BWSR uses appropriations from the Clean Water Fund—one of four funds established through the Clean Water, Land, and Legacy Constitutional Amendment approved by voters in 2008—to implement a number of clean water easement programs and the Clean Water Fund Competitive Grant Program, as well as the Feedlot Water Quality Management Program. The goal of the Clean Water Fund directed to BWSR is to reduce nonpoint source pollution by providing Clean Water Fund dollars to local government units for on-the-ground activities, many of them installed on private lands that will result in improved and protected surface and ground water. BWSR requires Clean Water Fund awardees to use the eLINK reporting program to track all Clean Water Fund grant-related projects. BWSR's Annual Report on Clean Water Fund Appropriations for the state legislature (*http://www.bwsr.state.mn.us/cleanwaterfund/2012_BWSR_CWF_Legislative_Rpt-rev4.13.12.pdf)* contains a detailed description of the easement programs receiving funding and the qualitative information on outcomes and effectiveness. More information is available at *http://www.bwsr.state.mn.us/cleanwaterfund/*.

Program (date of program initiation)	Program activities
Erosion Control and Water Management Program/State Cost-Share Program (1978)	The Erosion Control and Water Management Program, commonly known as the State Cost-Share Program, provides funds to Soil and Water Conservation Districts to share the cost of systems or practices for erosion control, sedimentation control, or water quality improvements that are designed to protect and improve soil and water resources. Reductions in erosion and sedimentation from agricultural lands will also result in a reduction of nutrients. Eligible practices that also have implications for controlling nutrients include filter strips, grassed waterways, and wastewater and feedlot runoff controls. BWSR requires the use of the eLINK reporting program to track all cost-share funded projects. More information is available at *http://www.bwsr.state.mn.us/cs/index.html*.
Feedlot Water Quality Management Grant Program (2010)	Clean Water Feedlot Water Quality Management Grant funds provide financial assistance to landowners with feedlot operations less than 300 animal units in size and located in a riparian area or impaired watershed. Technical staff and engineers from local government units and private contractors work with the landowner to develop and implement a pollution control system that protects the environment and maintains the economic viability of the farm.
Regional and Local Resource Management and Planning Programs (1982, 1989)	A number of programs are included under the umbrella of regional and local resource management and planning programs, including comprehensive local water management that focuses on the adoption and implementation of local water management plans linked to land use decisions; watershed planning, including Metro Area surface water management, that focuses on adoption and implementation of local water plans based on watershed district and watershed management organization priorities; Soil and Water Conservation District comprehensive planning that involves review from BWSR; and Metro groundwater planning. Through these programs, BWSR addresses nutrient load reductions by implementing regulations, developing plans, engaging the public, and funding BMPs. More information is available at *http://www.bwsr.state.mn.us/planning/index.html*.
Reinvest in Minnesota (RIM) Reserve Program (1986)	The Reinvest in Minnesota (RIM) Reserve program compensates landowners for granting conservation easements and establishing native vegetation habitat on privately-owned lands that are economically marginal, flood-prone, environmentally sensitive, or highly erodible. The program permanently restores wetlands, adjacent native grassland wildlife habitat, and creates permanent riparian buffers. The RIM Reserve program is implemented in cooperation with county SWCDs. The land remains in private ownership and the landowner retains responsibility for maintenance and paying applicable real estate taxes and assessments. Through the RIM Reserve program, land is retired from production and restored back to its pre-altered state. Once production of agricultural commodities ceases, the stabilized hydrology from the site reduces runoff, thereby reducing sedimentation and nutrients in sediment or soluble forms. Nutrient reductions from the RIM Reserve program would be limited initially during construction periods through full establishment of native vegetation (1-3 years). More information is available at *http://www.bwsr.state.mn.us/easements/rim/index.html*.

Program (date of program initiation)	Program activities
Minnesota Department of Agriculture (MDA)	
Agricultural Best Management Practices (AgBMP) Loan Program (1995)	The AgBMP Loan Program is a water quality program that provides low interest loans to farmers, rural landowners, and agriculture supply businesses. The purpose is to encourage agricultural BMPs that prevent or reduce runoff from feedlots, farm fields, and other pollution problems identified by the county in local water plans. More information is available at *http://www.mda.state.mn.us/en/grants/loans/agbmploan.aspx.*
Nitrogen Fertilizer Management Plan (NFMP) (1990 and updated in 2014)	The NFMP is a strategy for protecting Minnesota's water resources from nitrogen fertilizer use. Originally developed in 1990 and updated in 2014, the plan promotes voluntary nitrogen fertilizer BMPs, evaluates BMP use and effectiveness, and includes response strategies when BMPs are not used or are found to be ineffective. A key component of the NFMP is voluntary nitrogen BMPs based on University of Minnesota field research organized for the five regions of the state. More information is available at*http://www.mda.state.mn.us/en/chemicals/fertilizers/nutrient-mgmt.aspx*.
Farm Nutrient Management Assessment Program (FANMAP) (1993)	This MDA developed diagnostic tool called FANMAP is used to get a clear understanding of existing farm practices regarding agricultural inputs such as fertilizers, manures, and pesticides. Results can be used to design focused water quality educational programs and as a baseline to assist in determining if voluntary BMPs are being adopted. More information is available at *http://www.mda.state.mn.us/en/protecting/soilprotection/fanmap.aspx*
Nutrient Management Initiative (2006)	In cooperation with individual farms and certified crop consultants, the Natural Resources Conservation Service (NRCS), and University of Minnesota, MDA provides technical and financial assistance for on-Farm Evaluation of Nitrogen and Phosphorous Nutrient Management. Field plots are established to track different fertilizer rates and measure resulting yields. More information is available at *http://www.mda.state.mn.us/nmi*
Laboratory Manure Testing Certification (1996)	In response to a need for farmers to test manure for nutrients, MDA assists and validates agricultural laboratories in their manure testing and nutrient management services. More information is available at *http://www.mda.state.mn.us/licensing/licensetypes/mnrcertfaq.aspx*
Agricultural Fertilizer Research and Education Council (2008)	A farmer-led program to advance soil fertility research, technology development, and education that is environmentally and economically sound. More information is available at *http://www.mda.state.mn.us/chemicals/fertilizers/afrec.aspx*
Phosphorus Lawn Fertilizer Law (2002/2005/2007 [full implementation])	The Minnesota Phosphorus Lawn Fertilizer Law regulates the use of phosphorus lawn fertilizer with the intent of reducing unnecessary phosphorus fertilizer use and preventing enrichment of rivers, lakes, and wetlands with the nutrient phosphorus. The law prohibits use of phosphorus lawn fertilizer unless new turf is being established or a soil or tissue test shows need for phosphorus fertilization. This prohibition went into effect in 2004 in the Twin Cities metro area and statewide in 2005. The law also requires fertilizer of any type to be cleaned up immediately if spread or spilled on a paved surface, such as a street or driveway. A report on the effectiveness of this law was completed in 2007 which indicated that phosphorus fertilizer has decreased. More information is available at *http://www.mda.state.mn.us/phoslaw.*

Program (date of program initiation)	Program activities
Certified Animal Waste Technician Licensing (CAWT) (2000)	Minnesota law requires Commercial Animal Waste Technicians (CAWT) to obtain a state license. This license applies to those who apply or manage manure on a for-hire basis, although it does not apply to farmers who apply manure to their own fields. Licensing requires passing a test that is based on proper animal waste management and application. Training manuals and resources for two levels of manure applicators (senior applicators and field hands) have been developed. Education manuals and continuing education for manure applicators are developed through collaboration with the University of Minnesota. More information is available at *http://www.mda.state.mn.us/licensing/licensetypes/cawt.aspx*.
Minnesota Department of Health (MDH)	
Source Water Protection Program (Triggered by 1986 Safe Drinking Water Act amendments)	MDH's Source Water Protection Program contains three components: wellhead protection, source water assessments, and protection of surface water intakes. Under the provisions of the 1986 amendments to the federal Safe Drinking Water Act, states are required to have wellhead protection programs. MDH administers the state wellhead protection rule Minnesota Rules, Chapter 4720.5100–4720.5590 that sets standards for wellhead protection planning. A capture zone for the well (called the wellhead protection area) is designated and a plan is developed and implemented for managing potential contamination sources within the wellhead protection area. The 1986 Safe Drinking Water Act amendments also require states to develop source water assessments. Source water assessments identify potential sources of contamination to a well, lake, or river, and identify strategies for managing contamination. MDH completed assessments for the over 7,000 public water systems in the state. MDH provides source water protection grants using Clean Water Legacy funds to help local water suppliers to implement source water protection activities. Many of these grant funded activities help to reduce nutrient contributions, particularly nitrogen, to source water supplies. Surface water intake protection planning efforts are voluntary for the public water supplies. More information is available at *http://www.health.state.mn.us/divs/eh/water/swp/index.htm*.

Program (date of program initiation)	Program activities
Minnesota Pollution Control Agency (MPCA)	
Feedlot Program (Rules revised in 2014)	The MPCA Feedlot Program implements the MN Feedlot Rules that regulate the collection, transportation, storage, processing, and use of animal manure and livestock operation wastes. The program also provides assistance to counties and the livestock industry. Specific program activities and requirements that reduce agricultural runoff from transporting nutrient-rich manure to streams and lakes include the following: reducing feedlot runoff, improved construction methods and standards, soil testing for the majority of fields receiving manure application, manure application setbacks and rate restrictions, manure nutrient testing, nutrient planning, and enforcement actions. The Feedlot Program has provided oversight for various Clean Water Act (CWA) Section 319 grants that provided money for publications, training sessions, and other outreach that targeted land application activities. A key element of the Feedlot Program is the county feedlot program, a cooperative arrangement between the MPCA and county government to administer Minnesota's feedlot rule. This cooperative program is known as "county delegation" or the "county feedlot program." County feedlot programs are responsible for the implementation of feedlot rules and regulations for many of the feedlots in 54 Minnesota counties, including most of the major feedlot counties. More information is available at *http://www.pca.state.mn.us/index.php/topics/feedlots/index.html*.
Septic Systems or Subsurface Sewage Treatment System Program (SSTS) (1996; current regulations in place since 2011)	Under the SSTS Program, MPCA issues a license to SSTS businesses that design, inspect, install, pump, or site evaluate SSTSs. The SSTS program also provides a registration program for SSTS professionals who have completed training, taken an exam, and have experience in the SSTS field. The program also focuses on outreach, rule interpretation, and education through training and site visits. In 2004, MPCA prepared a 10-year plan to identify, upgrade, and ensure compliance for SSTSs. Regulations restrict nitrate leaching from large systems. More information is available at *http://www.pca.state.mn.us/index.php/water/water-types-and-programs/wastewater/subsurface-sewage-treatment-system-ssts/minnesotas-subsurface-sewage-treatment-systems-program-ssts.html*.

Program (date of program initiation)	Program activities
Industrial/Municipal Wastewater NPDES Permitting (Pretreatment final rules 2008; Minnesota River Basin General Phosphorus Permit – Phase I (Permit) 2005)	National Pollutant Discharge Elimination System (NPDES) permits regulate wastewater discharges to lakes, streams, wetlands, and other surface waters. State Disposal System (SDS) permits regulate the construction and operation of wastewater disposal systems, including land treatment systems. Together, NPDES/SDS permits establish specific limits and requirements for municipal and industrial WWTPs to protect Minnesota's surface and ground water quality for a variety of uses, including drinking water, fishing, and recreation. NPDES/SDS permit requirements may include monitoring, limits, and management practices designed to protect surface and ground water quality. MPCA requires a phosphorus technology based effluent limit of 1 mg/l for new and expanded WWTPs above 1,800 pounds/year. MPCA includes water quality based effluent limits (WQBELs) for phosphorus in permits for WWTPs that contribute to downstream eutrophication impairments; when permits expire, MPCA typically updates WQBELs. In addition, MPCA uses TMDLs to calculate and refine WQBELs. For WWTPs with permits that do not contain phosphorus effluent limits, MPCA includes Phosphorus Management Plans in permits. Nitrogen loads from WWTPs, which would be expected to increase with population increases, were likely reduced through pre-treatment programs over the past several decades. Most facilities in the state have not monitored influent or effluent for nitrogen; however, monitoring data for nitrogen from the state's largest discharges are available. More information is available at *http://www.pca.state.mn.us/index.php/water/water-types-and-programs/wastewater/index.html*.
NPDES/SDS Regulated Stormwater (1994 for Phase I MS4s, construction, and industrial; 2005 for Phase II regulated small MS4s)	The NPDES/SDS Stormwater Program administered by MPCA permits stormwater discharges associated with municipal separate storm sewer systems (MS4s), eleven categories of industrial activities, and construction activities. Most stormwater permits contain narrative effluent limitations expressed as BMPs that contribute to nutrient load reductions, with MS4 permittees required to develop and implement stormwater management programs, and industrial and construction permittees required to develop and implement stormwater pollution prevention plans. Stormwater discharges to or near impaired waters require additional controls or an individual permit. Stormwater permits provide additional nutrient load reductions. For example, the MS4 permit includes a volume control requirement that will reduce total loading to receiving waters and, as a result, reduce nutrient loads. In addition, the construction stormwater general permit requires permittees to design projects such that the water quality volume of one inch of runoff from the new impervious surfaces created by the project is retained on site (i.e. infiltration or other volume reduction practices). More information is available at *http://www.pca.state.mn.us/index.php/water/water-types-and-programs/stormwater/index.html*.

Program (date of program initiation)	Program activities
Nonpoint Source Management Program (Section 319) (1988)	The State of Minnesota Nonpoint Source Management Program Plan (NSMPP) allows Minnesota to receive nonpoint source (NPS) grant funds from the US Environmental Protection Agency under Section 319 of the CWA. The 2008 NSMPP sets Minnesota's Statewide NPS goals and provides a statewide multi-year approach for addressing water quality problems from NPS pollution. Nonpoint source water pollution control proposals submitted to MPCA must be cited in the NSMPP to be considered for Section 319 funding. During 2011, Section 319 funds were used for developmental, education, and research projects and total maximum daily load implementation projects. More information is available at *http://www.pca.state.mn.us/index.php/water/water-types-and-programs/water-nonpoint-source-issues/clean-water-partnership/more-about-the-section-319-program.html*.
Phosphorus Strategy (2000)	Adopted in March 2000 by the MPCA Citizens' Board, the Phosphorus Strategy focuses on addressing phosphorus in NPDES permits through the development of Phosphorus Management Plans. The purpose of Phosphorus Management Plans is to help WWTP operators and managers understand the inputs of phosphorus to, and treatment capabilities of, their facilities, and evaluate pollution prevention and WWTP optimization options that can reduce the amount of phosphorus discharged to Minnesota waters. The strategy also requires effluent limits for new and expanding facilities discharging greater than 1,800 lbs/yr. This portion of the phosphorus strategy was adopted into state rule in 2008. More information is available at *http://www.pca.state.mn.us/index.php/water/water-monitoring-and-reporting/water-quality-and-pollutants/phosphorus/mpca-phosphorus-strategy.html*.
Impaired Waters/Total Maximum Daily Loads (TMDL) Program (1998, first TMDLs approved in 2002)	Water bodies that do not meet Minnesota water quality standards are listed as impaired and require the development of a total maximum daily load (TMDL). Through the Impaired Waters/TMDL Program, MPCA monitors and assesses water quality, lists impaired waters, and develops or oversees development of TMDLs in Minnesota. TMDLs are the comprehensive identification of pollutant sources and assignment of allowable pollutant loads that can be discharged to a water body while still meeting designated uses and water quality standards. The agency also coordinates closely with other state and local agencies on restoration activities. Approximately 27 percent of Minnesota's impaired waters are listed due to nutrients. This number will likely increase with the adoption of nutrient criteria for river eutrophication and aquatic life toxicity. More information is available at *http://www.pca.state.mn.us/index.php/water/water-types-and-programs/minnesotas-impaired-waters-and-tmdls/minnesotas-impaired-waters-and-total-maximum-daily-loads-tmdls.html*.

Program (date of program initiation)	Program activities
Watershed Management Program (2007)	The MPCA Watershed Management program provides watershed planning and integrates program-level technical assistance. A key aspect of the program is the watershed approach, described in Chapter 1. Under the Watershed Management Program, MPCA oversees contract and grants management for nonpoint programs including Section 319 Grants, Clean Water Partnership, and Clean Water Fund (Watershed Restoration and Protection Planning and Surface Water Assessment). In addition, the Watershed Management Program participates in statewide projects that set state-level policy and program goals that align with other state agency water programs including the Nitrogen Loading Study, the Nonpoint Source Management Program Plan, and Statewide Measures. More information is available at *http://www.pca.state.mn.us/index.php/water/water-types-and-programs/surface-water/index.html.*
Water Quality Standards	The Clean Water Act requires states to designate beneficial uses for all waters and develop water quality standards to protect each use. Water quality standards include beneficial uses, narrative and numeric standards, and nondegradation. MPCA is in the process of developing amendments to Minnesota's water quality standards to address numeric river eutrophication standards for rivers, streams, the Mississippi River pools, and Lake Pepin. A nitrate toxicity standard is also being developed, but it will not be adopted into rule until after river eutrophication standards are adopted. More information is available at *http://www.pca.state.mn.us/index.php/water/water-permits-and-rules/water-rulemaking/water-quality-standards.html.*
Department of Natural Resources (DNR)	
Programs within Divisions of Fish & Wildlife and Ecological and Water Resources	DNR drafts forest harvest guidelines in riparian zones as part of the Forest Product Certification process. These guidelines were developed specifically to reduce pollution inputs to forest streams. The DNR's Wetlands Program is responsible for the development of a statewide comprehensive wetlands management plan which sets direction for managing and regulating the state's wetlands.
Shoreland Rules	Currently, MN Rules 6120.3300 require 50-foot buffers planted with perennial vegetation along public waters in agricultural lands in the state, unless the areas are part of a resource management systems plan. DNR drafts the state's shoreland zoning rules and implementation is the responsibility of the local government unit.
Farm Service Agency (FSA)	
Conservation Reserve Program (CRP) (1986)	CRP is a program for agricultural landowners. Through CRP, agricultural landowners receive annual rental payments and cost-share assistance to establish long-term, resource conserving covers on eligible farmland. Offers for CRP contracts are ranked according to the Environmental Benefits Index (EBI). FSA collects data for each of the EBI factors based on the relative environmental benefits for the land offered. EBI factors include water quality benefits from reduced erosion and runoff. The timeframe for CRP contracts is approximately 10 to 15 years. Commodity prices versus CRP rental rates affect enrollment in the program. Information on CRP enrolled acreage is available on a county-by-county basis. More information is available at *http://www.fsa.usda.gov/FSA/webapp?area=home&subject=copr&topic=crp*.

Program (date of program initiation)	Program activities
Conservation Reserve Enhancement Program (CREP) (1998)	CREP is a conservation easement program that helps agricultural producers protect environmentally sensitive land, decrease erosion, restore wildlife habitat, and safeguard ground and surface water. According to MN FSA, the last active CREP agreement was in 2005. County data on CRP (see above) takes CREP acreage into account.
Natural Resources Conservation Service (NRCS)	
Environmental Quality Incentives Program (EQIP) (1996)	EQIP is a voluntary program for agricultural working lands that provides financial and technical assistance to agricultural producers through contracts up to a maximum term of ten years in length. These contracts provide financial assistance to help plan and implement conservation practices that address natural resource concerns and for opportunities to improve soil, water, plant, animal, air, and related resources on agricultural land and nonindustrial private forestland. More information is available at *http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/financial/eqip*.
EQIP National Water Quality Initiative (NWQI) (2012)	The NWQI works in a limited number of select priority watersheds to help farmers, ranchers, and forest landowners improve water quality and aquatic habitats in impaired streams, while measuring the effects from field to streams. NRCS helps producers implement conservation and management practices through a systems approach to control and trap nutrient and manure runoff. Qualified producers receive assistance for installing conservation practices such as cover crops, filter strips, and terraces. NWQI watersheds include the Chippewa River, Seven Mile Creek, and Elm Creek. More information is available at *http://www.nrcs.usda.gov/wps/portal/nrcs/detail/mn/programs/landscape/?cid=stelprdb1047761*.
EQIP Mississippi River Basin Healthy Waters Initiative (MRBI) (2010)	MRBI's primary goals are to improve water quality, improve habitat, and restore wetlands through partnership projects in a limited number of select priority watersheds in the Mississippi River Basin. NRCS plans to achieve this goal primarily by working with producers to avoid, control, and trap nutrient and sediment runoff, and maintain or improve agricultural productivity. Reducing nutrients and sediment losses in MRBI project areas will improve local water quality and may demonstrate a pathway for addressing larger issues such as hypoxia in the Gulf of Mexico. NRCS and its partners are providing additional financial and technical assistance to help producers use agricultural nitrogen and phosphorus most efficiently and reduce nonpoint source pollution. Monitoring and modeling are being used to evaluate the effectiveness of conservation practices on agricultural land in the basin. A three-tiered monitoring and evaluation approach will be used strategically to assess water quality at the edge-of-field, in-stream, and on a watershed scale. Several watersheds are selected as MRBI priority watersheds in Minnesota including the Root River, Upper Cedar, Sauk River, and Middle Minnesota River, along with subwatersheds within the Vermillion River and Upper Minnesota River watersheds. More information is available at *http://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/mn/programs/landscape/?cid=stelprdb1048200*.

Program (date of program initiation)	Program activities
Conservation Security Program (CSP) (2004)	Authorized under the 2002 Farm Bill, but not reauthorized under the 2008 Farm Bill, CSP was a voluntary program that provided financial and technical assistance to promote the conservation and improvement of soil, water, air, energy, plant and animal life, and other conservation purposes on tribal and private working lands. The Conservation Stewardship Program (see below) is very similar to this program. The CSP started in Minnesota in 2004 and although it is no longer in existence, there are existing CSP contracts in Minnesota. According to the NRCS, there are 690 CSP contracts (active or completed) representing 218,329 acres. Program name changes may occur with the 2014 Farm Bill. More information about this former program is available at *http://www.nrcs.usda.gov/wps/portal/nrcs/detailfull/national/programs/?&cid=stelprdb1047061*.
Conservation Stewardship Program (CStP) (2008)	CStP is a voluntary program that encourages producers with tribal and private agricultural land and nonindustrial private forest land to install and adopt additional conservation activities, and improving, maintaining, and managing existing activities. NRCS makes CStP available on a continuous application basis. The program started in Minnesota in 2008. To date, there are 3208 active contracts with 2,100,421.7 acres across the state. CStP contracts last five years. More information is available at *http://www.nrcs.usda.gov/wps/portal/nrcs/main/national/programs/financial/csp/*.
Wetland Reserve Program (WRP) (1990)	WRP is a voluntary program offering landowners the opportunity to protect, restore, and enhance wetlands on their property. NRCS provides technical and financial support to help landowners with their wetland restoration efforts. The goal is to achieve the greatest wetland functions and values, along with optimum wildlife habitat, on every acre enrolled in the program. This program offers landowners an opportunity to establish long-term conservation and wildlife practices and protection. Minnesota has about 1000 WRP contracts covering approximately 100,000 acres. Approximately 37,112 acres of Minnesota's wetlands have been restored through the program. More information is available at *http://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/programs/easements/wetlands/?&cid=nrcs143_008419*.
Collaborative Plans/Initiatives	
Minnesota Agricultural Water Quality Certification Program (2014 pilot)	A new state and federal partnership intended to enhance Minnesota's water quality by accelerating the voluntary adoption of on-farm conservation practices. The program is staffed principally by MDA, and collaborators include MPCA, BWSR, DNR, NRCS, and U.S. EPA. More information is available at *http://www.mda.state.mn.us/en/protecting/waterprotection/awqcprogram.aspx*.
One Watershed One Plan (2014 pilot)	A campaign rooted in work that was initially done by the Local Government Roundtable and BWSR in 2011 which recommended that the various local governments charged with water management responsibility should organize and develop focused implementation plans on a watershed scale. One Watershed One Plan will build off of existing local water management plans and priority concerns, existing TMDLs, WRAPS, and other agency related plans. One Watershed One Plan will address the need for watershed based and focused implementation plans that will be prioritized, targeted, and measurable. More information is available at *http://www.bwsr.state.mn.us/planning/1W1P/index.html*.

Program (date of program initiation)	Program activities
Nonpoint Priority Funding Plan for Clean Water Implementation Funding (draft 2014)	The Nonpoint Priority Funding Plan is developed by BWSR every two years beginning in 2014 as required by the 2013 Clean Water Accountability Act. The Nonpoint Priority Funding Plan aims to provide state agencies with a systematic, coordinated and transparent process to provide assurance that clean water funding allocations are targeted to cost-effective actions with measurable water quality results. The process may also help agencies identify gaps in programming needed to accelerate implementation. Under the Nonpoint Priority Funding Plan, state agencies will use a set of criteria to tie funding decisions to cost-effective water quality outcomes. This will improve Clean Water Fund accountability. Over time, it may also provide local water management authorities with more predictability as they plan, and seek funding for, restoration and protection efforts. The draft Plan is currently under review.

4.4 Progress from Key Programs

As Chapter 3 describes, in-stream nitrogen levels at the Minnesota state line have not shown improvement relative to baseline conditions. Improvements due to implementation of agricultural BMPs focused on nitrogen may be partially offset by changes such as increased corn production and tile drainage, and wastewater point source loads of nitrogen have likely increased slightly over time. Also, where groundwater pathways of nitrogen transport to streams are dominant, the full benefits of BMPs will not show up in the rivers for years. In the case of phosphorus, there have been many known reductions in both agricultural and wastewater loads, some of which can be seen at monitoring stations located upstream of the state border (e.g., Lock and Dam 3). Because elevated soil phosphorus concentrations will take time to decrease after instituting better fertilization practices and because significant amounts of phosphorus can be stored and recycled in flood plains and stream sediments, as well as in Lake Pepin and Mississippi River backwaters, it will take time to see the full benefit of land and water management at the state border. For the Mississippi River, monitoring phosphorus at the state border is further complicated by missing data prior to 1992, as well as loads derived from Wisconsin watersheds.

Quantification of program data is meant to provide an estimate of the recent progress that has been achieved, in terms of nitrogen and phosphorus source load reduction, through implementation of BMPs and wastewater treatment. This recent progress (occurring since 2000) can be applied to meeting major basin reduction goals and milestones. Appendix B provides detailed methods and assessment results from the government program quantification.

The key nutrient-reducing programs identified in Table 4-3 implement or fund numerous structural and nonstructural BMPs. The Natural Resource Conservation Service (NRCS) and Farm Service Agency (FSA), along with the Board of Water and Soil Resources (BWSR) offer a long list of BMPs (see Appendix C for NRCS/FSA BMPs) that are beneficial to nutrient reduction. Not all programs had data that could be translated into spatially quantified nutrient load reductions. As a result, program quantification for assessing recent progress only addresses those programs with applicable data on a HUC8 scale and includes the following:

- Nutrient management (NRCS EQIP)
- Forage and biomass planting (NRCS EQIP)
- Residue management (NRCS EQIP)
- Conservation easements (BWSR Reinvest in Minnesota [RIM])
- Nonpoint source BMPs (as reported in BWSR's eLINK, not including feedlot BMPs)
- Septic system improvements (MPCA Subsurface Sewage Treatment System Program)
- Feedlot projects (MPCA Feedlot Program)
- Phosphorus lawn fertilizer ban

Conservation Tillage in Rice County Photo Credit: USDA NRCS

Data for nutrient management, forage and biomass planting, and residue management were obtained from EQIP, while data for conservation easements were obtained from the BWSR RIM program. Data for nonpoint source BMPs were provided primarily through the eLINK system, which BWSR maintains. The eLINK system allows users to input pollutant reduction estimates. BWSR does provide tools to users for estimating pollution reductions on the field scale but also allows for users to input estimates based on locally derived data from other models if they are available. BWSR staff review data input entered into the system for reasonableness but have no mechanism to evaluate pollutant reduction numbers entered. When analyzing data, BWSR does remove extreme outliers. Therefore, some caution should be used when using pollutant load reductions directly from eLINK.

Data for septic system improvements were based on the estimated number of septic systems that had been identified as an imminent threat to public health or safety and had been brought into compliance. Data for feedlots were derived from the MPCS's Feedlot Program information. A 10 percent reduction in phosphorus loading from urban areas was assumed to have resulted from the statewide phosphorus fertilizer ban; this percent reduction was estimated from research completed in Minnesota (Vlach et al. 2010), Michigan (Lehman et al. 2009), and the Chesapeake Bay watershed (Schueler and Lane 2013).

In addition to the cropland and miscellaneous source BMPs, recent trends in wastewater point source loads were also quantified. Recent trends in point source loads (wastewater) were quantified based on monitored data provided as part of the SPARROW model inputs (Appendix B). The difference in wastewater loads from 2002 and 2005–2006 for nitrogen and 2005–2009 for phosphorus were used to calculate the relative percent change in phosphorus and nitrogen loading from point sources that has recently occurred. The reductions as a percentage were then compared to baseline conditions (e.g., 1980–1996 for the Mississippi River Major Basin), which Table 4-4 presents.

Table 4-4. Summary of recent progress by sector as compared to overall load in each major basin. The load reductions in this table represent estimated load reductions that occur at the state border.

Major basin	Percent in load change by cropland BMPs		Percent in load change by certain misc. source BMPs		Percent in load change by wastewater		Recent progress (as % of total load delivered)	
	P	N	P	N	P	N	P	N
Mississippi River	-8%	-2%	-1%	NA	-24%	+2%	-33%	0%
Lake Winnipeg	-3.7%	0%	-0.3%	NA	-0.3%	0%	-4.3%	0%
Lake Superior	-0.7%	NA	-1.3%	NA	+2.8%	NA	+0.8%	NA

Note: P=phosphorus; N=nitrogen. A negative number indicates reduction; a positive number indicates an increase. Recent progress represents progress since 2000.

Available data indicate that wastewater nitrogen loads in the Lake Superior Major Basin have increased by 411 metric tons (over 12 percent increase) since 2000; however, there is a high level of uncertainty with these data that requires additional analysis and monitoring to verify.

Data are limited for evaluating the reductions resulting from nutrient management BMPs, and the estimates used for nutrient reductions likely underestimate the total reductions. Yet, the water quality findings in the Mississippi River south of the Twin Cities are generally consistent with what is expected due to the estimated reductions from documented BMPs. It may be that the additional BMPs not accounted for in this analysis were offset by other changes in the watersheds. Efforts between 2000 and present have resulted in significant progress in reducing phosphorus loads in the Mississippi River Major Basin, due to BMPs and wastewater treatment plant upgrades. There have also been reductions in phosphorus load to the Lake Winnipeg Major Basin, while estimated loads in the Lake Superior Major Basin (which wastewater point sources dominate) are estimated to have remained relatively stable. In contrast, little to no progress has been made in reducing nitrogen loads across all major basins, which is consistent with in-stream water quality data.

Interim tracking of progress toward the 2025 goals and milestones will be conducted in accordance with Chapter 7 and consistently with the Clean Water Fund Performance reporting. For the Mississippi River Major Basin, interim tracking will ensure environmental progress between recent conditions and the nitrogen milestone and provisional phosphorus load reduction goals. For Lake Winnipeg and Lake Superior, the milestones are equal to the current goal or provisional goals. For phosphorus, there has been strong recent progress toward the goals, but additional strategies will be necessary to reduce loading from all sources to achieve the goal. For nitrogen, there has been some recent progress in agriculture, but wastewater point source loads have generally increased with increasing population. A new focus on reducing nitrogen loads from both agriculture and wastewater point sources will be necessary to achieve the nitrogen milestone.

Chapter 5

Point and Nonpoint Source Reductions

Chapter 2 presented the *Minnesota Nutrient Reduction Strategy* (NRS) goals and milestones which are also in Table 5-1. Achieving the goals and nitrogen milestone by 2025 will depend on increased implementation of ongoing programs and practices by key sectors in targeted areas. This chapter describes practices and technology that can be used to reduce phosphorus and nitrogen inputs to waters from key sources and presents example scenarios projected to meet the nutrient reduction milestones.

Table 5-1. Goals and milestones

Major basin	Pollutant	2015 to 2025	2025 to 2040
Mississippi River (Includes the Cedar, Des Moines, and Missouri Rivers)	Phosphorus	Achieve 45% reduction goal (12% from current conditions)	Work on remaining reduction needs to meet water quality standards
	Nitrogen	Achieve 20% reduction from baseline (20% from current conditions)	Achieve 45% reduction from baseline
Lake Winnipeg [a] (Red River Only)	Phosphorus	Achieve 10% reduction goal (6% from current conditions)	Achieve any additional needed reductions identified through international joint efforts with Canada and in-state water quality standards
	Nitrogen	Achieve 13% reduction goal (13% from current conditions)	
Lake Superior	Phosphorus	Maintain goals, no net increase	
	Nitrogen	Maintain protection	
Statewide Groundwater/ Source Water	Nitrogen	Meet the goals of the 1989 Groundwater Protection Act	

a. Timeline and reduction goals to be revised upon completion of the Red River/Lake Winnipeg strategy.

To reach the 2025 goals and milestones, and eventually basin-wide goals, additional best management practices (BMPs), wastewater treatment, and other nutrient reduction activities will be needed. . The NRS includes select BMPs and treatment options to guide implementation; however, any combination of BMPs and treatment options that achieve the load reduction goals can be used. As new research is done, additional BMPs and treatment options are expected to become part of the NRS. Research is important to improving the current technologies and will be particularly critical to achieving nitrogen load reduction progress beyond the milestone target. As new technologies are made available and ongoing evaluation of progress toward goals is conducted, future adaptations to the NRS strategies will be needed.

5.1 SPARROW Model

U.S. Geological Survey (USGS) Spatially Referenced Regressions on Watershed (SPARROW) modeling provides a common reference point for evaluating loads from different source categories at major watershed outlets and in the state's rivers. SPARROW is based on land use conditions of 2002 (with a subsequent update for wastewater point source loads). SPARROW addressed land use decisions but does not allow quantification of the effects of specific BMPs or changes in water quality over time. However, the model is used to support calculating nutrient load reduction percentages based on the effects of BMPs quantified through separate efforts.

A spreadsheet tool was developed to evaluate phosphorus reduction scenarios for cropland, incorporating BMP efficiencies based on research, spatial data, SPARROW model outputs, and other information. The 2002 SPARROW results were used to provide a common reference point for the evaluation of watershed loads and the percent of change caused by various nutrient load reductions. Table 5-2 summarizes the loading results from SPARROW, both as an estimate of local stream loads aggregated at the Basin Scale which is labeled as "subwatershed", and as delivered downstream at the state line (measured at De Soto, Wisconsin). The "delivered" loads represent the loads at the state line, accounting for attenuation due to decay, settling, and other mechanisms as SPARROW specifies. The difference between subwatershed and delivered loads to state line reflects estimated transport losses occurring in the streams and rivers within Minnesota.

Table 5-2. SPARROW loading results by basin

Basin	Nitrogen subwatershed load (metric tons/year)	Nitrogen load, delivered, state line (metric tons/year)	Phosphorus subwatershed load (metric tons/year)	Phosphorus load delivered, state line (metric tons/year)
Cedar River	7,216	6,918	246	242
Des Moines River	5,726	4,507	367	251
Lake Superior	3,774	3,656	263	255
Mississippi River	116,200	99,441	6,351	5,553
Missouri River	6,617	5,208	424	290
Rainy River	3,791	2,606	301	204
Red River of the North	20,770	16,822	1,243	949

Notes:
Subwatershed loads include surface and subsurface transport to the SPARROW subwatershed stream reach and transport through half of the stream reach, representing the cumulative loads in the subwatershed near the sources.
Delivered loads represent the loads at the state line, accounting for attenuation due to decay, settling, and other mechanisms.

SPARROW load estimates are based on the following assumptions:

- The SPARROW model approximates nonpoint source loading for the 2000–2002 period.
- These loads reflect the wastewater point source update, which incorporates updated data from the Minnesota Pollution Control Agency (MPCA) (updated to 2005–2006 for nitrogen and 2005–2009 for phosphorus) and is assumed to approximate current wastewater point source loading.
- The Mississippi River Basin loads are tabulated at De Soto, Wisconsin, just downstream of the Minnesota-Iowa state line.
- The Cedar River and Des Moines River do not drain to the Mississippi River at the Minnesota state border. Rather, their basins ultimately drain to the Mississippi River farther downstream. For this analysis, the basin loads delivered to either the 8-digit hydrologic unit code (HUC8) outlets or the state line (the more upstream location) are used for Cedar and Des Moines, since the HUC8 outlets roughly correspond to the state line.
- Several HUC8 watersheds in Minnesota are not modeled in SPARROW. These include the following:
  - 04020300 (Lake Superior – HUC8 that only includes the lake)
  - 07080102 (Upper Wapsipinicon – Part of the Cedar River Basin, does not meet the Cedar until much farther downstream in Iowa; very small portion in Minnesota)
  - 10170202 (Missouri River – Upper Big Sioux)
  - 10170203 (Missouri River – Lower Big Sioux)

- 10170204 (Missouri River – Rock River)
- 10230003 (Missouri River – Little Sioux)

Loading for the Upper Wapsipinicon HUC8 was estimated by calculating the average unit area loading for the remaining Cedar River HUC8s from SPARROW and multiplying the unit area load by the HUC8 area. Similarly, the Des Moines River HUC8 loadings were used for approximating loading for the Missouri River HUC8s.

The SPARROW results can be used to estimate the proportion of delivered nutrient loads associated with different major source categories; however, communicating this must be done with some caution. For example, SPARROW provides estimates of delivered load associated with agriculture based on the regression model that includes manure, farm fertilizers, and fraction of catchment with tiles as parameters. However, SPARROW does not separate a number of the individual sources identified in the *Detailed Assessment of Phosphorus Sources to Minnesota Watersheds* (Barr Engineering 2004). Most notably, SPARROW does not separately account for the portion of phosphorus load due to streambank erosion and atmospheric deposition, estimated as 17 percent and 8 percent, respectively, of the total phosphorus load in the Mississippi River Basin (Table 3-2). The SPARROW estimates of agricultural load generalize the loads and implicitly include streambank erosion and atmospheric deposition in agriculturally dominated landscapes. The scenario analyses provided in the NRS require identification of the fraction of nonpoint loading that is attributable to those upland agricultural practices that can be controlled by BMPs. Therefore, we recalculate the upland agricultural fraction of load from the SPARROW results based on Table 3-2.

As indicated in Table 3-2, agricultural sources (cropland runoff and agricultural tile drainage combined) account for an estimated 38 percent of the total load in the Mississippi River Major Basin and 42 percent of the total load in the Lake Winnipeg Major Basin (sum of cropland runoff and agricultural tile drainage proportions). These percentages represent the baseline time period. As included in Table 3-2, point sources (NPDES permitted wastewater discharges) contribute 18 percent and 11 percent of the total phosphorus load in the Mississippi and Lake Winnipeg major basins, respectively. A refined estimate was used to determine the agricultural fraction of SPARROW loads by selecting 38 percent of the non-wastewater SPARROW load. Wastewater point source loads and agricultural loads are described further in Sections 5.2 and 5.3, respectively.

5.2 Recommended Wastewater Reductions

There has been a focus on wastewater treatment for phosphorus in Minnesota since 2000 with the adoption of the Phosphorus Strategy. While phosphorus loads from wastewater have reduced dramatically since 2000, nitrogen loads have remained constant or increased. Wastewater phosphorus and nitrogen loads account for approximately 16 percent and 8 percent of the total statewide loads delivered to the state border, respectively, based on USGS SPARROW outputs. Recommended reductions are provided below to achieve the goals and milestones.

5.2.1 Wastewater Technologies

Additional nutrient load reductions from wastewater are also needed to achieve milestones and goals. No new technologies are necessary for phosphorus removal. The majority of the municipal wastewater volume has already been treated to reduce phosphorus using biological phosphorus removal at the state's largest facilities and a mix of biological and chemical addition at other facilities. The majority of the state's municipal wastewater plants are stabilization ponds, which typically discharge at half the effluent concentration of mechanical facilities without phosphorus limits. Several smaller to larger sized mechanical facilities will still be required to reduce phosphorus discharges due to continued application of state and federal regulations. It is anticipated that biological chemical removal technologies will be used at these wastewater facilities. Some facilities might add effluent filters to achieve effluent limits less than 0.6 mg/l phosphorus consistently.

In the past, wastewater treatment technologies for nitrogen focused on converting ammonia plus ammonium-nitrogen to nitrate-nitrogen, to reduce aquatic toxicity and oxygen demand. Nitrate removal will be a new treatment consideration for most of Minnesota. Some facilities in Minnesota are required to meet a 10 mg/l nitrogen effluent limit to protect sources of drinking water. These facilities are relatively small in size and few in number.

The primary method for nitrogen removal from wastewater is biological nitrification/denitrification. Biological nitrification/denitrification is achieved by utilizing aerobic reactors to oxidize the influent ammonia nitrogen to nitrate, and anoxic reactors to reduce the resulting nitrate to nitrogen gas. Utilizing biological nitrification/denitrification, over 70 percent of the total nitrogen can be removed from the influent stream, depending upon the process flow design, temperature, and other factors. Adequate detention time is a key factor in biological nitrogen removal. A wastewater treatment plant (WWTP) utilizing a single anoxic reactor can achieve effluent total nitrogen concentrations of 6 to 8 mg/l. With multiple anoxic reactors, effluent nitrogen concentrations of under 3 mg/l can be achieved (EPA 2009, EPA 2010). If all WWTPs in Minnesota treated effluent down to a discharge concentration of

10 mg/l, a 41 percent reduction in wastewater nitrogen loads is estimated. If all WWTPs in Minnesota treated effluent down to a 6 mg/l effluent concentration, an estimated 62 percent reduction in wastewater nitrogen loads could be achieved.

As an alternative to utilizing multiple anoxic reactors, nitrate removal can be achieved by incorporating aerobic reactors with denitrification filters. The use of chemical addition, breakpoint chlorination, or ion exchange has diminished in recent years due to the effectiveness of achieving low total nitrogen effluent concentrations using biological treatment.

5.2.2 Phosphorus Wastewater Reductions to Achieve Goals

Substantial progress has been made in reducing wastewater loads of phosphorus in the Mississippi River Major Basin, particularly in the Minnesota River Basin and in the Metro Area Major Watershed. The focus now is to move forward to achieve the goal by pursuing additional wastewater reductions in the remaining basins with particular attention on the Cedar, Des Moines, Lower Mississippi, and Red River Basins, as well as further decreasing agricultural and miscellaneous sources by the year 2025.

Minnesota has established wastewater effluent limitations for phosphorus since the early 1970s for cases:

> *Where the discharge of effluent is directly to or affects a lake or reservoir, phosphorus removal to one milligram per liter shall be required… In addition, removal of nutrients from all wastes shall be provided to the fullest practicable extent wherever sources of nutrients are considered to be actually or potentially detrimental to the preservation or enhancement of designated water uses.*

This rule, referred to as the "Phosphorus Rule," had historically applied to discharges up to 50 miles upstream from the nearest lake or reservoir. This rule did not affect the majority of wastewater facilities in Minnesota during the Mississippi River baseline time period, since most facilities discharge to rivers. On March 28, 2000, the MPCA's Citizens' Board adopted *a strategy for addressing phosphorus in National Pollutant Discharge Elimination System (NPDES)* permits, which established a process for the development of 1 mg/L phosphorus limits for new and expanding WWTPs that had potential to discharge phosphorus in excess of 1,800 pounds per year. It also established requirements for other WWTPs to develop and implement Phosphorus Management Plans. The MPCA's Phosphorus Strategy was formally adopted as *Minnesota Rule Chapter 7053.0255* in 2008.

Implementation of MPCA's Phosphorus Strategy and Minnesota Rule Chapter 7053.0255 has resulted in significant wastewater effluent phosphorus load reductions since the year 2000 (Table 5-3). The modeled effects of these reductions at the state border are presented in Chapter 4.

Table 5-3. Statewide wastewater phosphorus effluent loading (metric tons/year)

	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
Industrial Wastewater	214	196	177	163	162	187	182	185	184	186	194	180	152
Domestic Wastewater	1,975	1,923	1,813	1,379	1,123	927	897	873	816	676	657	659	546
Total	2,189	2,119	1,990	1,542	1,285	1,114	1,079	1,058	1,000	862	851	839	698

The loads presented in this table are derived from facility monitoring data and do not represent load delivered to the state line. See Chapter 4 for a summary of modeled loads delivered to the state line.

The accuracy of phosphorus load estimates from wastewater has improved since the year 2000 because of an increase in monitored effluent concentrations requiring fewer assumed values for effluent concentration (Figure 5-1).

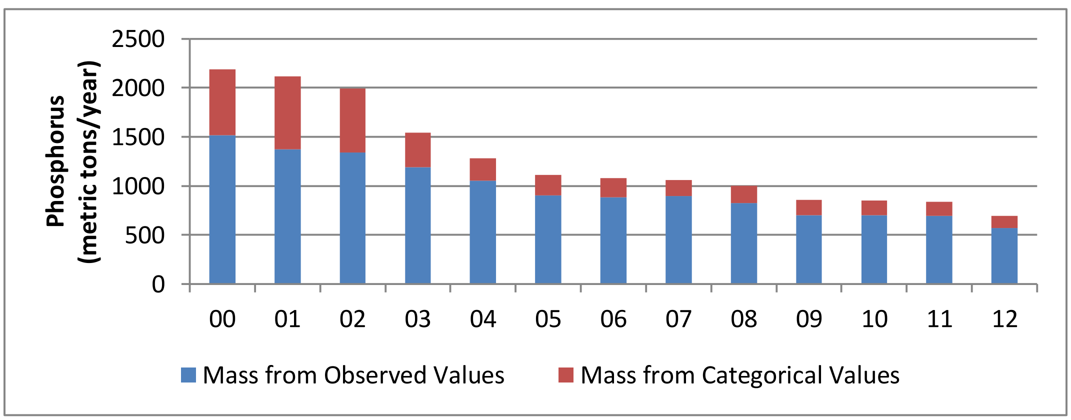


Figure 5-1. Confidence measure for effluent phosphorus data by year.

Mass estimates derived from categorical values (red) have less certainty than the mass based on observed monitoring results (blue).

The majority of effluent phosphorus loads generated are from domestic wastewater treatment facilities (Table 5-4, Figure 5-2), but the percentage of industrial phosphorus loading has increased in proportion to phosphorus reductions achieved by municipal wastewater treatment facilities.

Table 5-4. Proportion of wastewater phosphorus loading

	2000–2002 percent of total (%)	2010–2012 percent of total (%)
Industrial Wastewater	9%	22%
Domestic Wastewater	91%	78%
Total	100%	100%

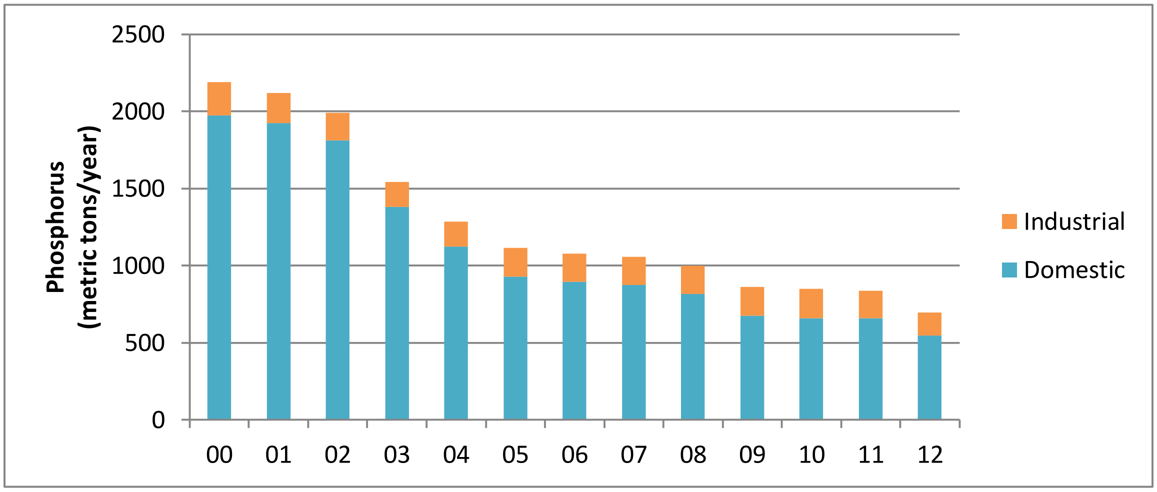


Figure 5-2. Comparison of annual industrial and municipal wastewater phosphorus loads.

Reduction percentages were calculated from 3-year loading averages to account for annual flow variability. The baseline load for the 2000–2002 period was 2,099 metric tons per year and the load for the 2010–2012 period was 796 metric tons per year, representing a 62 percent reduction in statewide wastewater phosphorus loading since 2000 (Table 5-5, Figure 5-3).

Table 5-5. Statewide wastewater effluent phosphorus percent reduction estimates

	Average 2000–2002 (MT/year)	Average 2010–2012 (MT/year)	Percent reduction (%)
Industrial Wastewater	196	175	11%
Domestic Wastewater	1,903	621	67%
Total	2,099	796	62%

Statewide NPDES wastewater effluent phosphorus load reductions are estimated at 1,303 metric tons per year (reflects facility discharge, not load delivered to the state line) since the MPCA's adoption of its Phosphorus Strategy in 2000. Figure 5-3 charts effluent phosphorus loads since 2000 (yellow line). The red line represents an estimate of increasing wastewater phosphorus loading based on an average effluent concentration of 4 mg/l and an annual effluent flow increase due to a 1 percent per year population growth. The blue horizontal line estimates the wastewater loading goal for full implementation of the state's existing phosphorus rule. The orange and purple lines represent a phase-in period and full implementation of the existing phosphorus rule. Compliance with existing rules includes water quality-based effluent limits for facilities upstream of impaired lakes such as Lake Pepin. The previously referenced "within 50-mile rule" no longer applies to discharges upstream of lakes. Thus, many facilities are receiving new limits based on Lake Pepin. Future adoption of river eutrophication standards will likely result in additional wastewater effluent load reductions.

Table 5-6 summarizes the anticipated phosphorus load reductions associated with permitted wastewater until the year 2025. Projected future loading is estimated based on the application of Lake Pepin Total Maximum Daily Load (TMDL)-style categorical effluent limitations to all wastewater dischargers in the state. Permitted loading assumptions were made on the basis of concentrations related to facility size, as well as type and flow related to currently reported values. Reductions were assumed to occur over a phase-in period ending in 2020. From then on, flows and loading are assumed to increase based on a natural population growth rate of 1 percent per year.

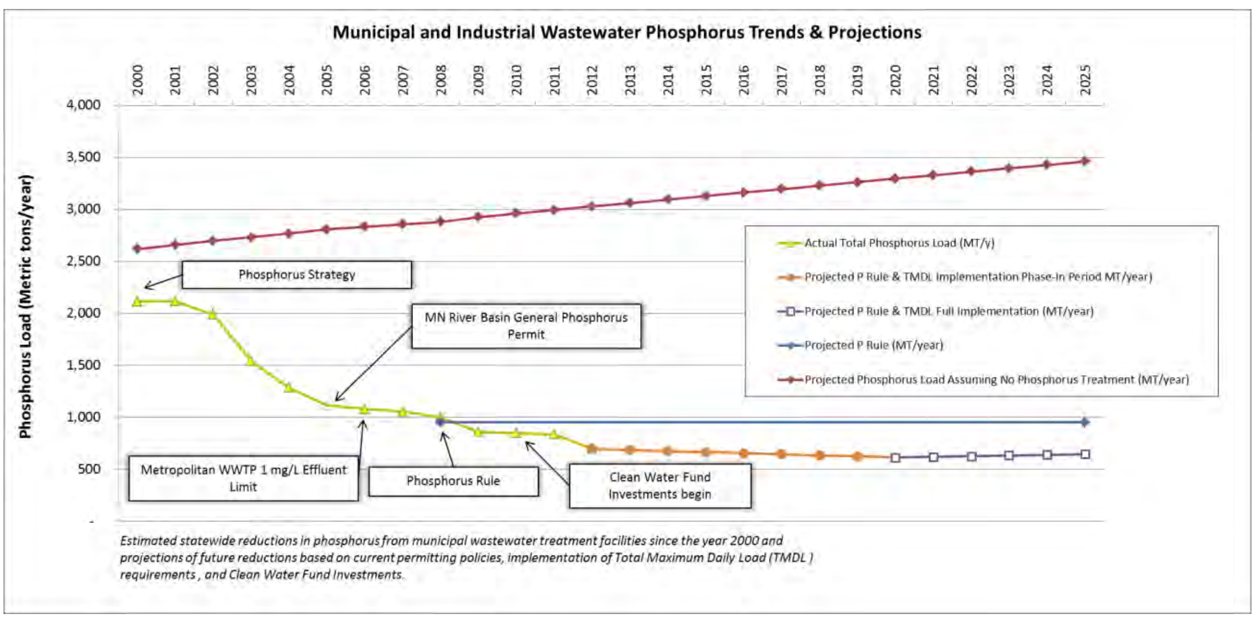


Figure 5-3. Domestic and industrial wastewater phosphorus loading trends and projections.

Table 5-6. Domestic and and industrial wastewater phosphorus loading trends and projections by basin (metric tons/year)

Basin	2000	2005	2010	2015	2020	2025
Lake Superior	36	49	42	52	48	51
Upper Mississippi	1,191	357	240	198	199	209
Minnesota	448	258	193	144	163	171
St. Croix	14	16	12	13	13	13
Lower Mississippi	272	219	115	82	74	77
Cedar	35	78	102	59	16	17
Des Moines	62	14	20	13	9	10
Red	31	51	51	32	22	24
Rainy	51	63	67	67	67	70
Missouri	18	8	9	5	4	5
Total	**2,158**	**1,114**	**851**	**667**	**615**	**647**

The loads presented in this table are derived from facility monitoring data and do not represent loads delivered to basin outlets. See Chapter 4 for a summary of modeled loads delivered to the state line.

Table 5-7 presents planned reductions in phosphorus loads from WWTPs, as included in the NRS. Values in this table represent loads delivered to the state line. The phosphorus load reductions were calculated by comparing the projected 2025 loads with the most recent (2012) monitored loads at the HUC8 level. The load reduction at the HUC8 level was then converted to an equivalent load reduction at the state line by applying the percent attenuation (between the HUC8 and state line) as calculated from SPARROW.

Table 5-7. Summary of expected wastewater phosphorus reductions for goal implementation

Major Basin	NRS wastewater phosphorus load reductions for goal (metric tons)
Mississippi River	37.2
Lake Winnipeg	14.9
Lake Superior	NA

5.2.3 Nitrogen Wastewater Reductions to Achieve Goals and Phase 1 Milestone

Municipal and industrial wastewater facilities contribute 9 percent of the nitrogen load to the Mississippi River Basin, 31 percent of the nitrogen load in the Lake Superior Major Basin, and 6 percent of the nitrogen load in the Lake Winnipeg Major Basin. Municipal facilities account for 86 percent of statewide wastewater nitrogen load. The 10 largest point sources, as measured by annual average nitrogen load, collectively amount to 67 percent of the load from point sources statewide.

Limited influent and effluent nitrogen concentration data are available. Table 5-8 represents current assumptions about effluent total nitrogen concentrations discharged by Minnesota wastewater treatment facilities and are based on a combination of effluent data from Minnesota and Ohio WWTPs. Increased effluent nitrogen monitoring frequencies are needed to validate current assumptions and understand the variability in wastewater effluent concentrations and loads. WWTP influent nitrogen monitoring is needed to develop an understanding of the magnitude and variability of loads and sources as a basis for development of nitrogen management plans.

Table 5-8. Nitrogen concentrations for treated municipal wastewater

Category	Concentration assumptions (mg/L) nitrogen
Class A municipal – large mechanical	19
Class B municipal – medium mechanical	17
Class C municipal – small mechanical/pond mix	10
Class D municipal – mostly small ponds	6

There are five municipal wastewater facilities in Minnesota that are required to reduce nitrogen loads through effluent limits (three WWTPs and two industrial dischargers). Table 5-9 provides a summary of the estimated existing nitrogen loads from point sources as reported in SPARROW (delivered to the state line).

Table 5-9. Wastewater loads by major basin, derived from SPARROW

Major Basin	Wastewater nitrogen delivered to state line (metric tons/yr)
Mississippi River [a]	9,363
Lake Winnipeg	304
Lake Superior	1,212
Total	**10,879**

a. SPARROW did not include the Missouri River Basin; therefore, wastewater loads for the Missouri River Basin are derived from MPCA estimates.

It is estimated that a 20 percent cumulative reduction in wastewater nitrogen loads, along with load reductions achieved for other sectors including agriculture, will achieve the goal in the Lake Winnipeg Major Basin and the Phase 1 nitrogen milestone in the Mississippi River Major Basin. Table 5-10 summarizes the anticipated load reductions by basin. Values in this table represent loads delivered downstream of Minnesota. Additional data from increased monitoring frequencies and nitrogen management knowledge gained in the coming years will allow for reevaluation of the goal's attainability in the future.

Table 5-10. Summary of 2025 wastewater nitrogen reductions

Major Basin	2025 wastewater nitrogen load reductions (metric tons)
Mississippi River	1,872.6
Lake Winnipeg	60.8
Lake Superior	NA

5.3 Recommended Agricultural Reductions

In 2004, cropland and pasture runoff plus tile drainage contributed an estimated 29 percent of the statewide phosphorus load in an average flow year (Table 3-2). This percentage has increased to an estimated 32 percent since 2003 due largely to the major phosphorus reductions accomplished in wastewater since 2004. A large part of the remaining nonpoint phosphorus load is due to near channel sources such as stream channel erosion, much of which is indirectly affected by an increase in erosive stream and river flows and atmospheric deposition, some of which is due to wind erosion. The *Nitrogen in Minnesota Surface Waters* study (MPCA 2013a) estimated that agriculture contributes 73 percent of the statewide nitrogen load in a typical year. Because agricultural sources contribute the bulk of the statewide nitrogen load and a substantial portion of the phosphorus load, nitrogen and phosphorus reductions from agricultural sources are key to successfully achieving the milestones. Recommended agricultural BMPs to address phosphorus and nitrogen are provided below.

Treatment Wetland under Construction Photo Credit: Tetra Tech

5.3.1 Agricultural Best Management Practices

A variety of management practices (Appendix C) are available to address agricultural nutrient loads. Selection of BMPs should be based on the specific characteristics of individual watersheds and fields as well as producer farming systems. Similarly, the performance of individual BMPs can vary widely depending on local soils, slopes, and other conditions. A challenge for developing a statewide NRS is describing approximate representations of the efficacy of BMPs across the entire state.

Phosphorus in fields is predominantly attached to soil particles, and measures that reduce soil erosion will also reduce phosphorus loading. Because phosphorus doesn't leach as readily as nitrogen, it tends to be persistent and can build up in soil. Where soil phosphorus concentrations are very high, soluble phosphorus can leach from fields and be transported with surface runoff or in drain tile water. Past over-application of phosphorus is especially likely to occur when manure is not credited for fertilizer value, or rates are based only on crop nitrogen needs without regard to potential over-application of phosphorus. Such practices can result in elevated soil phosphorus concentrations that can increase phosphorus loading rates for years. As a result, BMPs to reduce phosphorus loads from agriculture focus on increasing fertilizer use efficiency to maintain optimal soil phosphorus concentrations and decreasing soil erosion to reduce the risk of sediment and phosphorus loading from fields to water bodies.

Various tools can be used to estimate the risk of phosphorus loss from cropland, ranging from complex to simple models. Minnesota has a Rapid Phosphorus Index, which is a simple screening tool that helps determine when to apply the more complex Minnesota Phosphorus Index (MN P Index). The MN P Index incorporates multiple aspects of phosphorus management, and estimates the risk of phosphorus loading based on soil phosphorus concentrations, erosion risk (crops, soils, slope, and tillage), and phosphorus fertilizer and manure rate and method. The MN P Index estimates phosphorus loss risk through three major surface pathways: erosion, rainfall runoff, and snowmelt runoff. A first step in agricultural management for phosphorus loading is to encourage wider use of the MN P Index. While phosphorus is a necessary nutrient for plant growth, it can also be a pollutant in lakes and rivers that can cause degraded water quality and impairments. The management challenge for producers is the need to maintain adequate, but not excessive, soil phosphorus concentrations while minimizing erosion risk. Achieving an appropriate soil phosphorus concentration depends on fertilization practices over time that account for preexisting natural soil phosphorus levels and historical buildup of soil phosphorus due to livestock, green manures, and fertilization.

Like phosphorus, nitrogen is also a critical nutrient for plant growth. However, there are fundamental differences in the behavior of nitrogen and phosphorus in the environment that influence the performance of individual BMPs and also affect the evaluation of that performance. Unlike phosphorus that is conserved in the environment, nitrogen tends to be more mobile, and cycles within the air, land and water. The inorganic forms in particular are predominantly soluble. This means that much of the nitrogen load moves with water. For example, 6 percent of the statewide nitrogen load to rivers moves with cropland surface runoff, but 67 percent moves with drain tiles that collect and redirect subsurface flows to surface waters in areas that are naturally poorly drained, or to groundwater beneath cropland where soils are naturally drained. Because nitrate-nitrogen leaches from the soil, is taken up by the crop, or is lost to the atmosphere, it has low persistence in soil and cropping requires frequent replenishment by soil nitrogen mineralization and fertilization. As a result, nitrogen loading to surface waters is largely determined by hydrology; types of vegetation; and the form, rate, timing, and method of nitrogen fertilizer application. Management practices that reduce nitrogen application rates, remove dissolved nitrogen from soil and groundwater stores, modify hydrology, or trap and treat tile discharges. Most of these BMPs can be summarized in terms of nutrient load reduction efficiencies; however, actual removal efficiencies for nutrient management practices will depend on the difference between typical current practice and optimum fertilizer form, rate, timing, and method. The Watershed

Nitrogen Reduction Planning Tool (Lazarus et al. 2014) when used at the watershed or state level scale summarizes the efficacy of most of the well-developed BMPs available for nitrogen removal.

Potential agricultural BMPs selected for the NRS were identified from the *Nitrogen in Minnesota Surface Waters* study (MPCA 2013a), the Iowa Nutrient Reduction Strategy (Iowa Department of Agriculture and Land Stewardship et al. 2013 and Iowa State University 2013), the AgBMP Handbook (Miller et al. 2012), literature on the MN P Index (Moncrief et al. 2006), and the Lake Pepin implementation planning work (Tetra Tech 2009). BMPs were evaluated to determine which would be most likely to help achieve the nutrient reduction goals of the NRS. BMPs are grouped into the following four categories:

1. Increasing fertilizer use efficiencies (nutrient management practices)
2. Increase and target living cover
3. Field erosion control (for phosphorus reduction)
4. Drainage water retention for water quality treatment (for nitrogen reduction) and for control of erosive flows (to help address phosphorus loads from near-channel erosion, ravines, and streambanks)

Appendix C includes additional agricultural BMPs that could be used for reducing nutrients. A more complete listing of nitrogen fertilizer BMPs is provided at *http://www.mda.state.mn.us/protecting/bmps/nitrogenbmps.aspx* and at *http://www.extension.umn.edu/agriculture/nutrient-management/nitrogen/*.

Effectiveness and cost of BMPs depends on many site-specific factors. Representative values are used for this statewide analysis. These averaged results are approximations only, and BMP planning and efficacy is expected to vary significantly at the local scale. Iowa State University (2013) provided standard deviations for studied nutrient removal efficiencies. BMPs for both phosphorus and nitrogen included a high standard deviation; for example, the phosphorus removal efficiency of buffers is presented as 58 percent reduction with a standard deviation of 32.

The cost estimates for agricultural BMPs focused on estimating the net cost or cost-savings to the producer for the purpose of estimating the relative change in costs that would occur through implementation of the NRS. Cost data for construction and operation costs are readily available and provide a metric for gaging the financial impact of the NRS. The costs estimates were limited to readily available data and do not include costs relating to the government's role in implementation or land acquisition. Additional factors that were not considered quantitatively include monetary and non-monetary impacts to the public related to current agricultural incentives and other policies. Cost savings were assumed only where available quantitative information was relevant to the practices and geographic area considered. Some BMPs, like cover crops, may provide additional benefits to producers such as through improved soil quality, however these benefits were not estimated in this analysis. Due to these limitations, the cost estimates are provided as approximate measures and as a tool for comparing order of magnitude differences across the BMPs. As strategy recommendations are assessed in more detail at the community or site-scale, a more comprehensive cost-benefit analysis may be warranted.

Annualized cost per acre was obtained first from Lazarus et al. (2013), and then from Iowa State University (2013) for the remaining BMPs. Negative costs reflect a net return on investment (e.g., farmers can save money by reducing application of nitrogen fertilizer to economically optimal rates). The annualized costs, or lifecycle costs, reflect the cost per year (Table 5-11), that if held constant, would pay for both the upfront establishment and overall operation costs for the design life of the practice. Table 5-11 includes costs and effectiveness for various example BMPs.

Table 5-11. Representative BMP summary, including nutrient load reduction efficiencies in the BMP-treated area. Costs are approximate and change with changing markets and other factors.

BMP	Lifecycle cost ($/acre/year)	Nitrogen reduction efficiency	Phosphorus reduction efficiency	Notes
Increasing Fertilizer Use Efficiencies (Nutrient Management Practices)				
Nitrification inhibitors	($3) [2]	14%[1]	NA	Nitrogen removal efficiency based on average of literature reviews.
Reduced rates to MRTN (corn after soybeans and proper manure crediting)	($15-19)[3]	16%[1]	17%[2]	For phosphorus, based on no phosphorus applied until soil test phosphorus drops to optimum.
Shift fall application to spring and sidedresswith rate reduction	($7-26)[3]	26%[1]	NA	Efficiency applies only to fields currently using fall fertilization.
Phosphorus incorporated using subsurface banding	$15[2]	NA	24%[2]	Compared to surface application without incorporation.
Increase and Target Living Cover				
Cover crops (with establishment success)	$53[3]	51%[1]	29%[2]	See discussion of success rate below

BMP	Lifecycle cost ($/acre/year)	Nitrogen reduction efficiency	Phosphorus reduction efficiency	Notes
Perennial energy crops	$30[2,]	95%[1]	34%[2]	
Perennial buffers in riparian areas (replacing row crops)	$30-300[2,3]	95%[1]	58%[2]	See discussion of area treated in below.
Hayland in marginal cropland (replacing row crops)	$30-110[3,2]	95%[1]	59%[2]	
Conservation easements and land retirement	$6-110[3,2]	83%[2,6,7]	56%[2,6,7]	Average of values based on Upper Midwest research.
Field Erosion Control				
Conservation tillage and residue management	($1)[2]	NA	63%[2,4,5]	Average of Midwest and Chesapeake Bay studies.
Drainage Water Retention and Treatment				
Constructed wetlands	$6-18[3]	50%[1]	Drainage water retention can indirectly help mitigate phosphorus load through reduction of erosive flows; however, it is not possible to assign general reduction efficiency.	Wetlands not applicable for permanent phosphorus removal unless sediments cleaned out and vegetation harvested.
Controlled drainage	$9[3]	33%[2]-44%[1]		Nitrogen treatment applicable to tile-drained fields.
Bioreactors	$18[3]	13%[1]	NA	Net nitrogen reduction efficiency accounts for reduced treatment during spring flows.

[1]MPCA (2013a); [2]Iowa State University (2013); [3]Lazarus et al. (2013); [4]Miller et al. (2012); [5]Simpson and Weammert (2009); [6]Barr Engineering (2004); [7]MPCA (2013a); NA: BMP is not applicable to this nutrient. Parentheses indicate negative costs, which represent net dollar savings.

Increasing Fertilizer Use Efficiencies (Nutrient Management Practices)

Nitrogen

Corn and soybean cropping systems are inherently vulnerable to nitrogen losses, particularly during times of the year when row crop roots are not established enough to capture and use soil nitrate. Other crops can also affect nitrate losses to waters including potatoes, sugar beets and dry beans. Corn receives over 90 percent of Minnesota's nitrogen fertilizer additions to row crops; therefore the NRS focuses largely on fertilized corn, specifically corn following soybeans. The primary nitrogen efficiency goal is to reduce nitrogen losses on corn following soybeans, resulting from an industry average of fertilizer nitrogen (and manure on some farms) that has recently been estimated to be at least 30-40 pounds/acre higher than the mid-range of the University of Minnesota recommendations. The University of Minnesota recommended nitrogen fertilizer rates can be found at: *http://www.extension.umn.edu/agriculture/nutrient-management/nutrient-lime-guidelines/docs/corn-fertilization-2006.pdf*.

Improving the efficiency of nutrient applications by crediting all sources and adjusting rates, timing, forms, and placement of nitrogen can improve efficiency, resulting in better environmental and economic performance for these row crop systems. Using economically optimal application rates is a key nutrient management practice for nitrogen. Lazarus et al. (2013) provide a recommended "BMP target" nitrogen fertilizer rate based on current University of Minnesota recommendations. This rate is based on the maximum return to nitrogen and depends on the price of both corn and nitrogen fertilizer. At the time of this study, Lazarus et al. (2013) assumed a price ratio of nitrogen to corn of 0.11 (based on 55-cent nitrogen and $5 corn). This results in a nitrogen need for the corn following corn rotation of 141 pounds per acre (lbs/acre). The commercial fertilizer application target for corn following soybeans is equal to about 105 lbs/acre. It should be noted that these rates represent an average recommended fertilizer rate, and modifications (increases or decreases) might be required based on different site-specific considerations.

Data on nitrogen fertilizer rates are available through Bierman et al. (2011) and a companion study by the Minnesota Department of Agriculture (MDA) based on the 2009 growing season (MDA 2011). The 2009 survey of nitrogen fertilizer use on corn in Minnesota was collected from 1,496 farmers distributed across all corn-growing regions in the state, with their total acreage representing about 7 percent of the corn acres harvested in Minnesota in 2009. Data are provided by county and represent recent nitrogen fertilizer rate (lbs/acre) for fields growing corn. In 2009 there were 1,119 fields with corn following soybean surveyed across the state (MDA 2011). The highest reported county average nitrogen fertilizer rate in 2009 was 162 lbs/acre (Chisago County), and the lowest average rate was 111 lbs/acre (Clay County), with an overall state average of 141 lbs/acre.

The target average fertilizer rate of 105 lbs/acre, based on the mid-range of University of Minnesota recommendations, was subtracted from the current average fertilizer rate to determine the rate reduction needed to meet the mid-range of the recommended rate for corn following soybeans. Seventy-five percent of fields reported corn following soybean fields, while corn following corn and corn following other crops represented 19 percent and 4 percent of fields, respectively. Therefore corn following soybeans is the dominant rotation; but the cropping systems fluctuate and Minnesota also has a fairly large fraction of land in continuous corn.

Key Nitrogen Reduction Finding

By reducing rates to the mid-range of the University recommended rates (closer to 105 lbs/acre), many corn/soybean fields can potentially gain greater fertilizer and economic efficiencies, and at the same time reduce nitrate losses to waters.

The Bierman et al. (2011) survey results suggest that Minnesota nitrogen fertilizer rates are reasonably close to the University of Minnesota recommendations for corn following corn, but that greater fertilizer efficiencies can potentially be gained by bringing down the rate on corn following legumes. The University of Minnesota recommendations do not provide a single rate recommendation, but rather a range of recommended rates. For corn following soybeans, 2009 average fertilizer rates were higher than the top end of the University of Minnesota recommended rate range. By reducing rates to near the mid-range of the University recommended rates resulting in a statewide average of 105 lbs/acre), many corn/soybean fields can potentially gain greater fertilizer and economic efficiencies, and at the same time reduce nitrate losses to waters.

A recently published *updated fertilizer use survey* (MDA 2014) showed an average fertilizer rate of corn following soybeans in the 2010 cropping year of 148 lbs/acre, allowing an additional 8 lbs/acre reduction potential as compared to the 2011 Bierman report and the assessment developed for this NRS. Table 5-12 summarizes the reported fertilizer application rates compared to University of Minnesota recommended rates.

Table 5-12. Recommended nitrogen fertilizer rates and reported 2009 and 2010 rates

	Reported application rates (lbs/acre)		Maximum Return to Nitrogen - University of MN recommended rates for high productivity soils	
			N fert. price to corn value ratio	
	2009 cropping year [a]	2010 cropping year [b]	0.15	0.10
Corn following soybeans (no manure)	140	148	100	110
Corn following corn (no manure)	145	161	130	140
Corn following alfalfa (no manure)	97	115	30	40
Corn with manure (average of all rotations – fertilizer plus manure)	not reported	173	<130	<140

a. Bierman et al. 2011 and MDA 2011
b. MDA 2014

An additional component of nitrogen management efficiencies includes shifting from fall to spring or spring/sidedress applications on corn, along with a corresponding nitrogen rate reduction. Increased acreages of spring or sidedress applications and greater nutrient efficiencies from more precise crediting of nitrogen applications made through manure spreading are considered as part of the nitrogen load reduction scenarios. Manure nitrogen represents about 25 percent of the combined additions of manure and commercial fertilizer.

Nitrogen reduction estimates from reduced fertilizer rates and changed timing of fertilizer application were developed using the NBMP tool (Lazarus et al. 2014). Based on comparison of nitrogen fertilizer use from surveys and University of Minnesota recommendations, the NBMP tool provides results for the recent corn rotations in Minnesota, including mostly corn following soybeans, corn following corn and corn following alfalfa.

Phosphorus

For phosphorus, the assumed fertilizer application rate depends on the existing phosphorus concentration in the soil (soil test phosphorus) such that above a certain phosphorus concentration, additional fertilizer should not be applied. The MN P Index can serve as a measure of phosphorus loss potential and help identify areas where certain types of phosphorus management BMPs might be effective. The MN P Index depends on both soil test phosphorus and erosion risk. To reduce phosphorus export, the goal is to achieve a low MN P Index while maintaining minimum soil test phosphorus in order to maintain adequate crop growth.

There was no available statewide coverage of soil test phosphorus levels or the MN P Index for this analysis. An approximation of the potential role of increased fertilizer use efficiencies was therefore made through a back calculation of the MN P Index from SPARROW agricultural loading rates. Barr Engineering (2004, Appendix C) reports that Bray-1 soil test phosphorus can be related to the MN P Index by a factor of 0.75 and provides a conversion between the P Index and edge-of-field phosphorus loss rates such that loss rates in kg/ha/yr are equal to the P Index divided by 65. Therefore, a Bray soil test phosphorus of 21 ppm corresponds to a MN P Index of approximately 16. SPARROW agricultural loading rates that imply that the MN P Index is greater than 16 in a given HUC 8 were assumed to be reducible by better phosphorus fertilization practices.

As described above, the MN P Index depends on both soil test phosphorus and erosion risk. Representative BMPs are used to derive the phosphorus load reduction associated with achieving the target MN P Index. Subsurface banding of phosphorus serves as a representative BMP for fertilization practices, while conservation tillage (greater than 30 percent residue) is used as a representative BMP for erosion control (see Field Erosion Control below).

Existing Adoption Rates

There are no data available on a consistent HUC8 scale that shows how much increased adoption in nitrogen or phosphorus fertilizer management has occurred since the baseline time periods. Through farmer surveys and interviews, as reported in the Farm Nutrient Management Assessment Program (FANMAP) and by Bierman et al. (2011), evidence suggests that many farmers are already implementing fertilizer BMPs, but that there is still room for improvement on many farms.

The Nitrogen Fertilizer Management Plan (MDA 2013) shows a steady increase in nitrogen fertilizer use efficiency (nitrogen fertilizer used per bushel of grain) since the early 1990s across the state. However, some of the positive effects of such progress on the environment (lbs of nitrogen in the water per acre of cropland) can be masked by increased planting densities and changes in grain protein content. The BMPs and crop genetics leading to this increased efficiency may also be somewhat offset by reductions in legume crops, small grains, set-aside lands, and non-tiled lands, coupled with changing precipitation patterns. The combined effects of all these changes have not been determined. Water quality response to changes has an inherent lag time between the time of BMP adoption and improvements in monitored waters. For example, while the Mississippi River nitrogen levels have not shown decreases, much of the River's flow comes from groundwater which has a long travel time to the river. Further tracking of BMP adoption rates is needed.

Increase and Target Living Cover

Living cover BMPs selected for analysis include riparian buffers, cover crops, and conservation reserve areas. In addition to these specific BMP types, numerous other BMPs can be used to achieve the same or similar benefits such as forage, extended rotations including alfalfa, prairie strips and grassed waterways.

Riparian buffers described in the NRS include 30 meters on either side of all perennial and intermittent streams in the Minnesota Department of Natural Resource's 1:24,000 scale maps. A 30-meter buffer represents a highly protective scenario that minimizes the risk of channelized flow through the buffer. A statewide analysis of riparian buffers areas was conducted to determine the current presence of buffers and the suitable acres that could be converted into buffer. The 2012 Cropland Data Layer (CDL) was used to evaluate the presence of perennial vegetation in the buffer. The 2012 CDL datasets are derived from satellite imagery at a 30-meter (0.22 acres per pixel) resolution; therefore error is expected when evaluating a buffer strip that is 30 meters wide. Existing buffer data that were derived from high resolution photo interpretation by the Minnesota Center for Environmental Advocacy and the Cannon River Watershed Partnership were used to calibrate an analysis of riparian vegetation using the 2012 CDL. Appendix A further describes the buffer analysis.

The reduction for nitrogen only applies to the area of the buffer itself and is a result of less nitrate leaching in the footprint of the land conversion (from cropland to perennials) to create the buffer. For phosphorus, the percent reduction applies to the area of the buffer itself, as well as the immediate drainage area to the buffer. The drainage area being treated for phosphorus is assumed to be 3 times the area of the buffer. This ratio is set based on the ability of sheet flow to be maintained as runoff passes through the buffer.

Cover crops are also considered under this heading. A study of cover crops in the U.S. corn belt by Singer et al. (2007) reported that 5.1 percent of surveyed Minnesota farmers planted a cover crop in 2005 and that 10 percent of surveyed farmers planted a cover crop in five preceding years. The 2012 Census of Agriculture included a question on cropland area planted to a cover crop; these results will be available in 2014 for inclusion in future NRS updates. An existing adoption rate for cover crops was not estimated, therefore all current agricultural land was considered potentially available for cover crops.

Cover crops can be challenging in the Minnesota climate due to low success rates for establishment with aerial seeding onto traditional corn and soybean fields. Lazarus et al. (2013) suggested that success rates may be as low as 20 percent for typical corn and soybean fields. However, it is believed that higher success rates can be achieved depending on cropping system. For the NRS, cover crops were considered in two categories, those with a high seed germination success rate that are typically planted after shorter season crops and those with a low success rate. Cover crops with a high potential for success (80 percent success rate assumed) are those that follow early season harvest crops, and for this analysis were assumed to include peas, sweet corn, fallow, sugar beets, corn silage, or wheat, where applicable areas are determined based on the 2012 CDL. Cover crops with a lower potential for success at this time (40 percent success rate assumed, based on the possibility of improved seed establishment techniques potentially available by 2020) are assumed to include those that follow corn grain, soybean, dry bean, potato, or sorghum. However, in practice some early harvest varieties of dry beans and potatoes could also be included in the shorter season crop category.

Conservation reserve or land use retirement can be considered in scenarios as an alternative to nutrient control BMPs. The intention of evaluating land retirement is not to suggest that large acreages of existing cropland be permanently removed from production (which could have negative economic and other impacts), but rather to provide an argument for the implementation of innovative BMPs at this time, while working on research for long-term economically viable land use change possibilities.

There are several different management actions that could qualify as land use change. Some represent true land use change scenarios (e.g., perennial energy crops, land retirement), while others could be considered as adjustments to existing management practices (e.g., perennial buffers replacing row crops, hayland in marginal cropland). For this analysis, perennials are assumed to replace row crops (corn, sorghum, soybeans, sweet corn, sugar beets, potatoes, peas, and dry beans) only in targeted areas.

Field Erosion Control

Field erosion control is one of the most effective practices for limiting export of cropland phosphorus, although it does not affect loading of dissolved phosphorus. Barr Engineering (2004) reported that there is a strong linear correlation between the generalized MN P Index values Birr and Mulla (2001) reported and the observed phosphorus export (in kg/ha/year) at the field scale. Conservation tillage is used in this scenario as a generally accepted practice that can be effective for mitigation of phosphorus load by reducing net soil erosion rates from runoff, although conservation tillage can have additional benefits of reducing wind erosion and subsequent atmospheric phosphorus deposition. Data describing existing conservation tillage implementation (acres) and total planted acres are available through the Minnesota Tillage Transect Survey Data Center for 2007. Data are summarized by county and converted to the HUC8 level to incorporate into the analysis. Conservation tillage is assumed to have minimal net impacts on nitrogen export.

Conservation tillage reduces erosion by maintaining at least 30 percent residue cover on the surface. Reducing erosion reduces the transport of adsorbed phosphorus, although conservation tillage can also have an adverse effect on total phosphorus load if the practice results in less soil mixing and greater phosphorus concentrations near the surface, which can increase dissolved phosphorus export in runoff. The relatively high efficiency for reducing phosphorus export assigned to conservation tillage (63 percent) is realistic only if the practice is combined with other management practices that control surface soil phosphorus concentrations. Based on the literature, phosphorus reductions in the Midwest can range from 30 percent to greater than 90 percent depending on tillage method, fertilizer management, and other site specific conditions.

For the NRS, the recommended average phosphorus removal efficiency of conservation tillage is assumed to apply to high residue crops including corn, soybeans[1], sorghum and small grains based on the 2012 CDL. However, achieving this efficiency will only occur if conservation tillage is combined

[1] Soybeans are not typically referred to as a high residue crop; however the 2007 Tillage Transect Survey in Minnesota has documented greater than 30 percent residue on a significant number of soybean fields.

with other practices to manage excess soil phosphorus concentrations. Thus reductions, attributed in this NRS to conservation tillage, actually represent a combination of erosion reduction and nutrient management practices. Accordingly, the reduction efficiencies (and costs) associated with conservation tillage have been used in the analysis, but have re-apportioned part of the resulting phosphorus reduction to the fertilizer use efficiency category. Specifically, the portion of the reduction ascribed to conservation tillage that reduces the estimated P Index to the recommended level (as described above in the section on Increasing Fertilizer Use Efficiencies) is credited to the fertilizer use efficiency category while the remainder is tabulated as due to field erosion control. This approach is a rough approximation of the complexities involved in managing soil phosphorus concentrations over time and controlling phosphorus losses; however, it appeared to be the best option available for broad scale, statewide analysis given the unavailability of comprehensive data on soil test phosphorus distributions.

Drainage Water Retention and Treatment

Both constructed wetlands and controlled drainage were evaluated as practices to reduce nitrogen loading. Wetland treatment is not assumed to permanently reduce annual phosphorus loads unless sediments are cleaned out and vegetation is harvested and removed, which is not anticipated in the rural, agricultural region where these BMPs would be applied. In addition to wetland construction and restoration, additional nutrient reductions could also be achieved using other BMPs which provide short and long term storage.

Applicable areas assumed for wetland treatment (provided by the University of Minnesota) are based on an intersection of high Compound Topographic Index (CTI) and cultivated soils. Lands suitable for wetlands were assessed by first using a logistic regression model based on CTI. Once these areas were identified, the layer was further refined by intersecting likely historic wetlands with likely tile-drained lands, isolated by finding 2009 CDL crops that are likely drained (corn, beans, wheat, sugar beets) and intersecting them with SSURGO poorly drained soils on slopes of 0–3 percent.

Suitable acres for controlled drainage (provided by the University of Minnesota) are first determined by intersecting areas with poorly drained soils; 0–3 percent slope; and corn, soybeans, wheat, or sugar beet crops based on the 2009 CDL. This analysis is used to approximate acres of tile-drained lands, and is then intersected with lands having slopes less than 1 percent to identify appropriate controlled drainage locations. Controlled drainage is used in the analysis since it is shown to be more cost effective than some other treatment technique, but other techniques such as bioreactors could also be suitable for nitrogen removal from tile drainage, potentially in areas where slope make controlled drainage impractical. Another challenge with the use of controlled drainage can be difficulty in retrofitting fields with existing drainage where tile slope management was not a design priority. Pattern tiles designed to facilitate drainage flow controls holds the most promise for new tile installation, but can also be used in many situations for retrofitting existing tile systems.

BMP Opportunities

Suitable acres for each BMP category and current adaption rates are summarized in Table 5-13. Suitable acres were determined as described above. Existing adoption rates were calculated as the total BMP acres already established divided by the total suitable acres.

Table 5-13. Summary of suitable acres and existing adoption rates, total suitable acres includes all available land where that BMP can be applied, taking into account existing BMP adoption.

BMP Category	Example BMP	*Mississippi River*		*Lake Winnipeg (Red River Only)*	
		Total Suitable Acres	Existing Adoption Rate	Total Suitable Acres	Existing Adoption Rate
Increasing Fertilizer Use Efficiencies	Achieve target soil test phosphorus	*Suitable area includes all agricultural lands where Bray soil-test P exceeds recommended 21 ppm (Barr 2004)*			
	Subsurface banding	7,659,000	*Not quantified*	1,063,000	*Not quantified*
	Nitrogen fertilizer rate reduction (on corn) [a]	6,977,000 each year	*Average rates from survey*	740,000 each year	*Average rates from survey*
	Spring applications and rate reduced	3,000,000 each year	*Not quantified*	70,000 each year	*Not quantified*
Increase and Target Living Cover	Riparian buffers	442,000	70%	245,000	68%
	Cover crops [b] (short season crops)	751,000 – 1,051,000	*Not quantified*	1,575,000 – 1,628,000	*Not quantified*
	Cover crops [b] (grain corn and soybeans)	12,261,000	*Not quantified*	3,118,000	*Minimal*
	Conservation reserve (row crops) [c]	12,854,000	*Implicit in suitable acres*	3,506,000	*Implicit in suitable acres*
	Conservation reserve on marginal corn cropland	1,237,000		418,000	
Field Erosion Control	Conservation tillage [d]	8,354,000	38%	3,876,000	17%
Tile Drainage Treatment	Wetland construction/restoration	1,559,000	*Minimal*	Unknown [e]	*Minimal*
	Controlled drainage	1,321,000		Unknown [e]	

a. The fertilizer use efficiency BMP corn land which could receive optimal nitrogen fertilizer and manure rates and timing based on University of Minnesota recommendations. The total acres for fertilizer use efficiency BMPs represent the corn acreage during a given year, multiplying corn acreage by two is an approximation of total corn acres during a two-year period which can be used to estimate corn acres in rotation. It includes both existing corn land using the BMP rates/timing along with new land using the BMPs. The nitrogen fertilizer BMP is an approximate 35 pound average reduction of industry average nitrogen fertilizer rates on corn following soybeans and additionally meeting University of Minnesota recommended rates for corn following alfalfa and corn following corn.

b. Cover crop acres assume area where cover crops can be potentially seeded. Short season crops include peas, sweet corn, fallow, sugar beets, corn silage, or wheat for the low range; and peas, sweet corn, fallow, sugar beets, corn silage, wheat, dry edible beans, and potatoes for the high range.

c. Row crops are defined as corn, sorghum, soybeans, sweet corn, sugar beets, potatoes, peas, and dry beans.

d. Conservation tillage applied to high residue crops including corn, soybeans, sorghum and small grains.

e. The Red River Valley has historically had relatively little tile drainage. However, large acreages of tile-drained croplands are being added each year to the Red River Valley in recent years. The extent of this change is not well documented and is in a state of flux. Controlled drainage should be a suitable BMP for much of the added tile drainage acreage, but is less suitable for retrofitting existing tile drainage.

Nutrient Reduction in Action

Minnesota Farmer Recognizes Benefits of Vegetated Buffers and Easements Go Beyond Water Quality

For some Minnesota farmers, the reason to plant vegetated buffers between cropland and local rivers and streams goes beyond doing the right thing to protect water quality. These buffers can provide habitat for wildlife, translating to improved aesthetics and recreational opportunities. Steve Madsen, a lifelong farmer in Renville County, raises corn and soybeans on 1,000 acres of his 1,100 acre farm. The remaining 100 acres is planted in prairie grasses, tree windbreaks, and shelterbreaks using financial incentives provided through USDA's Conservation Reserve Program (CRP) and BWSR's Re-Invest in Minnesota (RIM) program.

While these natural areas help to capture and filter runoff, the primary focus of the incentive programs, Madsen sees other benefits. He planted a windbreak of red cedar and lilac in recent years along Highway 71 and installed a small corn crib to feed pheasants. Madsen said of the project, "It's a nice conservation project to stop the water erosion, and some wind erosion, too. And it's a benefit to the wildlife."

Some of the inspiration to participate in the conservation programs came from an example over the fence line. In the mid-1990s, the Department of Natural Resources acquired 320 acres to the west of the Madsen farm. Restored wetlands and prairie soon bustled with deer, pheasants, and other wildlife. "I saw how it worked out, how it stopped erosion," Madsen says. "And I really liked the wildlife." According to Madsen, those 100 acres will remain in trees and grasses, and they become the focus after harvest, when hunting season begins.

Increased adoption of vegetated buffers and conservation easements through CRP and RIM will not only provide nutrient reductions needed to achieve NRS goals and milestones, but these practices will also generate additional benefits for farmers who enroll. And, similar to the manner in which the DNR example inspired Madsen to adopt these practices on his own property, increased adoption might create a ripple effect throughout Minnesota.

(Adapted from MPCA's Minnesota Water Story series, "Prairie grass buffers a sign of efforts to keep soil and nutrients on cropland" available at *http://www.pca.state.mn.us/index.php/water/water-types-and-programs/surface-water/minnesota-water-stories/water-story-soil-conservation.html*)

5.3.2 Agricultural BMPs to Achieve Phosphorus Goals

As Chapter 4 discussed, recent efforts by both nonpoint sources and wastewater treatment facilities have resulted in substantial phosphorus load decreases in the Mississippi River Major Basin, although further progress is needed to achieve the ultimate reduction goals for both local and downstream waters. The Red River Basin has not made similar progress, and new reduction targets are being considered to protect and improve Lake Winnipeg.

Existing phosphorus goals can be achieved by various combinations of BMPs. Example BMP scenarios to achieve the goals were developed, with the selection of BMPs and adoption rates generally maximizing the combination of both BMP effectiveness and cost. In general, the conceptual strategy for phosphorus has the following priority order:

1. Optimize fertilizer and manure rates based on soil test phosphorus (estimated to provide a net savings to producers).
2. Increase use of conservation tillage with at least 30 percent residue where conservation tillage is not already being used (estimated to provide a net savings to producers).
3. Use precision application techniques such as subsurface banding (net cost uncertain).
4. Add living cover BMPs such as riparian buffers and cover crops that currently have a net cost to producers.

An example scenario was created to investigate what it would take to achieve the 45 percent reduction goal for phosphorus in the Mississippi River Major Basin, assuming recent progress accounts for approximately 33 percent reduction and that reductions will be made in both the wastewater and miscellaneous source sectors. Additionally, a scenario was developed to provide an indication of the level of agricultural BMP adoption needed to reach a 10 percent reduction in the Red River portion of the Lake Winnipeg Major Basin. Agricultural strategies are of lesser importance in the Lake Superior Major Basin where agriculture contributes only about 6 percent of the phosphorus load.

The example scenario was developed based suitable acres and current adoption rates for each BMP category (Table 5-13). Table 5-14 summarizes the results of this analysis, which suggest that the phosphorus goals can be achieved, but only through a combination of BMPs. Specifically, for the Mississippi River Major Basin the goal (45 percent reduction from baseline conditions) could be achieved if 55 percent of the applicable agricultural land instituted at least 30 percent residue conservation tillage where not already employed, assuming also that soil test phosphorus levels are also reduced to recommended levels. Additionally, to meet the phosphorus goals, 30-meter buffers would also be needed on both sides of 25 percent of the non-buffered perennial and intermittent streams, along with an increase in conservation reserve lands.

The net increase in BMP application area (after accounting for recent progress) is approximately 8 million acres in the Mississippi River Major Basin. Alternatively, some of the reduction in agricultural load could be achieved through greater application of BMPs, such as conversion to perennial energy crops. Substantially lower levels of effort will be necessary in the Lake Winnipeg Major Basin to achieve a 10 percent reduction. In part this is because soil test phosphorus concentrations are low in many parts of this basin, which is also the reason why there is little incremental gain from increasing fertilizer use efficiency for phosphorus in this basin.

Table 5-14. Example BMP scenario for achieving the phosphorus goals through cropland BMPs

		Mississippi River		*Lake Winnipeg (Red River Only)*	
BMP category	**Example BMP**	**Future adoption rate**	**Total new acres (million acres)**	**Future adoption rate**	**Total new acres (million acres)**
Increasing Fertilizer Use Efficiencies	Achieve target soil test phosphorus and use subsurface banding	55%	2.2	0%	0.0
Increase and Target Living Cover	Riparian buffers	78% (25% of existing non-buffered acres)	0.1	71% (10% of existing non-buffered acres)	0.02
	Cover crops (short season crops)	50%	0.3	50%	0.6
	Cover crops (grain corn and soybeans)	10%	0.5	0%	0
	Conservation reserve (row crops)	3% (32% of marginal corn cropland)	0.3	0.5% (15% of marginal corn cropland)	0.02
Field Erosion Control	Conservation tillage	72% (55% of available acres)	4.5	26% (10% of available acres)	0.4

Notes:

Future adoption rates are expressed as a percentage of the total area on which a practice is applicable. Riparian buffers and conservation tillage also express the percent of currently available acres which excludes land currently using the BMP.

Acreage from program quantification for 2000–2013 is excluded from total new acres where applicable. Total new acres represent the new area that would require the BMP.

It is important to note that approximately 17 percent of the total phosphorus load and 20 percent of the nonpoint phosphorus load in the Mississippi River Major Basin is derived from streambank erosion under average conditions (see Table 3-2). Mitigating streambank erosion is not considered in the agricultural BMP scenario described above, but could be an important part of the ultimate solution. Another 8 percent of the total phosphorus load is estimated to come from atmospheric deposition of dust. The extent to which atmospheric deposition of phosphorus can be reduced through better agricultural cover and tillage practices within Minnesota is not known. An *assessment* of atmospheric deposition conducted in 2007 (Barr Engineering 2007) evaluated available data and literature on atmospheric deposition as a source of phosphorus in Minnesota. The assessment identified the potential for wind erosion in agricultural areas as potentially contributing to atmospheric deposition loads; however a detailed analysis was not completed.

Figure 5-4 presents the percentage of total phosphorus reduction attributed to each of the basins in the Mississippi River Major Basin. The Minnesota River Basin is the largest source of phosphorous to the Mississippi River, and therefore also contributes the greatest load reductions.

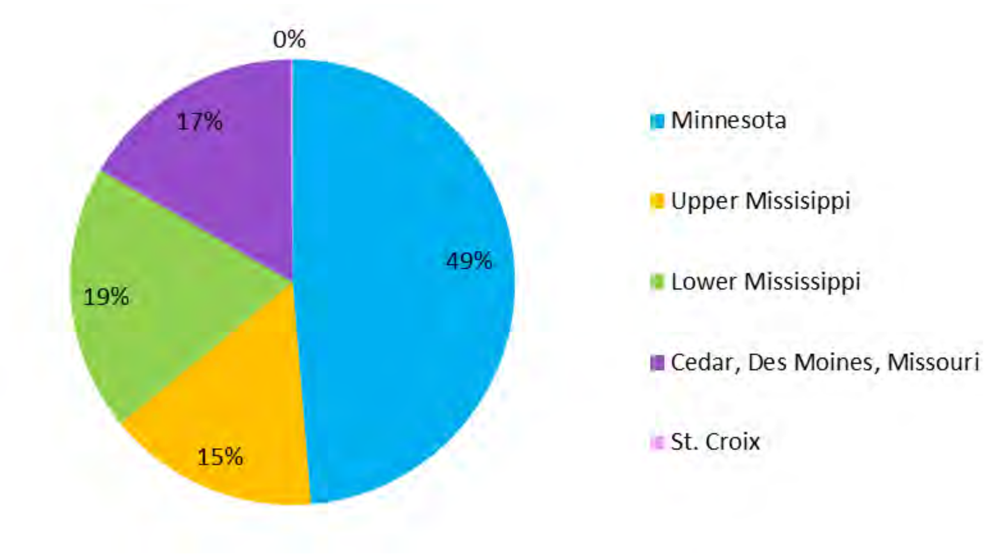


Figure 5-4. Percent of total reduction in Mississippi River Major Basin attributed to each basin.

High Island Creek in Spring, Tributary to Minnesota River Photo Credit: MPCA

Conservation Effects Assessment Project

The USDA NRCS Conservation Effects Assessment Project (CEAP) estimated the benefits of the 2002 Farm Bill's increase in conservation funding at a national, regional, and watershed scale (Appendix D). The Upper Mississippi River Basin was one of 13 basins studied by CEAP. Two nutrient loading scenarios in the CEAP study dealt with increasing treatment for undertreated areas and, more specifically, simulated the effects of structural conservation practices, residue and tillage management, and nutrient management. Similar to the NRS load reduction estimates, the practices used for simulation were selected as example practices that represent the broader range of practices available to operators. While using different analysis methods as compared to this NRS, the CEAP study showed that there is considerable room for improvement in reducing cropland nutrient transport to waters in Minnesota and neighboring states. By treating critical undertreated areas, the CEAP study estimated a 6 percent reduction of overall phosphorus loss to waters from all sources (12 percent reduction of the cropland only losses).By treating all undertreated areas the CEAP study estimated that phosphorus losses to water could be reduced by 17 percent or more (30 percent reduction in the cropland only losses).

The NRS goal of reducing Mississippi River phosphorus by 7.5 percent through cropland BMPs is within the 6 to 17 percent reduction range that the CEAP study determined possible through BMP adoption on some or all of the undertreated areas. The CEAP study supports the achievability of this NRS's recommendations for additional phosphorus loss reductions in the Mississippi River using traditional cropland conservation BMPs.

5.3.3 Agricultural BMPs to Achieve Nitrogen Goals and Phase 1 Milestone

As Chapter 4 discussed, while recent efforts by agricultural sources are estimated to have achieved a slight nitrogen reduction, the net reductions from improved fertilizer planning are offset by additional row crop acreage and tile drainage increases and are considerably smaller than those made for phosphorus. These losses have also been offset by slight increases in nitrogen from wastewater (due to population increases). The focus for nitrogen remains on the Phase 1 milestone for the Mississippi River Major Basin (20 percent reduction) and meeting the provisional goals in the Lake Winnipeg Major Basin. There are no goals for nitrogen reductions in the Lake Superior Major Basin.

An example scenario was created by an expert panel using the Watershed Nitrogen Reduction Planning Tool (Lazarus et al. 2014) to investigate what it would take to achieve the goals and milestones through more intensive application of agricultural BMPs after accounting for planned changes in wastewater discharges that include significant reductions in nitrogen loads. The example scenario was developed based on of suitable acres and current adoption rates for each BMP category summarized in Table 5-13.

The implementation of riparian buffers, cover crops, and conservation reserve is constrained to approximately match the phosphorus scenario, except that additional cover crops were needed to meet the nitrogen reduction targets (above the acreage needed to meet phosphorus reduction goals). The phosphorus scenario requires a relatively high rate of adoption of riparian buffers and cover crops to achieve phosphorus reduction goals in the Red River because soil test phosphorus concentrations are already low.

Table 5-15 summarizes the results of this analysis, which suggest that the Phase 1 Milestone could be achieved in the Mississippi River Major Basin (including the Cedar, Des Moines, and Missouri basins) with a mix of BMPs. The BMP application area in the Mississippi River Major Basin amounts to several million acres. Reduced fertilizer rates on corn, along with shifting fall fertilizer applications to spring, account for an estimated 13.6 percent reduction from all nonpoint source nitrogen loads to the Mississippi River. The addition of constructed wetlands and controlled drainage BMPs adds another 1.4 percent reduction, and another 5 percent of the nonpoint nitrogen load can be reduced through the vegetative cover BMPs.

Tile drainage is expected to increase rapidly in the Red River Valley. As a result, an increasing load of nitrogen is anticipated. Achieving the milestone for the Red River portion of the Lake Winnipeg Major Basin will require a focus on reducing baseline loads of nitrogen through increased fertilizer efficiency, as well as a strategy that includes wetland treatment and controlled drainage to offset new sources. Protection strategies are needed in the short term to mitigate new sources of nitrogen in the Red River Valley.

Table 5-15. Example BMP scenario for achieving nitrogen Phase 1 Milestone through cropland BMPs

BMP category	Example BMP	Mississippi River		Lake Winnipeg (Red River Only)	
		2025 adoption	New total acres (million acres)	2025 adoption	New total acres (million acres)
Increasing Fertilizer Use Efficiencies	Use recommended fertilizer rates/timing (corn only)	80%	See footnote a	80%	0.7
Increase and Target Living Cover	Cover crops (short season crops)	50%	0.7	50%	0.7
	Cover crops (grain corn and soybean)	10%	0.5	0%	0.0
	Riparian buffers	78% (25% of non-buffered acres)	0.1	60.8% (10% of non-buffered acres)	0.02
	Conservation reserve	3% (32% of marginal corn cropland)	0.3	0.5% (15% of marginal corn cropland)	0.02
Drainage Water Retention and Treatment	Wetlands	20%	0.5	New tile drainage [b]	0.01
	Controlled drainage	20%	0.1		0.01

Notes:

Future adoption rates are expressed as a percentage of the total area on which a practice is applicable. Riparian buffers also express the percent of currently available acres which excludes land currently using the BMP. Wetlands and controlled drainage adoption rates are expressed as the percentage of total drainage area to the practice.

a. Available data do not indicate how many acres are already using the reduced rates, but instead provide industry averages. The scenario assumes that the industry average for 11.2 million acres of corn following soybeans is reduced from about 140 lbs/acre to the Maximum Return to Nitrogen Rate, which is currently around 105 lbs/acre.

b. The Red River Valley has historically had relatively little tile drainage. However, large acreages of tile-drained croplands are being added each year to the Red River Valley in recent years. The extent of this change is not well documented and is in a state of flux and therefore the percent change for the added 0.01 million acres is also unknown.

Mississippi River Major Basin Nitrogen Goal Scenario – 45 Percent Reduction

Two hypothetical scenarios will achieve a 45 percent reduction of total nitrogen from cropland sources in the Mississippi River, assuming research can advance the success of cover crops in Minnesota. The two scenarios include:

(1) Use same adoption rates as for the Phase 1 Milestone except that cover crops are established on 80 percent of corn grain, soybean, dry bean, potato, and sorghum acres by improving the success rate on crops with current low establishment success from 40 to 80 percent.

(2) Increase adoption rates of the BMPs used for the Phase 1 Milestone to 100 percent of suitable acreages for those BMPs, and additionally increase cover crops from 10 to 60 percent of the corn grain, soybean , dry bean, potato, and sorghum acres (with current low establishment success) and improve establishment success to 60 percent.

If wastewater sources also make comparable percentage reductions, the long-term goal of a 45 percent reduction can potentially be achieved.

5.4 Recommended Miscellaneous Reductions for Phosphorus Goals

Miscellaneous sources (neither wastewater nor agricultural cropland) represent 48 percent of the statewide phosphorus load and 7 percent of the statewide nitrogen load in a typical year, as delivered to the state line. Much of this miscellaneous load will be addressed by existing programs and requirements, however, a third of this phosphorus load is a result of streambank erosion, which may be linked to erosive stream flows caused by natural and anthropogenic conditions and changes. In addition, atmospheric deposition also accounts for approximately 8, 7, and 18 percent of the loads in the Mississippi River, Lake Superior, and Lake Winnipeg major basins, respectively. A 12 percent reduction in total load from miscellaneous sources is assumed for phosphorus in the Mississippi River Major Basin, and one percent reduction in total load is assumed for the Red River Basin. Reductions in phosphorus from miscellaneous sources including streambank erosion, urban runoff, subsurface sewage treatment systems (SSTS), and feedlots are needed to reach the phosphorus goals in each of the three major basins. Control of nutrients from SSTS and feedlots in Minnesota are regulated by existing statute and rule, discussed in Chapters 4 and 6.

5.4.1 Streambank Erosion

Erosion of streambanks, bluffs, and ravines contribute to sediment and associated phosphorus loading. These loads can be reduced by watershed BMPs such as those included in Section 5.3 as well as stabilization or restoration of the channel, bluff, or ravine itself. BMPs which promote retention or detention of surface runoff or tile drainage can be used to help control downstream flows and potentially reduce streambank erosion.

Within the near channel area, various practices can be used for restoration and improvement including:

- Install buffers and perennial vegetation
- Armor slopes
- Restore sinuosity
- Reconnect floodplain
- Reduce upstream flow volume and velocity
- Riparian and upland forest management
- Streambank, gully, and bluff stabilization

The cost and effectiveness of these BMPs vary depending on the project and geographic location. A combination of activities will be needed to meet the miscellaneous source reductions.

5.4.2 Urban Runoff

Treatment of urban runoff from developed areas in the state is helpful to meet phosphorus reduction goals. The *Minnesota Stormwater Manual* provides detailed information related to stormwater management in Minnesota and includes descriptions of various structural and non-structural BMPs that can be used to address pollutant load reductions from urban runoff. The effectiveness of structural and non-structural stormwater BMPs vary. Examples of structural BMPs include:

- Bioretention
- Infiltration basin and trench
- Stormwater pond and wetland
- Green roof
- Permeable pavement
- Filtration including the iron enhanced sand filter (Minnesota Filter)

Examples of non-structural BMPs include pollution prevention, better site design, and education.

A combination of activities will be needed to meet the miscellaneous source reductions. These reductions rely predominantly on existing permit and program requirements, and therefore costs are not included in this analysis.

5.5 Nutrient Reduction Summaries

The overall practices to achieve nutrient reduction goals and milestones in the Mississippi River Major Basin and Red River Basin are summarized in Figure 5-5 through Figure 5-8. Each of the graphics includes suggested reductions by source for each of the BMP categories, urban stormwater and other sources, and wastewater treatment, as described in the preceding sections. Goals and milestones are presented in Chapter 2, baseline loads are presented in Chapter 3, progress since baseline is summarized in Chapter 4, and recommended NRS reductions are summarized above in Chapter 5.

45% Reduction

Mississippi River Phosphorus

	Source			
	Agricultural	Wastewater	Miscellaneous	Total
Baseline Load (1980–1996) Units = metric tons (MT) per year	1,337	1,739	1,551	4,627
Progress Since Baseline	356	1,113	51	1,519
Recommended Strategy Reductions				
Increasing Fertilizer Use Efficiencies on 2.2 Million Acres ▪ Recommended fertilizer rates ▪ Placement and timing of application ▪ Reducing soil P levels ▪ Livestock feed management	238			
Increase and Target Living Cover on 1.2 Million Acres ▪ Cover crops ▪ Perennial buffers ▪ Forage and biomass planting ▪ Perennial energy crops ▪ Conservation easements and land retirement	53			
Field Erosion Control on 4.5 Million Acres ▪ Conservation tillage and residue management ▪ Terraces/grassed waterways ▪ Sediment control basins	57			
Urban Stormwater + Other Sources			180	
Wastewater Treatment		37		
Total Reductions	348 +	37 +	180 +	1,519 = Total 2,084

Goal 45% from Baseline Load = 2,084 Metric Tons Reduced	Progress Since Baseline 1,519	+	Additional Reductions 565	=	Goal 2,084 MT Reduced = 45% by 2025

1,000 kg = 1 MT

Figure 5-5. Phosphorus goal reductions for Mississippi River Major Basin.

Notes:

Increasing Fertilizer Use Efficiency - In addition to load reductions gained from phosphorus banding, this load reflects the load reduction from applying conservation tillage that is attributable to fertilizer use efficiency. The area of conservation tillage listed under field erosion control in Table 5-14 is estimated to achieve load reductions from increased fertilizer efficiency and field erosion control.

Field Erosion Control - This load reflects the load reduction from applying conservation tillage that is attributable to field erosion control as opposed to fertilizer use efficiency.

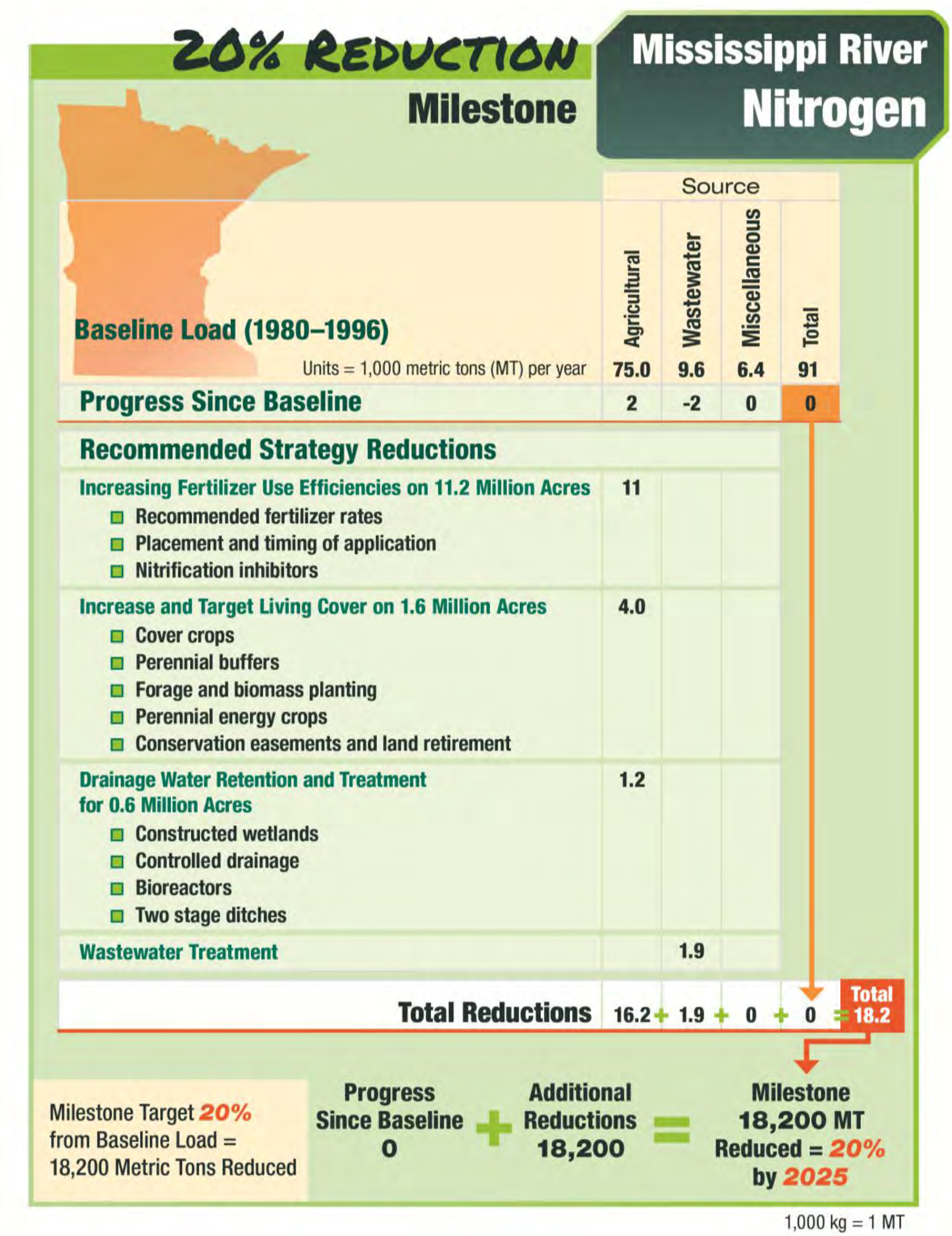


Figure 5-6. Nitrogen milestone reductions for Mississippi River Major Basin.

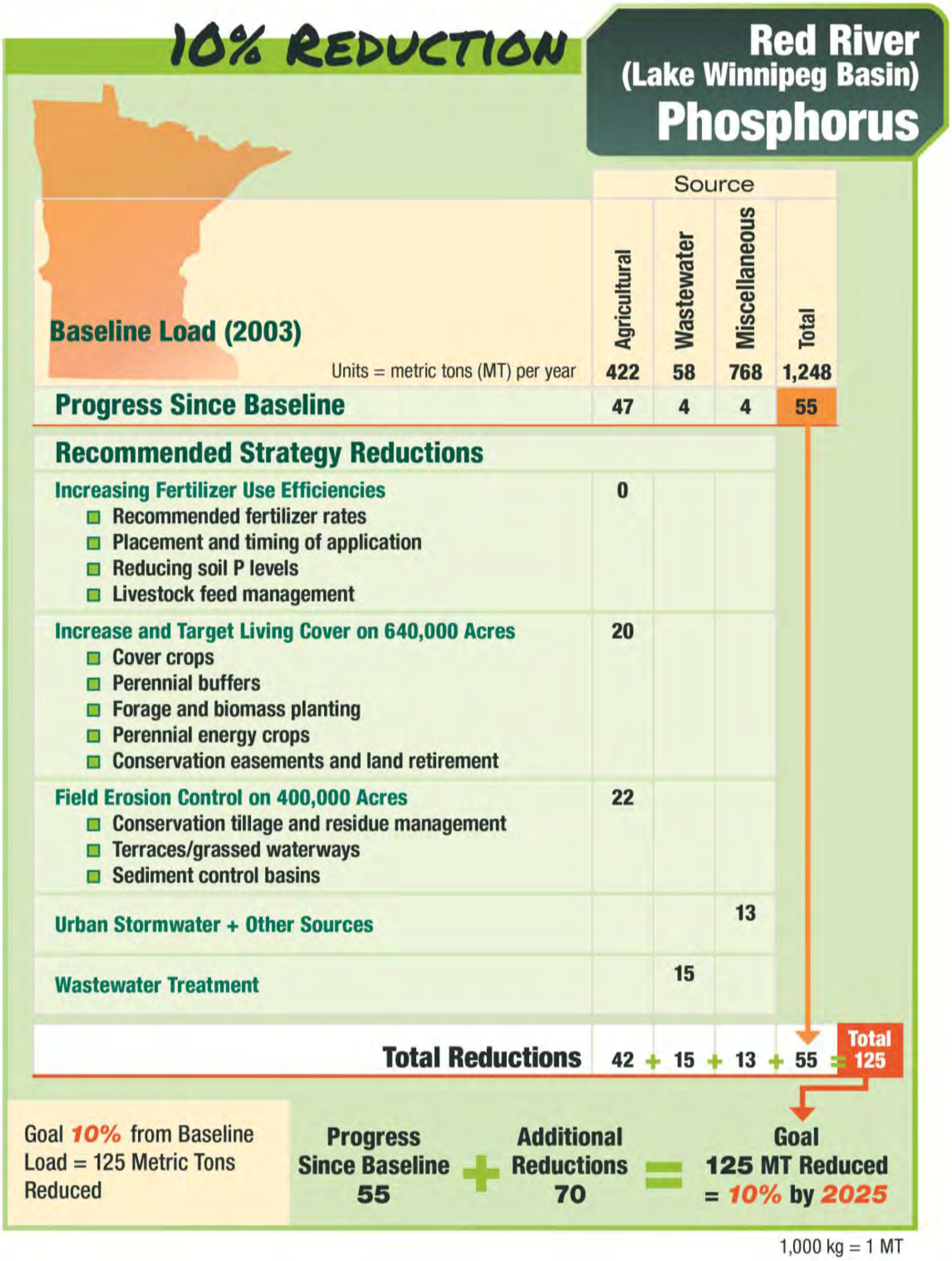


Figure 5-7. Phosphorus goal reductions for Red River/Lake Winnipeg Major Basin.

Notes:

Increasing Fertilizer Use Efficiency - This load reflects the load reduction from applying conservation tillage that is attributable to fertilizer use efficiency as opposed to field erosion control. The area of conservation tillage listed under field erosion control in Table 5-14 is estimated to achieve load reductions from increased fertilizer efficiency and field erosion control.

Field Erosion Control - This load reflects the load reduction from applying conservation tillage that is attributable to field erosion control as opposed to fertilizer use efficiency.

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13% Reduction

Red River (Lake Winnipeg Basin) Nitrogen

Units = 1,000 metric tons (MT) per year

	Source: Agricultural	Wastewater	Miscellaneous	Total
Baseline Load (2003)	7.2	0.3	1.4	8.9
Progress Since Baseline	0	0	0	0
Recommended Strategy Reductions				
Increasing Fertilizer Use Efficiencies on 700,000 Acres ▪ Recommended fertilizer rates ▪ Placement and timing of application ▪ Nitrification inhibitors	0.5			
Increase and Target Living Cover on 740,000 Acres ▪ Cover crops ▪ Perennial buffers ▪ Forage and biomass planting ▪ Perennial energy crops ▪ Conservation easements and land retirement	0.5			
Drainage Water Retention and Treatment for 20,000 Acres ▪ Constructed wetlands ▪ Controlled drainage ▪ Bioreactors ▪ Two stage ditches	a			
Wastewater Treatment		0.1		
Total Reductions	1.0 +	0.1 +	0 +	0 = Total 1.1

Goal *13%* from Baseline Load = 1,100 Metric Tons Reduced

Progress Since Baseline 0 **+ Additional Reductions** 1,100 **= Goal** 1,100 MT Reduced = *13%* by *2025*

1,000 kg = 1 MT

Figure 5-8. Nitrogen goal reductions for Red River/Lake Winnipeg Major Basin.

a. There is very little tile drainage during baseline period in this basin. BMPs are needed to mitigate increases from new tile installation.

5.6 Cost Analysis

An analysis of costs is provided below for both wastewater nutrient removal and agricultural BMP implementation. Costs are not presented for nitrogen removal costs in wastewater due to limited data. Literature sources were used for the agricultural BMP costs, which are documented in Section 5.3.

5.6.1 Wastewater Treatment

Costs for the vast majority (over 90 percent) of residents receiving municipal wastewater treatment range from $7 to $11 per pound of phosphorus removed to reach 1 mg/L concentration phosphorus in the effluent. However, removal costs escalate sharply with declining effluent concentration targets. Costs range from $39 to $175 per pound for removal to a 0.8 mg/L concentration and $91 to $344 per pound for removal to a 0.1 mg/L concentration. Table 5-16 presents the annual removal costs to treat wastewater (assumed influent concentrations of 4.5 mg/L) to 1.0 mg/L, 0.8 mg/L, and 0.1 mg/L effluent concentrations. These phosphorus removal cost estimates represent chemical phosphorus treatment by mechanical municipal wastewater treatment facilities only. Stabilization pond and industrial WWTP phosphorus removal costs are not included in these estimates.

Table 5-16. Summary of wastewater annual removal costs for phosphorus (MPCA calculations derived from Thorson 2011).

Design flow (mgd)	Population [a] (pop)	Annual removal cost to 1.0 mg/L [b] ($/year)	Annual removal cost to 0.8 mg/L [c] ($/year)	Annual removal cost to 0.1 mg/L [a] ($/year)
0.20 - 0.49	120,386	$3,575,501	$5,086,379	$13,660,247
0.50 - 0.99	194,117	$3,104,411	$4,665,486	$14,351,246
1.00 - 4.99	432,637	$5,436,306	$9,758,993	$25,349,659
5.00 - 9.99	225,393	$2,059,766	$2,869,941	$7,003,206
10.00 - 19.99	180,851	$1,446,127	$2,085,178	$4,900,305
20.00 - 39.99	506,769	$4,052,244	$5,812,076	$13,916,565
40.00 - 99.99	386,265	$3,529,904	$4,847,735	$12,178,169
100+	1,800,000	$14,393,224	$17,902,429	$37,861,033
	Total	**$37,597,483**	**$53,028,216**	**$129,220,430**

a. Population data derived from 2010 census; assumed flows of 100 gallons/capita/day.
b. Includes both capital and operations and maintenance costs.
c. Does not assume any additional capital costs.

Dividing these dollars per pound totals by the total population served by wastewater treatment facilities that discharge to surface waters (approximately 3.86 million) yields the following:

- Cost for phosphorus removal to a 1 mg/L concentration = $10/capita/year
- Cost for phosphorus removal to a 0.8 mg/L concentration = $14/capita/year
- Cost for phosphorus removal to a 0.1 mg/L concentration = $34/capita/year

5.6.2 Agricultural BMPs

The cost-benefit results for agricultural BMPs are presented both as annualized values. With the exception of conservation reserve values, MPCA (2013a) and Iowa State University (2013) developed the annualized values by calculating the net present value of the monetary costs and benefits associated with each practice from the producer's point of view. Costs included upfront establishment and operation costs. Benefits included any increases in production or cost savings to the producer gained by implementing the practice. For the conservation reserve values, an average of the costs from MPCA (2013a), Iowa State University (2013), and Miller et al. (2012) was used, which reflects the average across differing assumptions for site and program-specific details.

While an individual practice at the site-scale may change within 10 to 15 years, the NRS assumes, on average, that the acreages of BMPs implemented will be maintained in the long-term. The costs assume typical equipment replacement or other long-term maintenance requirements where appropriate.

The annualized value represents the net cost (or benefit in some cases) for the practice if it were paid in constant annual payments for the lifetime of the practice. The annualized value provides a means for comparing practices with different timing of costs and benefits (e.g., more upfront, less operation costs versus less upfront, more operation costs) or different time periods. These annualized values were referred to as lifecycle costs in Table 5-11 and presented there in terms of annualized costs per acre. The annualized values per acre were then applied to the acres of BMPs to calculate the cost per year to achieve the goals and milestone (Table 5-17).

The breakdown in costs by BMP category relate directly to the load reductions presented in Section 5.5. For example, the cost of the load reductions from increasing riparian buffer is estimated to achieve the reported load reductions for both nitrogen and phosphorus.

Table 5-17. Cost estimates by BMP, presents as a range of annualized values. Costs estimates will vary considerably with changing technologies, changing markets, new information and other changes. Parentheses indicate cost savings.

BMP category	Example BMP	Mississippi River Major Basin (per year)	Lake Winnipeg Major Basin (per year)
Increasing fertilizer use efficiencies	Nitrogen rates in accordance with the Maximum Return to Nitrogen	- ($80,000,000 - 95,000,000)	-($9,000,000 - 11,500,000)
	Achieve target soil test phosphorus and use subsurface banding	-(33,000,000 - $48,000,000)	$0
Increase and target living cover	Cover crops [a]	$42,400,000 - $63,600,000	$31,800,000 - $37,100,000
	Riparian buffers	$3,000,000 - $30,000,000	$600,000 - $6,000,000
	Conservation reserve	$1,800,000 - $33,000,000	$120,000 - $2,200,000
Drainage water retention and treatment	Wetlands and controlled drainage	$3,900,000 - $9,900,000	$150,000 - $270,000
Field erosion control	Conservation tillage	-($4,000,000 - $5,000,000)	-($375,000 - $425,000)
Cost of agricultural BMPs		**$51,100,000 - $136,500,000**	**$32,670,000 - $45,570,000**
Net cost (after subtracting savings)		**-($65,900,000 - $11,500,000)**	**$23,295,000 - $33,645,000**

a. Seed establishment cost estimates are based on aerial seeding for corn/soybean fields and no-till drill for short season crops. .

The results indicate that a net cost would be realized in the Mississippi River and Lake Winnipeg major basins. BMPs providing increased fertilizer use efficiencies are estimated to provide the greatest net benefit, while cover crops are estimated to provide the greatest net cost. In the Mississippi River Major Basin, the cost savings from the increased fertilizer use efficiency and conservation tillage BMPs offset greatly the net costs of the other BMPs. For an individual farm, the results would vary depending on which BMPs were implemented.

Increasing fertilizer use efficiency has a strong influence over the cost-benefit results. This BMP is estimated to provide a net cost savings, or benefit, due to reduced fertilizer costs. This value estimate assumes that the current nitrogen fertilizer application rate is above the recommended rate (on average) for the land where these practices would be implemented. Individual watersheds can use the NBMP tool to further evaluate the cost-effectiveness of numerous cropland BMPs adopted for nitrogen reduction to waters in a given watershed or basin (see Lazarus et al. 2014). The cost per pound of nitrogen prevented from entering waters for each BMP type is provided as an output of the NBMP tool (Table 5-18).

Table 5-18. Cost per pound of nitrogen reduced (Lazarus et al. 2014)

BMP	Cost per pound of nitrogen prevented from entering surface water in Mississippi Basin
Nitrogen rates in accordance with the Maximum Return to Nitrogen	(4.11) savings
Cover crops (short season crops)	$13.88
Cover crops (grain corn and soybean)	$8.90 to $31.80
Riparian buffers	$14.43
Conservation reserve on marginal cropland	$6.97
Wetlands	$1.59
Bioreactors	$14.66
Saturated buffers	$1.24
Controlled drainage (as a retrofit)	$2.40

Chapter 6

Nutrient Reduction Strategies

The *Minnesota Nutrient Reduction Strategy* (NRS) is intended to provide a roadmap as to the type of implementation activities that could be used to achieve the goals and milestones for reducing excess phosphorus and nitrogen in the waters of Minnesota and reducing Minnesota's contributions to downstream water quality problems. It is not intended to prescribe site specific best management practices (BMPs) and management actions. As a roadmap, the NRS acknowledges that additional planning activities will be necessary to support implementation actions for key strategies. In many cases this additional planning should integrate state level support and local implementation. This chapter identifies pathways for achieving nutrient reductions. Many of the strategies are contingent on a variety of factors, such as the collection of appropriate data, available financial and staff resources, and timing with other key initiatives and regulatory actions. As a result, an adaptive management approach to implementing the strategies will be used to guide and adjust implementation efforts over time. Chapter 7 of the NRS provides more detail on the adaptive management approach for gauging implementation progress as all stakeholders work toward meeting the goals.

6.1 Recommended Overarching Actions to Support Nutrient Reduction Strategy Implementation

The NRS builds on previous implementation efforts in the state. Working toward the goals and milestones will require a significant amount of coordination and communication at a statewide level. Infrastructure will be necessary to support coordination and communication among the various local, state, and federal partners. The first set of recommended strategies focus on developing and sustaining the necessary infrastructure to support coordinated implementation and communication on progress over time.

Strategy: Develop a Statewide NRS Education/Outreach Campaign. A significant portion of the nutrient reductions to be achieved through the NRS rely on voluntary actions from key sources, such as the agricultural community, and broad support from water users across the state. The NRS, and the scientific studies and other efforts that preceded it, expands conversations about the importance of reducing excess nutrient loss to waters and the most effective solutions available to meet nutrient reduction goals and milestones. Ongoing education and outreach are key to raising awareness about the need to reduce excess nutrient loss and to continue to make progress toward these reductions.

As a result, effective education and involvement are imperative to the success of the overall NRS. A multi-agency team of communications specialists, working with environmental educators and non-governmental stakeholder organizations, should develop and implement a coordinated NRS outreach campaign that integrates with other efforts to promote statewide stewardship of water resources. For example, the Draft *Nitrogen Fertilizer Management Plan* (NFMP) calls for a Nitrogen Fertilizer Education and Promotion Team to develop a prevention strategy to promote groundwater protection BMPs associated with nitrogen fertilizer use.

A Stakeholder Involvement and Education Plan to guide communication activities, crafted as part of the NRS development process, can serve as a foundation for outreach and education efforts. As the NRS moves into the implementation phase, the existing Stakeholder Involvement and Education Plan can evolve to identify outreach and involvement activities to communicate NRS -related messages and information to key audiences. Communication tools should inform, motivate, and assist with implementation of the nutrient reduction strategies. One of several tools could include a statewide coordinated advertising campaign intended to target nutrient behaviors from key target audiences, such as the Thank A Farmer! billboard campaign used in the Hinkston Creek (Kentucky) Watershed Project (Figure 6-1). The campaign could also include the development and distribution of nutrient reduction success stories and an associated awards program for the most successful nutrient reduction projects from across the state.

Figure 6-1. The Thank A Farmer! billboard campaign was used in the Hinkston Creek (Kentucky) Watershed Project to create a positive message for farmers about the use of grassed waterways.

Friendship Tours: Since some of the implementation actions needed are meant to help reduce impacts that are beyond the HUC8 watershed planning area, efforts should be made to increase direct interaction of local watershed managers with communities downstream that are being impacted. The Lake Pepin, Minnesota River and Mississippi River users and farther downstream, the Gulf of Mexico and Lake Winnipeg users, depend on local action far upstream. Friendship Tours which involve direct interactions of these upstream and downstream folks have been shown to help create the “small world” community perspective needed to make good stewardship decisions. Facilitation of these interactions may be needed to make this possible.

Basin Educators: As presented in the Minnesota Water Sustainability Framework (University of Minnesota 2011), Minnesota could consider funding basin educators through University of Minnesota Extension to work within the major river basins, focusing on the priority watersheds, to provide and coordinate water resources education and citizen engagement. This will increase capacity at both the state and local levels.

Strategy: Integrate Basin Reduction Needs with Watershed Planning Goals and Efforts. An expected outcome of Minnesota's Water Management Framework (described in Chapter 1) includes strategies for nutrient reduction, which are tailored to the 8-digit hydrologic unit code (HUC8) major watersheds and local water resources. The watershed restoration and protection strategy (WRAPS) for each HUC8 watershed includes such elements as timelines, interim milestones, and responsible governmental units for achieving the needed pollutant reductions. A comprehensive water management plan (e.g., One Watershed One Plan) is locally developed, which further defines the more specific actions, measures, roles, and financing for accomplishing the water resource goals.

While many major watersheds have nutrient impacted waters, in some cases the nutrient impacts to waters are greater downstream than at the local level, and in a few cases nutrient concerns are not evident until they show up in downstream waters. The WRAPS and associated comprehensive watershed management plan should be developed to not only have the goal of protecting and restoring water resources within the watershed, but to also contribute to nutrient reductions needed for downstream waters (in-state and out-of-state). For the WRAPS and watershed plans to achieve the downstream goals of this NRS, aggregated watershed reductions need to contribute to the overall milestones and goals.

A set of possible major watershed nutrient reduction targets is provided in Appendix E as a guide to collectively reach NRS goals and milestones. Watershed planning that addresses downstream needs should consider a proportional reduction from all anthropogenic sources based on the major basin goal or milestone (i.e., 20 percent nitrogen reduction for watersheds draining to the Mississippi River). Since the feasibility of BMP implementation practicality varies according to local conditions HUC8 watershed level reductions should also be guided by BMP implementation suitability in the watershed. Appendix E provides the HUC8 watershed nutrient reductions that would collectively achieve the goals and the Phase 1 nitrogen milestone for (a) all sources based on SPARROW modeling loads at the outlets of HUC8 watersheds, and (b) cropland sources alone based on the amount of land that is suitable and available for agricultural BMPs in each watershed as described in Chapter 5. Reductions are not expected for undisturbed landscapes such as undisturbed forests and grasslands; however preventative attention should be given to activities resulting in land disturbances.

Watershed modeling and local water planning through One Watershed One Plan can be used to develop the best scenario for BMPs in individual watersheds. The *Minnesota Nutrient Planning Portal* has been developed for accessing watershed nutrient-related information and includes information on nitrogen and phosphorus conditions and trends in local waters, nutrient modeling, local water planning, and other nutrient information. The information from this portal can be used when developing local plans and strategies to reduce nutrient losses to local and downstream waters.

Downstream Minnesota waters may require further evaluation to determine if additional nutrient reductions are needed, such as those reductions needed to meet approved total maximum daily loads (TMDLs) or downstream water quality standards (e.g., Lake Pepin). It is likely that future revisions of the NRS will include additional analysis of watershed-specific reductions undertaken to determine the most cost-effective approaches, especially when considering efforts to move toward final goals.

6.2 Strategies to Implement Wastewater Reductions

The current Phosphorus Strategy and Rule has and will continue to address phosphorus reductions in wastewater. The expected adoption of river eutrophication standards in 2014 is expected to result in additional wastewater phosphorus reductions in certain watersheds.

The history of phosphorus management at wastewater treatment plants (WWTPs) in Minnesota starting in 2000 is a relevant example of a successful program to reduce a pollutant of concern (Section 5.3.1). Several successful techniques utilized in the Phosphorus Strategy are proposed for nitrogen. An important caveat related to nitrogen removal is that nitrogen and phosphorous biological reduction can be competing processes depending on the facility type, and implementation of biological nutrient removal could compromise phosphorous removal efficiencies. Additional research and testing is necessary to develop cost-effective solutions for both phosphorus and nitrogen removal from wastewater. Until research and testing is completed, wastewater treatment facilities may be limited in their nitrogen removal achievements. This will need to be evaluated as more information is gathered and may result in modification of the nitrogen reduction milestones.

A series of steps are provided for the wastewater component of the NRS; and it is anticipated that the steps would be completed in sequential order. The steps described below are intended to build the knowledge base and generate the data necessary to support informed decisions and investments. The first step is to better understand nitrogen sources and concentrations in the wastewater influent and effluent. This step will provide information to support nitrogen management plan development. As a first step to reduce nitrogen in influent, facilities will identify high nitrogen contributors to the facility, if any, and target important nitrogen sources. Using information on nitrogen sources, facilities should develop optimization options for treatment processes that will enhance nitrogen removal without compromising phosphorus removal. As facilities complete these steps, the assessment will help to identify major changes needed to existing treatment processes and technologies. Major changes to treatment plants will require significant timeframes for design and construction.

Metropolitan Wastewater Treatment Plant Photo Credit: Metropolitan Council

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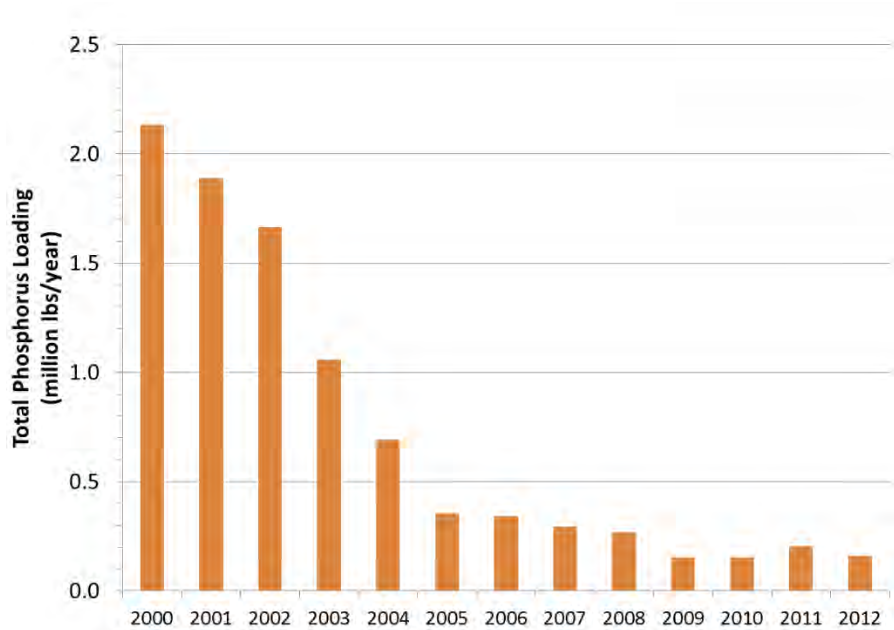
Nutrient Reduction in Action

Wastewater Treatment Success in the Metropolitan Area

The Metropolitan Council and its predecessor agencies have played a critical role in restoring the health of the Mississippi River in the 40 years since the passage of the Clean Water Act. Technology upgrades at WWTPs and partnerships with industry have greatly reduced pollutants such as phosphorus, mercury and other metals, suspended solids and ammonia-nitrogen in the river.

The Metropolitan WWTP is located on the Mississippi River in St. Paul, and is the largest wastewater treatment facility in Minnesota. When it opened in 1938, it was the first plant in a metropolitan area on the Mississippi River. Today it is among the nation's largest serving 1.8 million people.

Significant reductions in phosphorus loading from the Metro WWTP have occurred since 2000. The WWTP now consistently achieves less than 1 mg/l total phosphorus in the effluent.



Metro WWTP Phosphorus Loadings

Data provided by Metropolitan Council

Wastewater Strategy Step 1: Influent and Effluent Nitrogen Monitoring at WWTPs. Increase nitrogen series monitoring frequencies for all dischargers, including industrial facilities, starting with permits issued in 2014.

In the past, WWTPs in Minnesota have not regularly collected data on both influent and effluent nitrogen concentrations. Monitoring has been limited to ammonia primarily due to permit requirements. Those facilities with ammonia concentration or load requirements provide treatment to convert ammonia to nitrate-nitrite nitrogen, but do not reduce nitrogen loads in the effluent. Monitoring additional forms of nitrogen beyond ammonia is needed to more fully understand loading from WWTPs.

Nitrogen series (nitrate, total Kjeldahl nitrogen, ammonia) effluent monitoring is currently required twice per year for all dischargers with design flows over 0.1 million gallons per day. Influent monitoring should be added for municipal wastewater facilities and effluent monitoring frequency should be increased based on discharge type and size to obtain more data about point source nitrogen dynamics. More frequent data collection will help establish a better understanding of the variability in point source nitrogen discharges, and the comparison of influent and effluent nitrogen concentrations will allow for the development of nitrogen management plans and identification of dischargers with unusual (high or low) influent and effluent concentrations.

Monitoring also allows for information exchange among MPCA, operators, and consultants. Data could be used as background information for developing performance standards for various facility types.

Wastewater Strategy Step 2: Nitrogen Management Plans for Wastewater Treatment Facilities. Require nitrogen management plans for all major facilities and those facilities above certain effluent concentrations, except for industries such as power generation, which have limited potential to discharge new nitrogen to surface waters. Work with various organizations and existing programs to support nitrogen reduction planning for wastewater facilities, including the Minnesota Technical Assistance Program (MnTap), and identify possible funding and technical assistance. MnTap is a University of Minnesota organization whose mission is helping Minnesota businesses develop and implement industry-tailored solutions that prevent pollution at the source, maximize efficient use of resources, and reduce energy use and costs to improve public health and the environment. Their website contains more information: *http://www.mntap.umn.edu/*.

Historically, pollutant management plans have been developed for phosphorus and mercury. These plans were developed prior to, or in lieu of, implementing a permit limit. The plans identify cost-effective pollutant reductions depending on the facility, often targeting pollutant sources in influent. A nitrogen management plan could range from simple data analysis to complex engineering plans that reduce nitrogen at a given facility. Plans can allow a facility to identify cost-effective reductions that could be implemented in the near term and without the burden of effluent limits. The costs of such plans are relatively minor compared to a facility upgrade; however, if a facility upgrade is the only solution for nitrogen reduction, the plans might be unnecessary.

Timing of plan development is dependent upon monitoring data collection. Monitoring is anticipated to take a minimum of three years with plan development following. The first round of nitrogen management plans could be completed by 2020.

Wastewater Strategy Step 3: Nitrogen Effluent Limits as Necessary. After nitrate standards are adopted for protection of aquatic life, as currently required by 2010 legislation, begin incorporating water quality-based effluent limits (WQBELs) based on the new nitrogen standards for protection of aquatic life, as necessary.

The existing drinking water standard of 10 mg/l has resulted in very few nitrogen effluent limits. There are likely additional WWTPs in southern Minnesota that might need nitrogen WQBELs in the future, depending on the size of the discharge and the dilution of the receiving water during critical conditions. However, the number of WWTPs needing nitrogen WQBELs in the near-term to protect drinking water supplies is expected to be low due to the low number of streams currently designated for drinking water (see Chapter 2).

Future nitrate standards to protect aquatic life may be another driver in the future for nitrogen based WQBELs. Adoption of these standards is anticipated in the next 2–4 years. At that time, WQBELs will be incorporated into permit renewals as needed.

While the nitrogen milestone assumes an overall reduction of 20 percent nitrogen loads from wastewater sources by 2025, there are many unknowns that could affect this projection. It is critical for the state's largest facilities to reduce their nitrogen effluent to achieve the milestone, but more information is needed regarding potential industrial sources of nitrogen and treatment processes that would not compromise phosphorus removal at treatment facilities. Consideration should be given to the goal and milestone schedule when developing nitrogen management plans for wastewater point sources.

Wastewater Strategy Step 4: Add Nitrogen Removal Capacity with Facility Upgrades. Establish a technology-based threshold to achieve nitrogen reductions based on facility type and size. Encourage early adoption of nitrogen removal for major WWTPs planning to upgrade.

As part of the Phosphorus Strategy, which began in 2000, WWTPs began implementing phosphorus removal based on a technology limit. These actions allowed for early reduction in phosphorus, prior to the Phosphorus Rule and Minnesota River Basin Permit, which required phosphorus WQBELs.

A similar strategy is proposed for nitrogen. This strategy would encourage WWTPs to incorporate capacity and technologies for nitrogen removal into planned facility upgrades to save on overall planning and construction costs that could be necessary in the future. It is not likely that construction of nitrogen treatment technologies will be fully implemented until nitrogen standards for protection of aquatic life are complete, unless incentives for early adoption are identified and provided.

Wastewater Strategy Step 5: Point Source to Nonpoint Source Trading. Pollutant trading is an example of a market-based strategy since it is driven by finding the lowest cost treatment approach. In the case where Minnesota is working in concert with other states to reduce downstream impairments, the viability of an interstate nitrogen trading network should be considered. At the same time, Minnesota should continue to explore an in-state trading framework that allows for phosphorus and nitrogen point source-to-nonpoint source trading. Addressing the primary policy principles of trading including additionality (trades involve actions that otherwise wouldn't occur), equivalence (getting a similar outcome from the traded actions), and accountability (reasonable assurance that the actions are likely to happen) is critical to granting point sources authorization to trade. As water quality load capacity is established, trading has the potential to become more viable by generating a demand. Trading requires significant quantitative science for nonpoint source controls to demonstrate load reductions and decrease uncertainty. Development of a statewide trading framework would need to address these minimum requirements.

6.3 Strategies to Implement Recommended Agricultural BMPs

To achieve the goals and milestones, it is essential to develop strategies that will result in increased adoption of the BMPs identified in Chapter 5. Strategies to promote increased agricultural BMP adoption fall into the following categories: Increasing Agricultural BMPs in Key Categories; Accelerating and Advancing BMP Delivery Programs; Economic Strategy Options; Education and Involvement Strategies; and Research and Demonstration. Each action category is described below in more detail.

6.3.1 Stepping Up Agricultural BMP Implementation in Key Categories

Decisions that are made at the individual farm scale will be most successful when programs support and provide locally led assistance that motivates the needed changes. Annual farm planning creates the opportunity for farmers and industry and government advisers that serve them to continually improve nutrient use efficiency and reduce losses to the environment. Coordinated planning, whether through ongoing continual improvement efforts or new planning approaches, will provide the vision and pathway for achieving necessary programmatic support and local water planning activities. Conservation planning assistance from state and federal programs will create opportunities to combine efficient use of fertilizers with such practices as treating tile water and increasing living cover on the landscape.

Nitrogen and phosphorus reductions will be the result of pollution prevention and widespread BMP adoption. The following agricultural BMP implementation strategies are central to the success of the overall NRS.

Strategy: Work with Private Industry to Support Nutrient Reduction to Water. Changes that represent BMP introduction and incentive are common, but it isn't expected that government programs will be directly involved in all change that is needed. Recognizing the importance of BMP adoption that occurs outside of the direct involvement of government programs, tracking new BMP implementation stemming from private industry efforts is critical to understanding NRS progress. Private entities include individual farms, corporations, commodity groups, co-ops, certified crop advisers, and others. The NRS should build on existing partnerships among public and private entities, such as MDA's research and technical assistance program that typically includes the agricultural industry, producer groups, and individual farmers as well as consider new opportunities for private industry involvement in NRS implementation.

Strategy: Increase and Target Cover Crops and Perennial Vegetation. Large increases in living cover BMPs such as cover crops and perennial vegetation are needed to meet the milestones and goals, and are likely to become needed even more to reach the final nitrogen reduction goals. Cover crops and vegetative cover increases will need to become common if we are to meet the State's nutrient reduction goals. The NRS recommends that perennials be placed on sensitive lands such as riparian lands and on lands with marginal row crop production capability. This strategy recommends immediate promotion on two major areas, including establishing cover crops on short-season crops immediately and moving toward cover crops or double cropping of perennials within our traditional corn and corn/soybean crops. The greatest water quality benefits over the long term can be gained by establishing cover crops or perennial double cropping within our existing corn/soybean rotations; thus we need to continue research and increase the widespread practicality of such practices in Minnesota climates. The successful advancement of vegetative cover BMPs on agricultural lands hinges on a common vision and approach that is understood and supported among all key agencies, academia and private industry. Three key barriers have been identified in Minnesota to make progress in this area: (1) cover crop seed establishment in our relatively short Minnesota growing season, (2) genetics improvements on cold weather crops that can be successfully used in Minnesota, and (3) finding markets to create economic incentive for growing cover crops and perennials. MDA and USDA have prioritized cover crops as a research priority, and it is anticipated that research will address the lack of market incentives for cover crops and further the existing knowledge base on cover crop management, equipment, cost considerations, and environmental quality issues such as soil health, nutrient and sediment reduction, and water management.

Strategy: Soil Health. While the goals of the NRS are related to excessive nutrient loading to surface and groundwater, this strategy integrates those objectives with a goal of restoring and maintaining excellent soil health. Practices to improve water quality and soil health are both related to farm sustainability; and while water quality impacts generally show up downstream of the farm, soil health is more directly related to the sustained productivity of the soil on the farm itself. Integrating water quality and soil quality adds increased on-farm value to many of the practices used to mitigate nutrient loading. National initiatives are increasingly emphasizing the importance of soil health. In Minnesota, NRCS and BWSR, along with the University of Minnesota, MDA and other agencies, are working with agricultural and environmental organizations to include soil health as a conservation objective and to incorporate soil health principles with the types of BMPs in this Strategy to reduce nutrient transport to water. The four principles to improving soil health include:

- Keep the soil covered as much as possible.
- Disturb the soil as little as possible.
- Keep plants growing throughout the year to feed the soil.
- Diversify as much as possible using crop rotation and cover crops.

Improved soil health will sustain soil productivity for future generations, absorb and hold rainwater for use during drier periods, filter and buffer nutrients and sediment from leaving the fields, increase crop productivity, and minimize the impacts that severe weather conditions can have on food production and environmental quality. Thus the benefits of making widespread changes to cropland management, as outlined in this strategy, extend beyond water quality improvement, and include protecting our soil productivity for future generations.

The NRS seeks to incorporate soil health promotion as an overarching educational emphasis. As we promote the BMPs needed for nutrient reduction to waters, we should do so in concert with promoting soil health for long term food productivity and sustainability. By focusing attention on soil health and by providing education about the positive impact healthy soils can have on productivity and sustainability, Minnesota farmers will understand the multiple benefits of the BMPs to reduce nutrient losses to waters. This will increase the motivation for adopting these practices under the current policy framework.

Conservation programs such as EQIP and CRP are important to soil health. Conservation programs contribute to soil health by addressing some of the technical and financial risks associated with implementing practices that increase organic matter, water infiltration, water-holding capacity, and nutrient cycling.

Strategy: Riparian Buffers. Riparian lands, because of their close proximity to waters, contribute a higher and disproportional amount of nutrients to surface waters. Vegetative buffers are a primary watershed feature for assimilating sediment and phosphorus in overland flow. Minnesota's Shoreland Rules require that riparian lands adjacent to public waters be maintained in perennial vegetation. In addition to those streams regulated under the Shoreland Rules, buffers are encouraged along all waterways. Tracking implementation at a watershed or county scale is useful for understanding how effective the local implementation efforts are at achieving adoption and maintenance of buffers. Counties have been working for several years to implement county or watershed-scale projects to ensure that all waters regulated under the Shoreland Rules have adequate perennial buffers. An example of a local initiative is the Blue Earth County Shoreland Buffer Initiative, which was funded by a Clean Water Fund grant in 2011 with a goal of 100 percent voluntary compliance. The County and Soil and Water Conservation District (SWCD) used mapping and photo interpretation to determine areas that required a perennial buffer per county ordinance and state statue, and then worked one-on-one with landowners to implement the necessary projects. The SWCD provided technical assistance to landowners and directed landowners to available funding sources.

Strategy: Fertilizer Use Efficiencies. Increasing the efficient use of nitrogen and phosphorus fertilizers and manure is a fundamental strategy for reducing nutrient movement to waters. Fertilizer efficiency involves using BMPs for fertilizer rate, form, timing and placement. This strategy places a large emphasis on reducing industry average fertilizer applications on corn following legumes, and taking full credit for manure nitrogen sources (see also Chapter 5). Fertilizer and manure applications made in accordance with soil phosphorus testing results are also an element of the fertilizer efficiencies strategy. Expanded use of precision agriculture techniques should also be included in the fertilizer efficiency part of this strategy. The NRS recognizes that farmers rely heavily on private industry for the promotion and delivery of these potential cost-saving fertilizer efficiency improvements, with support from governmental programs relative to research, education, and demonstration. The NRS encourages crop advisors to include more emphasis on environmental protection and improvement during farm planning.

Strategy: Reduced Tillage and Soil Conservation. A key phosphorus reduction strategy is to increase crop residue on the soil surface through conservation tillage practices. The NRS calls for millions of additional acres to change tillage practices so that more than 30 percent of the ground is covered with crop residue. At the time of this NRS, crop residues may be increasingly removed from cropland for biomass energy production, potentially exacerbating soil erosion and reducing soil carbon. Private industry promotion of these practices will be key to the successful implementation of this soil conservation BMP emphasis. Re-introduction of tillage transect surveys and tracking from governmental programs will help to provide information on progress.

Strategy: Drainage Water Retention and Treatment. Reduction of nitrogen in the Mississippi River and Winnipeg major basins are dependent upon treatment or mitigation of tile drainage water that is resulting from subsurface drainage or tiling. Even with good nutrient efficiency, high nitrate levels in drainage water are observed. Wetlands, controlled drainage, bioreactors, saturated buffers and other BMPs are needed to treat tile drainage for the removal of nitrogen, and potentially dissolved phosphorus. While these BMPs are eligible for funding under existing federal and state cost-share programs, widespread increase in implementation is needed. Key strategy elements include:

- Identifying and targeting funding sources to support drainage water retention and treatment practices such as the Targeted Drainage Water Management Grants Program implemented by BWSR.
- Working with watershed groups and drainage authorities to develop tools and incentives to promote drainage water retention and treatment practices for both existing tile drainage and when new tiling is being proposed.
- Providing financial and technical assistance to implement BMPs for storing and treating tile drainage water in new and existing drainage systems.
- Mapping of drained fields and drain tile outlets on a county or watershed scale.
- Accounting for altered hydrology when drainage and watershed authorities consider new drainage systems or drainage improvements, and recommending appropriate mitigation techniques to minimize alterations to hydrology that can negatively impact water quality.

6.3.2 Support for Advancing BMP Delivery Programs

Several federal, state, and local programs currently focus on promoting and supporting implementation of many of the BMPs in Chapter 5. Where programs exist, it is necessary for program staff to work with stakeholders to identify optimization opportunities to improve targeting of BMPs in priority areas where additional nutrient reductions are most necessary. To achieve the goals and milestones, it is likely that additional resources will be needed. A federal-state partnership should be one of the primary implementation drivers. This NRS provides support for an outcome-based problem solving partnership. Consideration should be given to seeking a federal to state block grant from the USDA to provide enhanced implementation through a closely coordinated federal-state multi-year and multi-program initiative (i.e. 75 percent federal funding linked with 25 percent state funding). This block grant should support the goals and strategies described in the NRS.

Strategy: Coordinated Planning to Increase BMP Implementation. The analysis of programs described in Chapters 4 and 5 note that while progress has been made through implementation of BMPs, the current level of BMP implementation is not sufficient to achieve the NRS goals for nutrient reduction if implementation is maintained at the current pace. Stepping up the pace of BMP implementation will require coordination of state and federal program and policy support, locally led service delivery for assistance and education, and landowner readiness and motivation. The conversation that has begun with the NRS will need to become more specific to key strategies and integrate the critical links. Priority state or federal programs that deliver and support nutrient reduction BMPs should partner with key stakeholders to develop plans for coordinating these activities to meet the NRS goals and objectives. Where programs exist that currently address BMP implementation, the best approach to accelerate and advance nutrient reductions is to start with these existing program policy

Conservation Reserve Enhancement Program – An Example of Stepping Up BMP Implementation

An example of accelerated implementation planning is found in the Conservation Reserve Enhancement Program (CREP). CREP brings together the resources of Federal and State government around priority solutions such as wetland restoration and floodplain and riparian easements and accomplishes multiple benefits including nutrient retention on the landscape at an adoption scale and pace that wouldn't occur otherwise. By providing coordinated and focused planning, all stakeholders are able to more successfully achieve their objectives and accelerate overall progress. The first Minnesota CREP combined state and federal land set-aside programs and leveraged federal money (more than $163 million was available) for Minnesota. CREP 1 targeted the Minnesota River Basin, with an aim of enrolling 100,000 acres. Eligible lands include drained wetlands (for restoration), riparian lands, and flood prone lands.

The program leverages about $2.30 for each state dollar spent. BWSR and FSA jointly administer the program.

Minnesota is considering a new CREP project in the state. Nutrient retention should be one of the priority objectives in this example of an approach to integrating federal state and local actions around increased implementation.

frameworks, but also working with stakeholders to determine what additional policies, funding, support, partnerships, etc., will be necessary to accomplish the levels of BMP adoption needed to achieve the NRS milestones and goals. For some of the key BMP categories there isn't currently a coordinated program. In those cases it may be warranted to consider developing a coordinated program or project sufficient to support BMP implementation to the levels contemplated in the NRS. Chapter 5 outlines the magnitude of additional BMP implementation needs. Key categories of BMPs that need increased in BMP adoption include such areas as crop nutrient management, tile water treatment and storage, cover crops, and perennials.

Strategy: Increase Delivery of Industry-Led BMP Implementation. Strengthen public and private partnerships so that communication and promotion of BMPs is coordinated, and opportunities for improving both public and private BMP delivery can be identified and implemented. Develop mechanisms to increase delivery and account for conservation practices implemented voluntarily through industry or nongovernmental organization-led initiatives or local programs that are not reflected in existing state and federal programs. Conservation practices that agricultural industries develop and implement at the local level are keys to NRS success.

Strategy: Study Social and Economic Factors Influencing BMP Adoption. Determine the best ways to maintain an understanding of social and economic changes, constraints and considerations associated with adoption of conservation practices, participation in existing programs, perspectives on trusted sources of information, perspectives on stewardship and conservation, and role of financial and technical assistance in adoption decisions, among other factors. One area of potential study is to determine differences between rented and non-rented land regarding the acceptance and implementation of various structural and non-structural cropland BMPs, and if warranted develop effective incentive and educational programs for implementing BMPs on land that is rented.

This information would assist program managers in identifying options to optimize existing BMP delivery programs, developing more effective behavior change approaches that go beyond current education efforts, and determining what additional resources might be needed to increase local capacity to deliver agricultural BMPs. Minnesota should build on previous work aimed at better understanding social and economic factors affecting change or lack of change.

Strategy: Create a Stable Funding Source to Increase Local Capacity to Deliver Agricultural BMPs. SWCDs and watershed organizations conduct a variety of activities important to BMP implementation such as developing working relationships with landowners and delivering technical assistance and outreach and education at the local scale. Successful implementation of the NRS will require people in the field working one-on-one with landowners to explain incentives, enroll landowners in appropriate programs, design appropriate practices, and conduct appropriate follow-up and monitoring. It is recognized that additional local capacity will be required to implement the needed BMPs and strategies to achieve NRS goals and milestones. This strategy focuses on creating a stable funding source that will allow local partners to have a stronger watershed presence, resulting in more robust working relationships.

6.3.3 Economic Strategy Options

Historically, cost-share programs have been one of the most significant mechanisms for supporting voluntary agricultural BMP adoption. For areas where land is environmentally sensitive or marginal for crop production, programs to create easements that restrict crop production have been effective. However, increasing commodity prices and constrained federal resources are affecting enrollment in these programs. Since the NRS incorporates the need for maintaining perennials in sensitive and marginal lands, there is a need to develop new economic and motivational strategies to create incentives for achieving nutrient reductions, as well as disincentives for actions that could result in increased nutrient loads. Where row crops are re-established on conservation lands, BMPs are especially critical to mitigating nutrient loss.

Strategy: Nutrient BMP Crop Insurance Program. Farmers have always faced uncertainty. Weather and commodity pricing are notable, but so are the nutrient value in non-fertilizer nutrients and the fate of nutrients due to environmental factors. As farm input costs have increased, farmers have paid more attention to farm risk management. The Farm Bill's shift from direct payments to insurance subsidy reflects this, and farm surveys show that farm nutrient decision-making also includes elements of risk perception. Insurance programs can be created to reduce a farmer's risk associated with adopting a specific practice (Huang 2002). In essence, the insurance company charges a fee that is less than the farmer's perceived cost risk for adopting the practice. If the crop yield, for example, is reduced due to the adopted practice, then the insurer reimburses the farmer the difference between the profit from the actual yield and the yield that would have been obtained without the insured BMP. If the yield is not reduced, the insurer uses the premium from the farmer to cover program costs. While similar programs have been piloted in the past, they have not been successful, perhaps due in part to a lack of priority placed on incrementally reducing nitrate leaching to waters. Applying fertilizer and manure at the upper end of recommended rates is a common practice to mitigate risk of yield losses by following more conservative BMP fertilizer rates. For a farmer to enter into a nutrient insurance program, they need to be willing to take year-to-year yield loss risks to maximize long-term economic return. The insurance program can increase economic certainty and mitigate the perceived risk of changing fertilization practices.

No Till Field Photo Credit: NRCS

USDA conducted a pilot study in Minnesota in 2003 called *Nutrient BMP Endorsement* as part of the USDA's Federal Crop Insurance Corporation. *Nutrient BMP Endorsement* was created to give producers a risk management tool. Producers were required to follow the state's extension service agronomic recommendations and BMPs for nitrogen, and the program provided insurance when yield potential was less than optimal. In that case, a nutrient management plan was required to purchase the endorsement. A similar program could be further evaluated, developed, and implemented in Minnesota.

The American Farmland Trust adopted this basic approach in its *BMP Challenge for Nutrient Management* and *BMP Challenge for Reduced Tillage.* Under these programs, American Farmland Trust paid farmers cash if yield and income were reduced while participating in the BMP Challenge (*http://www.farmland.org/programs/environment/solutions/bmp-challenge.asp*). Unique performance guarantees allowed farmers to try conservation practices on their own land, observe performance over time in side-by-side comparisons, and evaluate economic impact without risk to income due to yield loss.

Strategy: Develop Markets and Technologies for Use of Perennials. Growing perennials can have as much as 95 percent removal efficiency for nitrogen as compared to row crops. As a result, research to develop the appropriate perennials and marketable uses needs to be a priority. A multi-University Midwest cornbelt project (including the University of Minnesota) funded by USDA-National Institute of Food and Agriculture is underway to develop a Sustainable Bioenergy Production and Distribution System for the Central USA. This project is being led by *CenUSA Bioenergy* at Iowa State University. Where soils are highly productive and row crops will continue to be grown, research should strive to develop a profitable cover crop or intercrop to provide ground cover and tie up nutrients prior to and following corn and soybean crops. An additional project, led by the University of Minnesota, is underway to develop a plan for Minnesota to increase long-term widespread use of perennial and cover crops. While research and development are underway and improved technologies are being established, current promotion of cover crops in Minnesota should be focused primarily on shorter-season crops and marginal lands for corn production. Development and support of new or expanded markets for perennials, such as harvested forages including alfalfa, pennycress, orchard grass, red clover, switchgrass, and smooth brome grass, could provide initial implementation opportunities, while federal research focused on energy crops will likely be critical to reaching the NRS's goal for nitrogen reduction.

Strategy: Quantify Public Environmental Benefits of Reducing Nutrient Levels in Water. Monetary and non-monetary environmental benefit information on reducing nutrient levels in waters can be used in a variety of messaging to provide additional motivation through a clearer understanding of ecosystem and other benefits to society from reduced nutrient transport into waters.

6.3.4 Education and Involvement Strategies

Adopting BMPs requires agricultural producers to make changes that are often linked to values, perceptions, and awareness of a problem. As a result, it is imperative to understand the values, perceptions, and awareness levels of Minnesota's agricultural producers and those advising agricultural producers about nutrient BMP implementation and, using this information, to develop an effective outreach and education strategy. Education and involvement strategies should be developed in coordination with the NFMP's Nitrogen Fertilizer BMP Education and Promotion Team described as an overarching strategy in Section 6.1. A wide variety of educational approaches designed to motivate BMP adoption should be considered, including messages that highlight economic benefits, peer-to-peer networks, and stewardship. The findings generated through the Study Social and Economic Factors Influencing BMP Adoption strategy described in Section 6.3.2 would significantly influence the educational messages and approaches tailored to agricultural community. Each of the following educational strategies is intended to target a specific key audience. These strategies would be supported by the Statewide Nutrient Reduction Strategy Education/Outreach Campaign described in Section 6.1

Strategy: Targeted Outreach and Education Campaign with Expanded Public-Private Partnerships. Some past studies have suggested that outreach and education activities are most effective in promoting conservation practice adoption when conducted one-on-one and coordinated by a trusted, local point-of-contact who is experienced with local farming practices and respected by the agricultural community (i.e. Jennings at al. 2012). Incorporating one-on-one education activities using trusted messengers is important to successful NRS implementation. The NRS recognizes that we will need to reach a very large number of land owners and managers. Combining multiple educational approaches will be needed for a successful strategy outcome. Nonprofits, such as the Sustainable Farming Association, and conservation organizations, such as Ducks Unlimited and Pheasants Forever, can connect with land owners and identify opportunities to promote BMPs such as wetland restoration and buffers that have multiple benefits including nutrient reduction and waterfowl habitat. Other key education and outreach partners can include watershed organizations, lake and river associations, and local government (cities, townships, counties). The goal is to build on local relationships and partnerships and ensure that outreach and education campaigns are tailored to specific sub-target audiences in locations where BMP adoption is critical. Examples of effective private-public educational partnerships should be shared across the state to allow other organizations to learn from successes and adopt similar approaches.

Strategy: Encourage Participation in the Agricultural Water Quality Certification Program. Farmers will have an opportunity to self-demonstrate a number of BMPs through participation in Minnesota's Agricultural Water Quality Certification program. This program promotes the use of BMPs, including nutrient management. While the program is farm and field specific, there is the potential for the program to promote adoption of the BMPs that are key to achieving the goals and milestones in the NRS. This program is currently in a pilot phase in four watersheds across the state, with the intent of statewide implementation in the future.

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Strategy: Focus Education and Technical Assistance to Co-Op Agronomists and Certified Crop Advisers. Agricultural producers rely on a variety of individuals for technical assistance, including fertilizer dealers, co-op agronomists, and certified crop advisers, who provide information on farm nutrient plans and improved approaches for fertilizer application and other important management practices. While it is important to inform agricultural producers directly, it is also important to inform their trusted advisers about key soil and water quality approaches for reducing nutrients, such as the online courses taught through the American Society of Agronomists (*https://www.agronomy.org/education/4r-approach*). The goal of the course is to encourage agricultural service providers to understand and use the process of evaluation, learning, and refinement with their farmer clients to identify the Four Rs (right fertilizer source, right rate, right time, right place) for individual fields to optimize crop yields while reducing the environmental impact of crop production systems. Increased education and certification as part of the crop adviser certification program should be developed.

Strategy: Involve Agricultural Producers in Identifying Feasible Strategies. As the NRS shifts to the implementation phase, it is imperative to engage agricultural producers and their business associations in discussions about BMPs and strategies to address nitrogen and phosphorus. These discussions will generate a better understanding of producers' perspectives and concerns, as well as enhance their ownership of the process. Such discussions, in either survey or focus group format, are essential to identifying the most cost-effective BMPs and achieving greater implementation of proposed BMPs and strategies.

Strategy: Watershed Hero Awards. Identify agricultural producers who are watershed heroes—adopters and supporters of nutrient reduction BMPs that can serve as a champion for these practices and convey the benefits of nutrient reductions to other agricultural producers in the watershed. Several award programs exist in Minnesota, including the Minnesota Association of SWCDs award programs to recognize outstanding conservation achievements. An award program for watershed-specific leaders in the agricultural community could inspire more agricultural producers to demonstrate innovative practices and share this information with other producers in the same or nearby watersheds.

Stream in the Red River Valley Photo Credit: MPCA

Strategy: Work with SWCDs, MDA and University of Minnesota Extension to Increase Education and Involvement. Minnesota has a history of commitment working with county SWCD staff and the University of Minnesota Extension to determine opportunities for improving education/involvement with agricultural producers. The form of this relationship has shifted from County Extension Agents to regional and state experts supporting local outreach opportunities. County SWCD staff provides technical, educational, and financial assistance to promote conservation activities on private lands. Under this strategy, SWCD staff would evaluate current nutrient-related education and involvement efforts targeting agricultural producers and identify opportunities to evaluate and improve delivery of these services. Additionally, University of Minnesota, MDA and BWSR regional specialists with expertise in nutrient reduction should be available to support effective education and involvement.

Strategy: Promote Youth-Based Nutrient Reduction Education. A variety of organizations focused on educating Minnesota's youth about water-related environmental issues have the potential to bring nutrient reduction curriculum into classrooms and other educational settings. As a first step under this strategy, the Minnesota Association for Environmental Education, or another environmental education partner working in the state, should inventory existing water quality-based educational curriculum to determine which currently incorporate nutrient-related information. Where necessary, existing curriculum should be updated to include information on nutrients and nutrient-reduction activities that are age-appropriate. The Environmental Learning in Minnesota (ELM) grant program, previously funded by MPCA, is one avenue to help provide environmental education opportunities and teacher training that could bring a nutrient-reduction focus to students. The ELM grant project reached over 7,000 children in 36 schools in Minnesota when it was funded during the 2008-2010 grant cycle. Minnesota State University's programs in sustainable agriculture could help to integrate nutrient reduction education into existing agricultural programs at the college level. Other educational organizations that reach children in an agricultural setting, such as 4-H, could also use existing water-based educational resources (*http://www.4-h.org/resource-library/curriculum/4-h-theres-no-new-water/*) to focus on nutrient-reduction activities.

6.3.5 Research Strategies

In order to achieve the needed reductions to meet goals in the Mississippi River Major Basin and expected future goals for the Lake Winnipeg Major Basin, new BMPs and management approaches are necessary. Research is key to development of these practices.

Strategy: Consolidate and Prioritize Research Objectives. Develop collaborative relationships between organizations conducting research related to agricultural BMPs in Minnesota including local, state, and federal agencies, land grant universities, and industry. Leverage resources and work in partnership to achieve prioritized research objectives. Implement a method of communicating between researching organizations to share results and plan for future research needs. The Minnesota Water Research Digital Library, expected for release in 2014 by MDA, will provide a foundation for this strategy.

Strategy: Conduct Research Activities. Conduct research to enable higher levels of nutrient reductions from current and speculative BMPs and management approaches. Include the following at a minimum:

- Research on how to increase grass-fed systems for meat production and on diets for bovines to reduce nutrient losses.
- Increase knowledge base regarding fertilizer use efficiency, including ways to assess growing season crop nutrient needs and make additional applications based on those needs.
- Research on innovative approaches for reducing nutrients from tile drainage waters, including use of saturated buffers, two-stage ditches, bioreactors, constructed wetlands, and controlled drainage.
- Development of approaches that will reduce soluble phosphorus, as well as BMPs which can address multiple nutrients.
- Soil and plant tissue testing as well as remote sensing for nitrogen and phosphorus losses to the environment to help in developing nutrient efficient cropping systems.
- Further development of the NBMP tool for use in HUC8 watersheds and expansion of the tool to address phosphorus reduction BMPs.
- Increased knowledge of the potential hydrologic effects of tile drainage on downstream flows and near channel erosion.
- Expanded research on the nutrient removal efficiency of agricultural BMPs and their potential to mitigate peak flow and volume.
- Increased knowledge of cost-effectiveness of agricultural BMPs.

- Research on cover crops and intercropping techniques with corn and soybeans to increase the success rate for establishment and use as a profitable cover crop. Research should include crop genetics and crop establishment techniques. A project is underway, being led by the University of Minnesota, to consider priorities for the research needs. Results are expected Fall 2014.
- Research on soil health to demonstrate benefits.
- Research on the sources of nutrients in atmospheric deposition (local versus regional) and associated BMPs to address these sources.
- Development of effective metrics for tracking and determining how to evaluate progress toward reducing nutrient losses to waters.

6.3.6 Demonstration Strategies

Learning by doing is a powerful tool to educate and change perception about nutrient reduction practices, particularly for those agricultural producers who are not traditionally early adopters of new management approaches and technologies. Providing technical assistance through demonstration projects and hands-on opportunities will help to both increase confidence in new management approaches and minimize risk when these practices are adopted full-scale.

Strategy: Watershed Scale Nutrient Reduction Demonstration Projects. NRCS National Water Quality Initiative (NWQI), Mississippi River Basin Initiative (MRBI), and Minnesota Sentinel Watersheds are examples of watershed scale nutrient reduction demonstration projects. These projects and potential additional watershed demonstration projects will be used to create confidence in our ability to reduce nutrients in waters by better demonstration of the extent of BMP adoption that is needed. Monitoring, modeling and other information can help demonstrate that cumulative adoption of BMPs from many farms in a watershed can result in monitored water quality improvement.

Strategy: Field Scale BMP Demonstration Projects. One way to address agricultural producers' perceptions of uncertainty, risk, and other constraints associated with new BMPs is to provide opportunities for on-farm trials and demonstrations. This can be achieved by continuing and expanding MDA- and NRCS-initiated on-farm-demonstration programs, the Discovery Farms Minnesota (*http://www.discoveryfarmsmn.org/*) model, and other similar producer-led initiatives to test a variety of practices. Discovery Farms Minnesota is a farmer-led water quality research and educational program that collects field-scale water quality data under real-world conditions on a variety of farming systems and landscapes throughout Minnesota. This type of approach could be used to test specific practices in priority watersheds to demonstrate effectiveness and effect on yield. Monitoring results from demonstration projects should be compared to local and downstream water quality protection and restoration needs and goals so that edge of field benchmarks can be established.

6.4 Recommended Strategies for Miscellaneous Sources

Significant new strategies are not suggested at this time to reduce loads from Subsurface Sewage Treatment Systems [SSTS]), urban/suburban stormwater, and feedlots. Existing programs have strategies in place that allow for systematic reductions in loads from these sources. In addition, implementation of TMDLs, particularly for turbidity-impaired streams, will likely address sediment-bound phosphorus sources that are a result of bank and channel erosion.

6.4.1 Subsurface Sewage Treatment Systems Strategies

Of the approximate 500,000 septic systems across the state, slightly less than 25,000 are estimated to be imminent threats to public health and could therefore potentially be direct sources of pollution to Minnesota's water resources. The number of septic systems that are imminent public health threats has been cut by half as compared to 2002. As described in the 2013 *Draft Nonpoint Source Management Program Plan*, the SSTS program is engaged in a number of different efforts to prevent and minimize impacts to water quality degradation that include: incorporating nitrogen BMPs into SSTS rules, requiring registration of treatment products for nitrogen reduction, and identifying imminent threats to public health and safety from uncontrolled discharges. The SSTS Program is also in the middle of a 10-year plan to upgrade and maintain Minnesota's SSTS. One of the main objectives of the SSTS Program is to strengthen local county programs to reduce the percentage of failing SSTS from 39 percent to less than five percent. In 2012, about 21 percent of systems were believed to be failing. Additional information can be found at *http://www.pca.state.mn.us/index.php/water/water-types-and-programs/subsurface-sewage-treatment-system-ssts/index.html*.

In addition, the MPCA has a Large Subsurface Sewage Treatment System (LSTS) Groundwater Nitrogen Policy for systems which serve flows of 10,000 gallons per day or greater. Due to the volume of wastewater treated by LSTS systems and the associated potential for environmental and health risks, Minnesota rules require that the MPCA regulates LSTS. The discharge of LSTS facility effluent must result in a 10 mg/l or less nitrogen concentration in groundwater at the property boundary or nearest receptor (i.e., drinking water well), whichever is closer. More information can be found at *http://www.pca.state.mn.us/index.php/water/water-types-and-programs/wastewater/wastewater-technical-assistance/wastewater-engineering/technical-information.html*. Current SSTS program implementation will serve as the strategies to reduce nutrient loads from individual and LSTS.

Amity Creek, Duluth Area Photo Credit: Tetra Tech

6.4.2 Feedlot Strategies

Animal manure contains significant quantities of nutrients which, if improperly managed, can lead to contamination of surface and groundwater. The Feedlot Program reduces direct runoff from feedlots and also regulates the land application and storage of manure in accordance with Minnesota Rules §7020 for over 25,000 registered feedlots in Minnesota. The Feedlot Program requires that the land application of manure, and its storage in manure storage basins, is conducted in a manner that prevents contamination of waters of the state. Manure management plans, facility inspections, enforcement, permitting, technical assistance, and record keeping are all used to protect water quality from both the feedlot facility and the land application of manure sites.

The Feedlot Program has set the following operational measures to prevent the impairment or degradation of state waters:

1. All large concentrated animal feeding operations (CAFOs) and feedlots with greater than or equal to 1,000 animal units are in compliance with discharge standards at the time of inspection.

2. All large CAFOs and feedlots with greater than or equal to 1,000 animal units are in compliance with nitrogen and phosphorus management requirements at the time of inspection.
3. All feedlots not covered by a National Pollutant Discharge Elimination System (NPDES) or State Disposal System (SDS) permit are in compliance with discharge standards at the time of inspection.
4. All feedlots not covered by a NPDES or SDS permit are in compliance with nitrogen and phosphorus management requirements at the time of inspection, including management of land application of manure activities.

Manure use efficiency and proper accounting for manure nutrient credits should be a long range program priority. Implementation of the Feedlot Program operational measures serves as strategies to reduce nutrient loads from feedlots. Additional information on the Feedlot Program can be found on the MPCA website at *http://www.pca.state.mn.us/index.php/topics/feedlots/index.html*.

6.4.3 Stormwater Strategies

The MPCA Stormwater Program regulates the discharge of stormwater and snow melt runoff from municipal separate storm sewer systems (MS4s), construction activities, and industrial facilities, mainly through the administration of NPDES and SDS permits. These permits form the basis of the stormwater strategies. For more information, go to *www.pca.state.mn.us/stormwater*. In addition, strategies are also provided to address non-regulated stormwater sources and the need for stormwater research and demonstration projects.

Strategy: Nutrient Reduction Associated with Regulated Stormwater Sources. Regulated stormwater sources will continue to reduce nutrients associated with permitted discharges based on existing and future permit requirements.

MS4 Permit

The MS4 General Permit became effective on August 1, 2013 and requires the MS4 operator or owner to create a Stormwater Pollution Prevention Program with seven important components:

1. Public education and outreach, which includes teaching citizens about better stormwater management.
2. Public participation, which involves including citizens in solving stormwater pollution problems. This includes a required public annual meeting and an annual report.
3. A plan to detect and eliminate illicit discharges to the stormwater system (like chemical dumping and wastewater connections).

4. Construction-site runoff controls.
5. Post-construction runoff controls.
6. Pollution prevention and municipal "good housekeeping" measures, like covering salt piles and street-sweeping.
7. Requirements for discharges to impaired waters with an EPA-approved TMDL that includes an applicable wasteload allocation.

Construction General Permit

Minnesota's State Construction General Permit (CGP) was reissued and became effective on August 1, 2013. The CGP applies to new developments and redevelopments over a certain size. From a nutrient reduction perspective, the CGP addresses both construction activities including erosion control and post-construction water quality requirements. A prominent change to this updated permit is the inclusion of volume control requirements to provide for water quality treatment post-construction. The permit states that one inch of stormwater runoff from new impervious areas will be retained on-site via infiltration, harvesting or reuse, unless prohibited.

Industrial Stormwater – Multi-Sector General Permit

Minnesota's Multi-Sector General Permit was last reissued on April 5, 2010. This permit addresses stormwater being generated on industrial properties and requires a series of benchmark and effluent monitoring activities for various pollutants, depending on the type of industrial activity. Effluent limitations are required for certain categories of industrial activity (e.g., sector C1 Phosphate Subcategory of Agricultural Chemicals includes a phosphorus effluent limit for stormwater discharges). Typically, most industrial activities do not have effluent limits but are required to mitigate for pollutants that exceed the monitored benchmark values through BMP implementation.

Strategy: Stormwater Technical Assistance. Stormwater technical assistance can be found in the form of the Minimal Impact Design Standards (MIDS), as well as in the Minnesota Stormwater Manual.

The Minnesota Stormwater Manual provides detailed information on stormwater management approaches and BMPs that are recommended for use in Minnesota. The Manual is kept up-to-date via a wiki format, and work is ongoing to maintain the Manual with the most recent and relevant information.

Minnesota began development of MIDS in 2009. The Minnesota State Legislature allocated funds in 2009 to "develop performance standards, design standards, or other tools to enable and promote the implementation of low impact development and other stormwater management techniques" (Minnesota Statutes 2009, section 115.03, subdivision 5c). Adapting and using low impact development approaches offers multiple benefits including minimizing and reducing the amount of pollution reaching our lakes, rivers and streams and helps to recharge groundwater. MIDS helps communities measure progress toward water and natural resource protection and restoration goals. MIDS represents the next generation of stormwater management and contains three main elements that address current challenges:

- **A clean water performance goal** for new development and redevelopment that will provide enhanced protection for Minnesota's water resources.
- **New modeling methods and credit calculations** that will standardize the use of a range of innovative structural and nonstructural stormwater techniques.
- **A credits system and ordinance package** that will allow for increased flexibility and a streamlined approach to regulatory programs for developers and communities.

A Community Assistance Package is being developed to provide ordinances and tools that help integrate low-impact development principles, including the MIDS performance goals and calculator, into a package that can be used by local units of government. These tools can be used by communities to help them achieve MIDS performance goals for stormwater volume.

Strategy: Stormwater Research and Demonstration. Research and demonstration are needed to further enhance the design, effectiveness, and adoption of stormwater BMPs. The Minnesota Stormwater Manual Wiki maintains a list of stormwater research needs and foci, examples include:

- Performance of emerging and non-traditional BMPs
- Cold climate adaptation and simulation tools
- Low impact development/better site design construction and maintenance
- The potential impact of infiltration practices
- Incorporating new climatic and hydrologic understanding into predictive models
- Short- and long-term field data for a variety of BMPs in conditions relevant to Minnesota

There are numerous research centers in Minnesota that focus efforts on stormwater-related research needs including the University of Minnesota St. Anthony Falls Laboratory. Many other organizations conduct and fund stormwater related research, although there is no unifying group to compile and compare various research efforts.

6.4.4 Sediment Reduction Strategies

Phosphorus bound sediment sources include streambanks, bluffs, ravines and uplands. Generally, the contributions from these sources vary by watershed and geography. Sediment may run off from fields or enter through unprotected tile intakes. Higher flow conditions within stream channels can lead to an increase in near channel and bluff erosion.

Research has shown that the near channel sources, such as streambanks, bluffs and ravines, contribute the most sediment to the Minnesota River. The Minnesota River is the largest source of sediment to the Mississippi River. Several TMDLs have been completed or are underway to address turbidity and sediment in each of the basins.

Confluence of St. Croix and Mississippi Rivers Photo Credit: MPCA

A draft Sediment Reduction Strategy has been developed to address sediment loading in the Minnesota River and the South Metro Mississippi River (defined as the Mississippi River between the confluence with the Minnesota River and Lake Pepin) (MPCA 2014, draft). Priority initiatives are identified in the draft Sediment Reduction Strategy to address nonpoint upland and near channel sources, as follows:

- **Reduce peak flow magnitude and duration**. Near-channel sources of sediment are the dominant sources at the mouths of the major watersheds in the Minnesota River basin. Sediment erosion and deposition in these tributaries are not in balance given the high rates of loading. Part of the erosive process in the Minnesota River basin is caused by base level fall of the Minnesota River that occurred when it was formed some 13,000 year ago. Another factor driving erosion is that stream flows have increased, along with the rate of erosion from near channel sources such as stream banks, bluffs and ravines. Decreases in peak flows are needed to bring the system into balance. Flow reduction goals include:

  Magnitude goal: Reduce two-year annual peak flow by 25% by 2030

  Duration goal: Decrease the number of days the 2-year annual peak flow is exceeded by 25% by 2030

- **Set water storage goals by watershed**. Managing hydrology is a way to decrease stream flows and near channel sediment sources. A water storage goal is needed for each watershed that would provide a target in acre-feet of water storage in an effort to meet stream flow targets. Methods to achieve the goal could be broadly defined and include surface storage, soils with higher organic matter on working lands, perennial vegetation (increased transpiration), among others. The targets need to be set at a level to make a difference, but not too high to unnecessarily impact current land use.
- **Define effective water storage practices**. Installing practices adjacent to the near-channel sources for direct protection, for the most part, is cost prohibitive. An exception is protecting infrastructure. Water management practices need to be defined and adopted in the portions of the watersheds upstream of the near-channel sources. Some of the modeling and research of the past has pointed to the types of practices needed, but not specific BMPs. The Greater Blue Earth River Collaborative for Sediment Source Reduction is one such initiative that will provide information for the Greater Blue Earth watersheds.
- **Consider hydrology and downstream waters in local watershed planning efforts**. Downstream needs concerning flow, water quality, and stream stability should be considered in local planning efforts. Today’s land use is efficient at moving water off of land. Watershed planning processes need to consider downstream waters and articulate methods to reduce the impact on them.
- **Funding assistance**. Provide funding assistance for design and implementation of water storage options in priority watersheds. Develop a sliding incentive scale to drainage authorities - the closer the mitigation site is to the impacted site, the more the incentive the state will provide.
- **Increase living cover**. Perennial vegetation increases transpiration and can protect soil during times of the year when crops are not in place or of sufficient size. Some of this vegetation could be placed in riparian areas or as vegetated floodplains to take up nutrients, slow water and trap sediment near streams.

- **Funding.** Combine state and federal funding for a CRP-RIM partnership for water storage which would be similar to CREP.

In addition to the above initiatives, civic engagement is identified as an important component of implementation. Coordination between the NRS and the sediment strategy in the Mississippi River Basin will be critical to ensuring effective use of resources and achieving multiple benefits. In the Lake Superior Basin and Red River Valley, stream turbidity impairments are widespread. Strategies similar to those presented above for the Minnesota and Mississippi River basins can be adapted for other parts of the state.

6.5 Protection Strategies

Protection strategies are needed in watersheds that are subject to changes in agricultural and land use practices, as well as vulnerable groundwater drinking water supplies in Minnesota. The Minnesota Water Management Framework, as Chapter 1 described, requires protection strategies as part of WRAPS development and watershed planning, and therefore should address the potential for increased nutrient loads at a watershed scale. Protection strategies for both new nitrogen sources and for soil phosphorus increases from land use changes are both important elements that should be addressed in WRAPS and local water planning (e.g., One Watershed One Plan).

6.5.1 Protecting the Red River from Nitrate Increases

Tile drainage is expected to increase rapidly in the Red River Basin in the coming years. As a result, an increased load of nutrients is possible. Achieving the milestone for the Red River portion of the Lake Winnipeg Basin will need a combined focus on reducing baseline loads of nitrogen through increased fertilizer efficiency combined with a strategy of wetland treatment, bioreactors, and controlled drainage to offset new sources. Protection strategies are needed to mitigate new sources of nitrogen in the Red River Basin within the next five years.

The current analysis of suitable acreage for wetlands and bioreactors in the Red River Basin does not take into account future tiling, and therefore limited pollutant load removal is identified in this NRS. An analysis of potential areas that will likely be tiled in the future would help to identify opportunities to promote mitigation. A focus on land conservation programs in the Red River Basin is also needed to protect low lying areas that could potentially be tiled in the future. Permanent conservation easements could also be used to protect these areas. An initiative is needed to 1) identify current and potential tiled lands and 2) promote mitigation in these areas.

Future protection activities in the Red River Basin should consider recent developments related to tiling. The Red River Watershed Management Board recently finalized a set of model rules/ordinances for watershed districts to adopt, as well as tile drainage permitting guidance. In addition, the Red River Retention Authority created the Basin Technical and Scientific Advisory Committee, which has been working on briefing papers related to tiling issues in the Red River Valley.

6.5.2 Lake Superior Nutrient Load

Although there are no current reductions identified for the Lake Superior Major Basin, we should continue vigilance in protecting Lake Superior from nutrient increases, while at the same time researching the effects of added nitrogen in the Great Lakes.

6.5.3 Groundwater Protection Strategies

The 2013 Draft *Nitrogen Fertilizer Management Plan* (NFMP) is Minnesota's blueprint for prevention and minimization of the impacts of nitrogen fertilizer on groundwater. The prevention goal in the NFMP is the same as the NRS goal, as defined by the Groundwater Protection Act (Chapter 103H Section 1); to maintain groundwater

> *[I]n its natural condition, free from any degradation caused by human activities. It is recognized that for some human activities this degradation prevention goal cannot be practically achieved. However, where prevention is practicable, it is intended that it be achieved. Where it is not currently practicable, the development of methods and technology that will make prevention practicable is encouraged.*

As such, the strategies outlined in the NFMP will serve as the groundwater protection strategies in the NRS:

1. Implementation of BMPs the University of Minnesota Extension and the MDA developed, which are based on the *Four Rs* (right fertilizer source, right rate, right time, right place), and consider the different geology and climate across the state.
2. Alternative management tools to reduce nitrogen fertilizer inputs—perennial crops such as alfalfa, retiring land from production for CRP, Reinvest in Minnesota, grazing, etc., alternative cropping variety that requires less nitrogen, and other new technologies.
3. Wellhead protection planning and implementation (as administered by Minnesota Department of Health's State Wellhead Program [Minnesota Rules 4720]).
4. A Nitrogen Fertilizer Education and Promotion Team will be convened to assist MDA with the coordination of prevention activities and programs and specifically promote BMPs and

alternative management tools in areas with vulnerable groundwater resources, such as wellhead protection areas, the Central Sand Plains, and southeastern Minnesota's karst area.

5. A phased mitigation strategy to reduce groundwater nitrate concentrations below the 10 mg/l drinking water standard that starts in a voluntary mode and can elevate to a regulatory mode, depending on the severity of nitrate contamination and whether BMPs are being adopted.

The NFMP emphasizes that local participation (farmers, citizens, local government units, crop consultants) is imperative in any prevention or mitigation activities, if they are to be successful. In addition to fertilizer management, the NRS also recognizes the importance of irrigation management as related to movement of nutrients in the environment. Priority areas for groundwater protection are provided in Chapter 4 based on groundwater vulnerability and existing land uses.

MDA has expressed its intention to begin a process for developing rules related to: (a) restricting certain types of fertilizer application during the fall in areas vulnerable to groundwater contamination, and (b) regulatory requirements in areas with a combination of high nitrate in groundwater caused by fertilizers and inadequate adoption of nitrogen fertilizer BMPs (in accordance with the phased approach described in the NFMP).

6.6 Summary of Strategies, Priorities, and Costs

A summary of the strategies presented in Sections 6.1 through 6.5 are presented in Table 6-1 along with the strategy's priority, expected level of costs, and lead organizations. Costs take into consideration program investments and implementation activities.

Table 6-1. Summary of strategies, priorities, schedule and costs

Strategy	Strategy Priority (H-M-L)	Anticipated Costs ($ - $$$)	Lead Organization(s)
Recommended Overarching Actions to Support NRS Implementation			
Develop a Statewide NRS Education/Outreach Campaign	H	$$	MPCA and Accountability Team
Integrate Basin Reduction Needs with Watershed Planning Goals and Efforts	H	$	
Strategies to Implement Wastewater Reductions			
Continued Implementation of the Current Phosphorus Strategy and Rule	H	$	MPCA, Met Council
Influent and Effluent Nitrogen Monitoring at WWTPs	H	$	
Nitrogen Management Plans for Wastewater Treatment Facilities	H	$$	
Nitrogen Effluent Limits as Necessary	H	$$	
Add Nitrogen Removal Capacity with Facility Upgrades	M	$$$	
Point Source to Nonpoint Source Trading	L	$$	
Strategies to Implement Recommended Agricultural BMPs			
Stepping Up Agricultural BMPs Implementation in Key Categories			
Work with Private Industry to Support Nutrient Reduction to Water	H	$$	NRCS, MDA, BWSR, DNR, LGUs, Industry
Increase and Target Cover Crops and Perennial Vegetation	H	$$$	
Soil Health	M	$	
Riparian Buffers	M	$$$	
Fertilizer Use Efficiencies	H	$$$	
Reduced Tillage and Soil Conservation	H	$$$	
Drainage Water Retention and Treatment	H	$$$	
Support for Advancing BMP Delivery Programs			
Coordinated Planning to Increase BMP Implementation	H	$$	MDA, BWSR, MPCA, UM Extension, Industry
Increase Delivery of Industry-Led BMP Implementation	H	$$	
Study Social and Economic Factors Influencing BMP Adoption	H	$	
Create a Stable Funding Source to Increase Local Capacity to Deliver Agricultural BMPs	H	$$	
Economic Strategy Options			
Nutrient BMP Crop Insurance Program	L	$$	MDA
Develop Markets and Technologies for Use of Perennials	H	$$	
Quantify Public Environmental Benefits of Reducing Nutrient Levels in Water	M	$	

Strategy	Strategy Priority	Anticipated Costs	Lead Organization(s)
Education and Involvement Strategies			
Targeted Outreach and Education Campaign with Expanded Public-Private Partnerships	H	$$	BWSR, UM Extension, MDA
Encourage Participation in the Agricultural Water Quality Certification Program	H	$	
Focus Education and Technical Assistance to Co-Op Agronomists and Certified Crop Advisors	H	$	
Involve Agricultural Producers in Identifying Feasible Strategies	H	S	
Watershed Hero Awards	M	S	
Work with SWCDs, MDA, and University of Minnesota Extension to Increase Education and Involvement	M	$	
Promote Youth-Based Nutrient Reduction Education	L	$	
Research Strategies			
Consolidate and Prioritize Research Objectives	H	$	Academia, USGS, Industry, MDA
Conduct Research Activities	H	$$$	
Demonstration Strategies			
Watershed Scale Nutrient Reduction Demonstration Projects	M	$$	MDA and Industry
Field Scale BMP Demonstration Projects	M	$$	
Recommended Strategies for Miscellaneous Sources			
Subsurface Sewage Treatment Systems Strategies	M	$	MPCA, LGUs
Feedlot Strategies	H	$	
Nutrient Reduction Associated with Regulated Stormwater Sources	M	$	
Stormwater Technical Assistance	M	$$	
Stormwater Research and Demonstration	M	$$$	
Sediment Reduction Strategies	M	$$$	
Protection Strategies			
Protecting the Red River from Nitrate Increases	H	$$$	MDA, BWSR, LGUs, NRCS
Lake Superior Nutrient Load	L	$	MPCA
Groundwater Protection Strategies	H	$	MDA, MDH

TBD – To Be Determined

a. Anticipated costs represent new efforts and do not include existing funding.

$ - Tens of thousands

$$ - Hundreds of thousands

$$$ - Millions+

Chapter 7

Adaptive Management and Tracking Progress

While the *Minnesota Nutrient Reduction Strategy* (NRS) is based on scientific analysis and considerable agency, academic and public input, there will continue to be a need to improve and refine the NRS based on new information and input from scientists, key stakeholders and partners. The NRS will be frequently evaluated and periodically updated using an iterative process of planning, implementing, assessing and adapting, often referred to as *adaptive management* (Figure 7-1). In essence, adaptive management is learning by doing and using improved data and information over time to improve decision making with the intent of achieving a goal within a specified timeframe. Adaptive management incorporates data gathering and learning from experience and improved science. The adaptive management plan described in this chapter documents the procedures for assessing progress over time and the triggers for updating the NRS to achieve the nutrient reduction goals and milestones.

The NRS sets out goals and milestones for nutrient load reductions, as well as recommended approaches for achieving the milestones. To ensure that on-the-ground implementation is on pace with the NRS milestones and goals, it is imperative to have an adaptive management plan that will guide an evaluation of the NRS's progress over time. The basic components of the NRS's adaptive management plan are as follows:

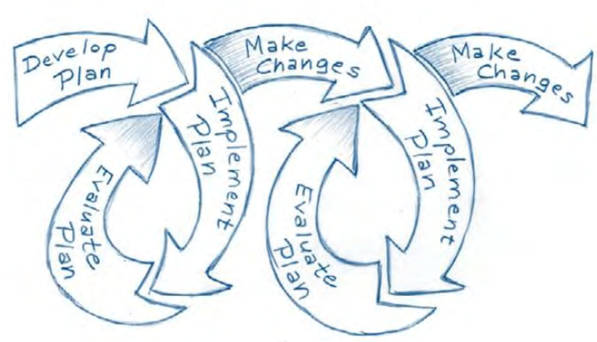

Figure 7-1. Adaptive management iterative process (USEPA 2008).

- Identify data and information needed to track progress toward NRS goals and milestones.
- Create a system or approach for collecting data and information needed to track progress toward NRS goals and milestones.
- Evaluate trends as well as relationships between actions and outcomes.
- Adjust the NRS as necessary.

Each of these components as it relates to the NRS is discussed in more detail below.

7.1 Information Needed to Track Progress

To understand the level of nutrient reduction progress being achieved, it is important to evaluate both changes in the adoption of best management practices (BMPs) (human actions) and water quality monitoring information (environmental outcomes). Water quality monitoring data alone will not provide sufficient information to evaluate progress and make needed adjustments to the NRS. Water monitoring does not provide reliable information on incremental nutrient reduction progress when the level of BMP adoption is not extensive enough to overshadow natural water quality variations, or when lag times are large due to phosphorus cycling in stagnant waters or when nitrate movement through the groundwater hydrologic pathway is slow compared to other pathways.

Both action and environmental outcome data will be necessary to track progress toward NRS goals and milestones. Implementation data provides early indicator information about nitrogen and phosphorus reductions that, over time, should translate to in-stream nutrient reductions. Expected water quality changes can be analyzed and modeled when the following types of information are available:

- BMP implementation through programs
- Overarching management changes through BMP adoption by all government and private action
- Land use and management changes apart from BMP adoption (i.e., cropping rotation changes, deforestation, urbanization, tiling, etc.)
- Precipitation and hydrologic information

Environmental outcomes as represented by water quality monitoring trends are an important part of tracking NRS success, since they are a direct measure of NRS goals. This is especially the case when the monitoring results are analyzed in concert with the above list of information, allowing evaluation of not only progress toward goals, but the effectiveness of actions taken to influence those outcomes. Water quality monitoring results should be evaluated at different points and scales, including:

- Watershed outlets (i.e., major 8-digit hydrologic unit code [HUC8] watershed, basin and major basin)
- Major river monitoring sites with historical monitoring
- Water supply wells (for nitrate)
- Sentinel and demonstration watersheds for studying water quality cause and effects

When all of the information above is considered together, progress toward achieving milestones and goals can be evaluated. Each information need and corresponding evaluation approach is described below.

7.1.1 BMP Implementation Evaluation

The implementation evaluation piece of the NRS's adaptive management process focuses on implementation of the most influential categories of BMPs and management actions described in Chapters 5 and 6. The objective of evaluating programs and BMP implementation is to determine progress toward the milestones and goals outlined in Chapter 2. The emphasis of this initial version of the NRS is on reaching goals and the Phase 1 nitrogen milestone and has an 11-year planning horizon from 2014 to 2025. Under an adaptive management approach, the implementation evaluation would allow opportunities to gauge implementation progress at several key intervals to ensure implementation is on track to achieve the goals and Phase 1 nitrogen milestone. Tracking environmental outcomes helps to inform needs to achieve environmental goals. Quantifying changes in both program implementation and water quality outcomes are complementary parts of the NRS. The approach for quantifying these changes must be meaningful, sustainable, and replicable.

The selected key programs identified in Chapter 4 implement a variety of structural and nonstructural BMPs. While programs are expected to provide accounting of the actions that they directly control, whether through permit or assistance contracts, attempting to quantify nutrient reductions for every BMP influenced by each program is not always possible with limited resources. Federal programs play an important role in promoting adoption of agricultural conservation practices using key BMPs. There is a need to develop mechanisms that allow for improved federal agency data sharing and changes to existing federal databases to support NRS tracking over time. It is expected that the public will continue to call for improved accountability in government programs.

A suite of program measures have been developed in an effort to narrow down the potential BMPs under each identified program to focus on those that are the most meaningful indicators of readily available data on statewide nutrient reduction progress. This can streamline the tracking process, but where only indicator BMPs are being tracked, a relationship to overall BMP implementation should be developed. Tracking the implementation information associated with the selected program measures provides the pulse of key implementation programs. Nutrient reduction trends for the selected program measures will show progress related to certain BMPs; yet it is important to keep in mind that there is a wide range of BMPs that are beneficial to achieving the nutrient reduction goals (as listed in Appendix B). Table 7-1 summarizes the priority programs with the associated measure and indicator BMPs. It is important to note that some measures capture more than one program. Not all programs have measures at this time due to data limitations, specific program development issues, or project resource constraints.

Each program measure has a corresponding metadata worksheet (see Appendix F). The metadata worksheets capture all the relevant information about the measure to ensure that the methodology is documented and replicable in the future. The metadata worksheets also capture data limitations and caveats associated with each measure to help the reader understand how best to interpret the measure and the type of future improvements that are necessary to make the measure more robust over time. The format used for the metadata worksheets follows the template used in the Clean Water Legacy Fund Performance Report. This will allow for agency familiarity with the format, as well as integration of measures from that effort that capture programmatic progress related to nutrient reductions.

Table 7-1. Program measures summary

Program	Measure for quantification	Indicator BMPs
Erosion Control and Water Management Program/State Cost-Share Program (BWSR)	Implementation of nonpoint source BMPs tracked via eLink and estimated BMP nutrient load reductions	All BMPs captured in eLink
Reinvest in Minnesota (RIM) Reserve Program (BWSR)	Implementation of permanent easements and associated nutrient load reductions	Acreage and percent of permanent conservation easements on environmentally sensitive and marginal agricultural land (as defined in RIM eligibility handbook)
Nonpoint Source Management Program (Section 319) (MPCA)	Implementation of nonpoint source BMPs tracked via eLink and estimated nutrient load reductions	All BMPs captured in eLink
Nitrogen Fertilizer Management Plan (NFMP) (MDA)	Implementation of nitrogen fertilizer management BMPs	1. Nitrogen fertilizer application rates 2. Nitrogen fertilizer application timing 3. Nitrification inhibitor use 4. Use of additive and specialty formulations
Clean Water Land and Legacy Program (BWSR)	Implementation of nonpoint source BMPs tracked via eLink and estimated nutrient load reductions	All BMPs captured in eLink
Conservation Reserve Program (CRP) and Conservation Reserve Enhancement Program (CREP) (FSA)	Implementation of priority CRP conservation practices and estimated nutrient load reductions	1. Filter strips (CP 21) 2. Riparian forested buffers (CP 22)
Conservation Security Program (CSP)/ Conservation Stewardship Program (CStP) (NRCS)	No measure at this time	

Program	Measure for quantification	Indicator BMPs
Environmental Quality Incentives Program (EQIP) (NRCS)	Implementation of priority EQIP management practices and estimated nutrient load reductions	1. Residue management 2. Nutrient management 3. Forage and biomass planting
Wetland Reserve Program (WRP) (NRCS)	No measure at this time	
Agricultural Best Management Practices (AgBMP) Loan Program (MDA)	Implementation of conservation tillage funded through AgBMP Loans	1. Conservation tillage projects
Commercial Animal Waste Technicians (CAWT) Program (MDA)	No measure at this time	
Minnesota Agricultural Water Quality Certification Program	No measure at this time	
Industrial/Municipal Wastewater National Pollutant Discharge Elimination System (NPDES) Permitting (MPCA)	Municipal wastewater phosphorus trends (excerpted from the Clean Water Fund performance measures)	Phosphorus effluent statewide trends

The selected program measures reflect government programs and do not capture all voluntary or industry-led conservation activities. Voluntary conservation activities that are not related to a specific government program can contribute a significant percentage of overall BMP adoption, especially for practices including precision farming, conservation tillage, nitrogen fertilizer BMPs, phosphorus use, and cover crops. While government funded education, demonstration and research can increase private action, BMPs adopted apart from government programs are more difficult to track and evaluate. However, certain indicators of progress can be useful for evaluating the overarching BMP adoption changes that occur through the collective private actions. Changes to the National Resource Inventory or Agricultural Census could provide statistical representation of land management and should be explored.

It is anticipated that through NRS assessments, additional measures will be developed in the future to track implementation success related to other programs and implementation-related activities. For example, measures should be evaluated to determine the applicability of existing techniques to track vegetative cover changes. With advancements in satellite imagery and other remote sensing techniques, it is now possible to discern changes in vegetative cover. This NRS recommends using such technology, along with on-the-ground inventory information, to evaluate changes in vegetative cover practices such as establishment of cover crops, perennials, hay, riparian buffers and potentially crop residue cover. Crop residue cover and other ground-cover BMPs should also be determined with transect surveys, similar to transect surveys conducted during previous years so that changes can be evaluated from historical levels of crop residue cover.

Because nutrient efficiency is such a critical NRS element, metrics need to track improvements in overall nutrient efficiencies. These efficiencies should be also be used to estimate nutrient changes in the receiving waters. Nitrogen fertilizer sales and crop yield information are tracked and have been used to show that, during the past couple of decades, agricultural producers have made progress in growing more corn for each pound of nitrogen fertilizer. Fertilizer sales and crop yield information, when combined with trends in planting densities, manure nutrient availability, grain protein content, and other information, could provide an indication of trends related to nutrient efficiencies and changes in the amount of soil nutrients that are potentially available for losses to the environment.

BMP implementation that takes place on a watershed scale, but is occurring outside of government assistance, is likely the largest gap relative to measuring success of the NRS. Comprehensively determining outcomes will require measuring of conservation practices and farming activities that are not funded and tracked through government programs. Potential BMP implementation not accounted for due to private implementation efforts could include conservation tillage, nitrogen fertilizer BMPs, phosphorus use, cover crops and non-commodity crops.

Other metrics of nutrient efficiency, based on data from combined public and private efforts, should also be considered and developed. Sources of data for additional metrics of nutrient efficiency could include farmer and crop advisor surveys (i.e. NASS and FANMAP surveys), soil phosphorus test results, sales and use of farm implements and equipment needed for BMPs and higher precision nutrient management, and a geographically based statistical survey similar to a natural resources inventory.

Other future measures could address the following:

- Improvements in working with national and regional statistical surveys as well as with local partners to track voluntary, non-government funded BMP implementation
- CSP/CStP program measure
- Municipal wastewater nitrogen effluent trends
- Tile drainage water management practices
- Other program BMPs (e.g., constructed wetlands, cover crops)

7.1.2 Estimating Effects of BMPs on Nutrient Reduction

Estimates of expected nutrient reductions in waters from BMP adoption can be developed based on the level of BMP adoption change using various models and tools. However, evaluation of NRS progress should also consider the effects of non-BMP land use and management changes, as well as climate influences, so that both the estimated effects of the BMPs and other factors influencing water nutrient levels can be understood.

One of the models that can be used to evaluate the effects of changing precipitation and land use is the Hydrologic Simulation Program FORTRAN (HSPF) model. In an effort to aid the completion of watershed restoration and protection strategies (WRAPS), the Minnesota Pollution Control Agency (MPCA) is in the process of constructing HSPF watershed models for many of the HUC8 major watersheds. The HSPF model is a comprehensive model for simulating watershed hydrology and water quality for both conventional pollutants such as nutrients and sediment and toxic organic pollutants. HSPF allows the integrated simulation of land and soil runoff processes with in-stream hydraulic and sediment-chemical interactions. In the Minnesota River Basin, HSPF models for ten major watersheds have been aggregated to represent the larger basin. The results of HUC8 watershed modeling will further inform NRS implementation in the future.

Figure 7-2 provides a summary of the current status of HSPF modeling in the state (current through August 2014). HSPF and other models such as Soil Water Assessment Tool and SPARROW combined with other modeling approaches, such as the University of Minnesota's NBMP spreadsheet, should be used to estimate the NRS's progress made by BMPs, along with confounding effects of changing crop rotations, hydrologic modifications, and precipitation.

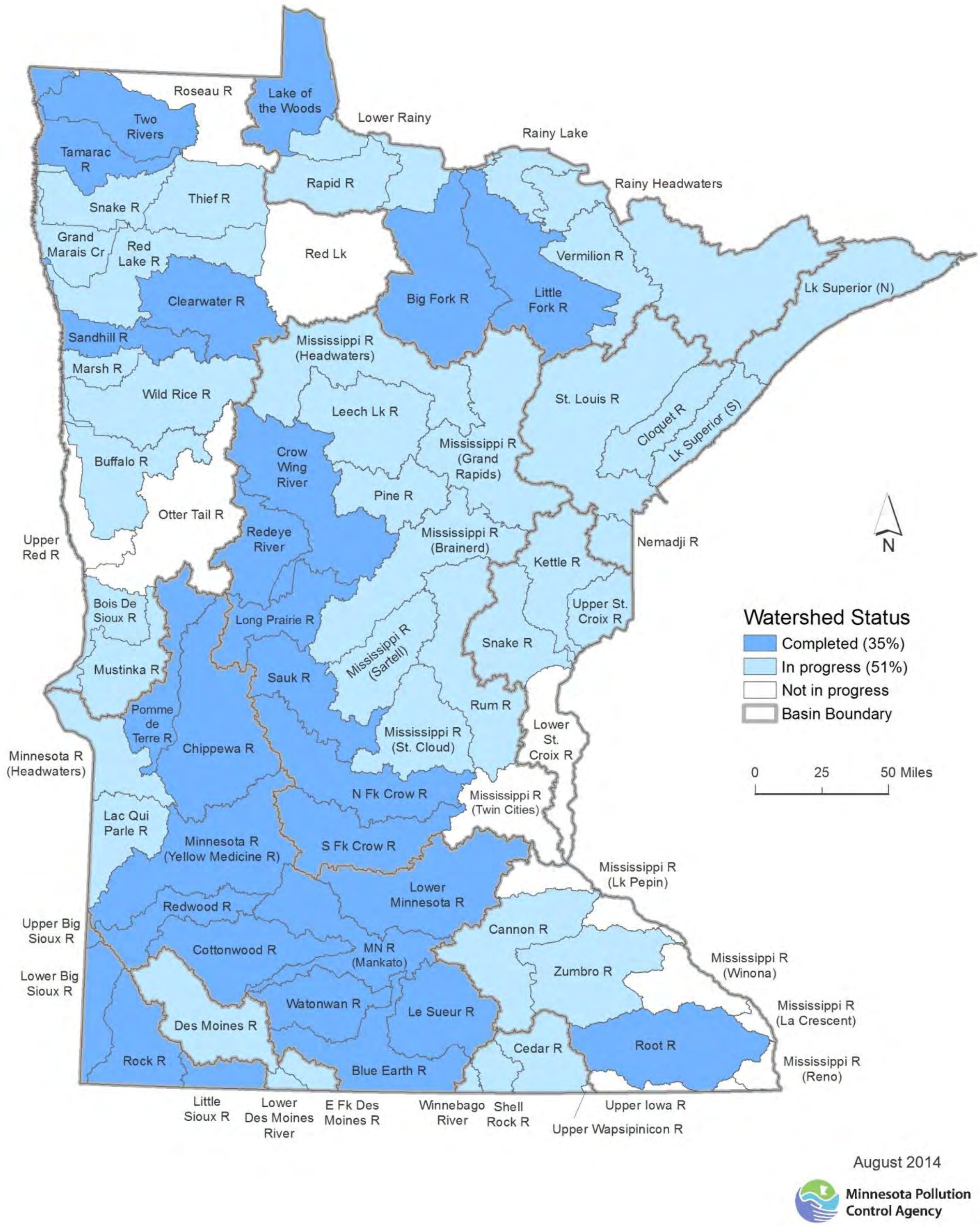

Figure 7-2. Status of HSPF modeling (August 2014).

7.1.3 Water Quality Monitoring Evaluation

Water quality evaluations will largely rely on the Watershed Pollutant Load Monitoring Network (WPLMN). This network will be supplemented with special watershed monitoring projects for environmental changes below the HUC8, monitoring of sentinel watersheds, ground water nitrate monitoring, National Water Quality Initiative projects, Targeted Watershed Demonstration Program Projects, BMP effectiveness as provided in research and Discovery Farm monitoring, along with other special projects and water quality modeling. There are many other local, regional, statewide, and national monitoring programs that will inform water quality evaluations including those being conducted by the new Mississippi River Monitoring Collaborative, which is made up of federal and state agencies along the Mississippi River between the Gulf of Mexico and Minnesota. Efforts will be made to coordinate Minnesota monitoring with national monitoring initiatives.

Due to lag effects in transport of nutrients through groundwater, lakes and reservoirs, the full effects of BMPs often do not show up at river monitoring stations for years or even as long as decades. Therefore, the monitoring results will be evaluated along with estimated lag times. Some monitored watersheds will show quicker response times to BMP implementation, such as heavily tiled watersheds and watersheds where phosphorus is less likely to by cycled and held in reservoirs or stagnant waters.

Water quality and flow analysis will include trends in total load and flow weighted mean concentrations (FWMC) (see Chapter 3). Both measures are important to understand changes in load over time and tracking progress toward milestones and goals. Progress toward achieving eutrophication standards in lakes and flowing waters also provides a measure for how well the

How soon will the effects of BMPs show up in the water?

It is difficult to predict when in-stream conditions will respond to implementation activities. As a general rule, larger watersheds are slower to respond because of the pollutant transport mechanisms involved. Watersheds exceeding 5,000 acres generally require monitoring programs of 10 years or more to measure the effects of management measures, although the exact timeframe depends on a range of factors, including the type of problem being addressed, the monitoring design employed, the weather during the monitoring period, and the type and extent of treatment implemented. HUC 8 major watersheds are much larger than 5,000 acres.

In rivers fed largely by groundwater, as opposed to surface runoff or tile drainage, there can be a lag time of decades or more before the effects of nitrate reduction BMPs can be observed in the river. Groundwater often moves very slowly toward streams, whereas tile drainage and surface runoff pathways to rivers are much faster.

For phosphorus, a key factor is the amount of reservoirs and pools of more stagnant water that exist. In these pools, phosphorus can settle and then be released over time back into the water.

NRS addresses in-state load reduction goals. Important measures of NRS progress include:

- Trend in actual load
- Trend in FWMC
- Extent of stream and lake eutrophication impairments
- Statistical comparisons of baseline loads and concentrations at low, medium and high flow periods with comparable flow periods during recent years
- Extent of groundwater nitrate above drinking water standards in high-nitrate areas, including those watersheds where nitrate coming from groundwater currently impairs surface waters

When multiple water quality monitoring measures are considered, along with the BMP adoption and modeling evaluations previously described, then progress toward NRS goals and milestones can be more accurately assessed.

Watershed Pollutant Load Monitoring Network

The WPLMN is a multi-agency effort that the MPCA leads to measure and compare regional differences and long-term trends in water quality among Minnesota's major rivers including the Red, Rainy, St. Croix, Minnesota, and Mississippi, the outlets of major HUC8 watershed tributaries draining to these rivers, and select subwatersheds. The network was established in 2007. Site-specific streamflow data from U.S. Geological Survey (USGS) and Minnesota Department of Natural Resources (DNR) flow gauging stations is combined with water quality data collected by Metropolitan Council Environmental Services, local monitoring organizations, and MPCA staff. Annual pollutant loads are computed from these data at river monitoring sites across Minnesota. The WPLMN is summarized at *http://www.pca.state.mn.us/pyrieeb*.

The WPLMN has been collecting water quality at an increasing number of locations since 2007, reaching 79 major watershed and mainstem river monitoring sites by 2010 (Figure 7-3). The design scale is focused toward, but not limited to, monitoring HUC8 watershed outlets within the state. By the end of 2014, about 150 additional subwatershed monitoring sites will be installed to further apportion pollutant loads. Strategic major river mainstem sites are included to determine basin loads and assist with statewide mass balance calculations.

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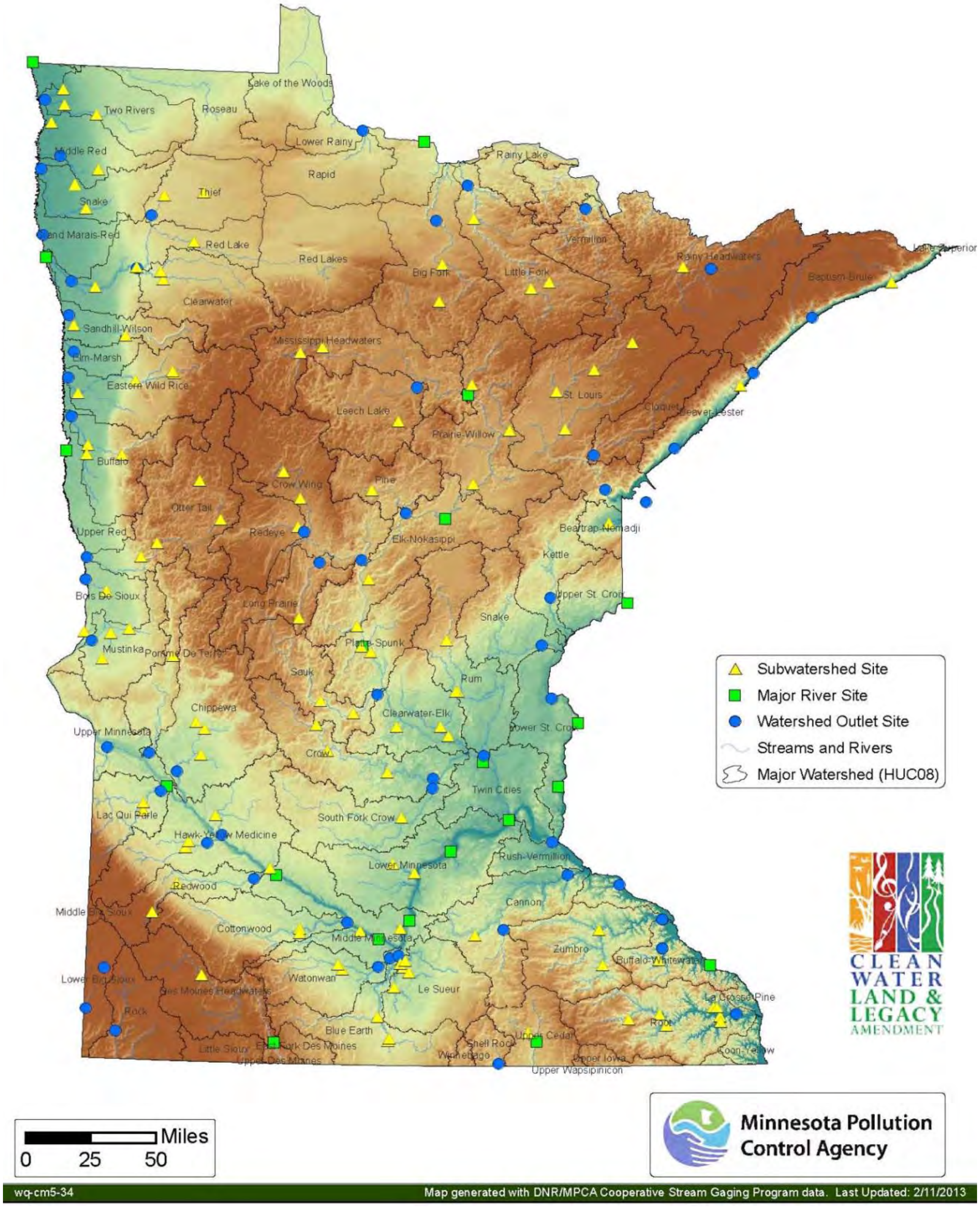


Figure 7-3. WPLMN monitoring sites.

Pollutant loads are calculated from water quality analysis and daily average discharge data collected at each site, using the Flux32 software. The software was designed to provide seasonal or annual pollutant loads and flow-weighted mean concentrations, but enhancements to the program allow the estimation of daily loads and concentrations. Loads and flow weighted mean concentrations are calculated annually for total suspended solids, phosphorus, dissolved orthophosphate, nitrate plus nitrite nitrogen and total Kjeldahl nitrogen. The nitrate plus nitrite nitrogen parameter is added to total Kjeldahl nitrogen to represent total nitrogen.

This network can be used to track changes in nutrient pollutant load, yields, and mean concentrations at a major river/basin, watershed, and subwatershed scales.

Sentinel Watersheds

The *Selection of Sentinel Watersheds* in Minnesota was developed by the University of Minnesota and a working group consisting of agency and stakeholder representatives in 2013 as part of a project funded by the MDA. Watersheds at the HUC10 and HUC8 scales were prioritized for long-term, intensive monitoring. Criteria in the selection process included:

- Available historical data
- Diversity of landscapes and watershed characteristics
- Entities with demonstrated local capacity present
- Existing programs could be used to coordinate new activities
- Representation of water quantity and quality issues at different scales

Nineteen HUC8 watersheds and eleven HUC10 watersheds were selected as sentinel watersheds. These watersheds may be used to be used to monitor changes in water quality as a result of conservation practices on the ground.

Ground Water Monitoring

Long-term ground water monitoring for nitrate conducted by state and local agencies should continue for public wells, private wells and monitoring wells, so that trends and progress to reduce nitrate levels can be evaluated. This monitoring should be coordinated with the NFMP and Source Water Protection Program efforts.

7.2 Tracking and Communicating Progress

Teamwork through the NRS Interagency Coordination Team (ICT) was integral to NRS development and teamwork will continue to be integral to overall NRS implementation. Accountability has been given a high priority through the legislatively mandated Clean Water Accountability Act of 2013. Accountability to the NRS should be integrated and coordinated with those existing coordinating mechanisms where possible with a subcommittee or adjunct team maintaining the perspective of the NRS. An Accountability Team could be formed, composed of a person or small group of implementation coordinators who would oversee the implementation of the NRS with input from critical program managers, represent NRS interests at a statewide level, lead tracking and reporting efforts, and oversee adaptive management adjustments to the NRS over time.

The Clean Water Accountability Act of 2013 will guide tracking efforts which may include annual or biennial reporting on the program measures developed as indicators of implementation progress, as well as planning and assessment activities triggered at 2 years, 5 years, and 10 years for reassessment, starting with the NRS implementation kickoff date and working toward the year 2025. Reporting and NRS updates will be led by an Accountability Team, who may report findings to the Clean Water Council or Minnesota Legislature. An outline of the tracking steps is outlined below.

First year of NRS (2015)

- Determine and initiate appropriate accountability process
- Identify Tracking Tool Team (see Section 7.2).
- Tracking Tool Team begins implementation of activities included in Section 7.2.

Two-year tracking and reporting (2016)

- Agencies and stakeholders develop approaches and plans to achieve BMP adoption goals
- Update NRS to incorporate additional implementation activities such as stepped up actions and tracking tool development.
- Evaluate program output and water quality outcomes.
- Evaluate implementation progress reported through the 2013 Clean Water Accountability Act to determine relevance to NRS progress reporting and tracking.
- Review progress toward goals and milestones.
- Update research for expanding feasible implementation activities (e.g., cover crops and biomass crops).
- Review effectiveness of comprehensive NRS outreach campaign and adjust as necessary.

Five-year tracking and reporting (2019)

- Assess implementation progress through other reporting (e.g., 2013 Clean Water Accountability Act).
- Report on success of implementation activities and strategies and identify needed adjustments to achieve goals and milestones.
- Survey key target audiences to gauge changes in management associated with comprehensive NRS outreach campaign.
- Evaluate program output and water quality outcomes.
- Continue to assess voluntary and industry-led implementation activities and associated nutrient reductions.

Ten-year NRS reassessment tracking and reporting (2024)

- Evaluate goals and milestones for future phases of implementation.
- Assess changes in natural conditions (e.g., climate and landscape) and potential impact on reductions.
- Establish new higher milestones that will make use of the researched BMPs.
- Continue making nutrient reduction progress as new research begins.
- Publish updated NRS document.

7.2.1 Approach for Tracking Progress

As described in the previous section, a wide range of data and information is needed to track progress in meeting the NRS goals and milestones. Synthesizing this array of data and information will require a coordinated system for tracking nutrient reductions associated with implementation activities. The previously described program and water quality measures highlight the challenges associated with compiling the data necessary to quantify implementation activities and nutrient loads. The data compiled for the suite of programmatic and water quality measures vary in collection methodology and frequency, documented in the metadata worksheets provided in Appendix F. Data from several nutrient reduction programs are tracked through grant or program-specific systems such as the BWSR's eLink database. Over time, an interagency, integrated tracking tool would provide a more systematic approach for compiling the data from the various programs to support regular assessments of the NRS's progress and reporting to key stakeholders within and outside of Minnesota.

A systematic approach for collecting and analyzing the output and outcome data and information would be helpful to track and communicate progress over time. The metadata worksheets in Appendix F provide an initial mechanism for capturing key output information about the suite of NRS measures.

Updating the metadata worksheets on a regular basis (e.g., annually) will help generate trend information on the particular BMPs associated with each measure to compare against the BMP adoption needs identified in Chapter 5. This will require a comparison of the BMPs identified on the NRS Reduction Summaries for each major basin presented in Chapter 5 with the BMPs associated with the quantified program measures at the HUC8, basin, and major basin scales. The comparison of these two components of the NRS will illustrate where BMPs have been implemented at the needed levels through existing government-based programs. The approach for tracking progress needs to also account for nongovernment-affiliated BMP implementation and the water quality monitoring findings.

7.2.2 Tools for Tracking Progress

There are a variety of ongoing information technology-related activities taking place within the MPCA and other key agencies. Under the Clean Water Accountability Act of 2013, MPCA must report progress toward implementation milestones and water quality goals for TMDLs and, where available, WRAPS beginning July 1, 2016, with updates on progress made every other year. The MPCA's Watershed Data Integration Project (WDIP) is an initiative to improve data sharing among MPCA programs at a watershed level to support the Minnesota Water Management Framework. WDIP is also working to develop a template for the TMDL and WRAPS Web-based implementation tables. MPCA also has a transformation project underway that is converting MPCA's existing databases to an enterprise system. These are examples within one agency that will provide information for the NRS. It is likely that similar data management projects and initiatives key to tracking the NRS's progress are also underway within other federal and state agencies. Ongoing and planned information technology-related efforts provide an opportunity to integrate the NRS's tracking needs into the design and development of new and upgraded systems. Similar considerations may be necessary for other Minnesota agencies with key nutrient reduction programs.

There is currently no integrated tool that will allow for automated tracking of NRS output and outcome information to assess progress over time. The approach for tracking progress requires developing a tool to ensure efficient and reliable progress tracking. Developing a tool of this nature will be a multi-agency undertaking that must take into consideration the existing data management approaches and numerous programs being uses within several agencies.

An evaluation of the website and tools used to track water quality implementation in the Chesapeake Bay (*ChesapeakeStat*) was conducted to determine if this existing tracking tool could provide a framework to incorporate an effective method for tracking nutrient reduction progress in Minnesota (Appendix G). ChesapeakeStat was viewed as a potential model for a new tool to communicate with stakeholders and watershed managers in Minnesota as well as other states and interested parties. Analysis performed during the evaluation revealed significant gaps between data required to support a Chesapeake-style website and the current abilities of state and federal agencies to provide that data. Future planned work will increase data availability, but significant work remains to be done for watershed modeling as well as program requirements.

A NRS tracking tool would improve process and information management efficiency among the many state and federal agencies, as well as local partners, that promote BMP adoption necessary for NRS success. The recommended approach for a NRS tracking tool is one that would serve as a hub of information, extracting data from a variety of existing monitoring and program implementation databases. Using a Web-based interface, the NRS tracking tool would not only present integrated information from existing databases, but also allow for the input of voluntary BMP information by private landowners and key local or nongovernmental organizations working with private landowners (e.g., county soil and water conservation districts, university extension staff, crop advisors).

A brief overview of the recommended tasks for developing this type of NRS tracking tool is provided below. Appendix H provides more detailed information on the preliminary requirements of developing this type of tracking system and each task.

Task 1: Identify Tracking Tool Team. A subgroup of existing Interagency Coordination Team (ICT) members, as well as program data analysts, will provide input on the preliminary system requirements and aid in refining those requirements.

Task 2: Review Existing Program Measures, Refine Metrics, Select Measures for Tracking Pilot. The NRS tracking tool team will identify program measures that require updating or refinement for tracking purposes and select 3—5 measures to use during the pilot phase of the tracking tool. The metadata worksheets presented in Appendix F should be evaluated to determine what is adequately measured and areas that are not adequately measured. This analysis could be used to develop a matrix that identifies which existing tracking efforts are adequate, what voids exist, and whether a new tracking tool needs to be developed, or if existing tracking tools can be modified.

Task 3: Analyze Existing Data Management Systems to Support Data Extraction and Integration. The NRS tracking tool team will collect detailed information on the functionality of each data management system that will contribute nutrient data to the System, including the type of system, planned or existing changes, users, maintenance procedures, and other factors that could influence export of data from the system into the NRS tracking tool.

Task 4: Identify Data Sources or Approaches for Obtaining Voluntary or Industry-Led BMP Information. The NRS tracking tool team would work with local partners (e.g., county SWCD staff, watershed districts, crop advisors, extension staff, and other entities) working with agricultural producers to improve adoption of conservation practices and BMPs, inventory voluntary BMPs not associated with governmental programs, and understand existing systems used to track this information.

Task 5: Conduct Comprehensive System Requirements Analysis. The NRS tracking tool team would verify the preliminary tracking tool requirements and, as necessary, add other requirements to inform tool development.

Task 6: Develop NRS Tracking and Accounting System Web Page. The final comprehensive system requirements analysis would then allow the NRS tracking tool team to proceed with initial development and piloting of the tool using the 3–5 selected program measures.

Task 7: Long-Term Operations and Maintenance System Plan. In support of the production deployment of the tool, the NRS tracking tool team should develop an Operation and Maintenance Plan, which will address staffing, tasks, processes, and tools necessary to ensure consistent, reliable, and comprehensive production support of the NRS tracking tool.

The timing of the NRS and the associated data tracking needs coincides with several other tracking and reporting efforts taking place within the state. This allows for the incorporation of the NRS's tracking needs into other ongoing system development and refinement projects. Examples of ongoing system development opportunities that could integrate NRS tracking needs include the following:

MPCA's Transformation Project. MPCA is currently changing their information systems to a tempo-based enterprise system. As a result, all program data will be managed in a similar manner, allowing program data within the agency to be better integrated.

MPCA's Watershed Data Integration Project (WDIPs). A multiyear data integration project intended to improve MPCA's staff handling and sharing of data and information generated through the watershed management process. (*http://www.pca.state.mn.us/index.php/view-document.html?gid=15386*) Through the WDIP, MPCA staff are working with total maximum daily load and WRAPS program staff to develop a data capture tool to meet a 2016 deadline of making implementation tables available on MPCA's website.

Portal. Minnesota agencies are also engaging in a Portal project that would allow better interagency data sharing. This project is currently in the discovery stage. It would offer the opportunity to integrate MPCA's data systems with those at other key agencies, including the BWSR, MDA, Minnesota Department of Health, DNR, and the Metropolitan Council.

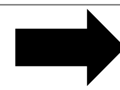
There is also a need for improved data collection and sharing among Minnesota agencies and key federal agencies working within the state, specifically Farm Service Agency and Natural Resource Conservation Service (NRCS). There is also a need for a tracking tool that would allow private landowners or other local government entities such as counties and SWCDs to provide information on voluntary conservation practices that are not related to state or federal programs and funding.

7.2.3 Communicating Progress

Communicating the ongoing level of progress can be challenging, especially given that progress is not evaluated by a single indicator, but rather by a suite of indicators including BMP adoption, modeling and monitoring. The tracking tool described in the previous section, once developed, could serve as a way of communicating ongoing progress to interested parties. Until a tracking and communication tool is developed, Program Output Scorecards could be used which are similar in concept to the report cards used in the Clean Water Fund Performance Report *http://www.legacy.leg.mn/sites/default/files/resources/2012%20Clean%20Water%20Fund%20Report%20Card_web%20version.pdf*.

The report card can provide both a qualitative and quantitative approach to reporting on progress toward nutrient reduction goals (Table 7-2). A program measure that is showing negative implementation trends (e.g., diminished voluntary participation or significant exceedances of a mass limit) can be represented by a red symbol on the NRS report card. A yellow symbol can represent programs that have no change in implementation over time. A green symbol can represent programs that demonstrate progress toward programmatic nutrient reduction goals over time. As NRS implementation actions are further derived, specific targets can be added to the measures, and the report card can be updated to reflect quantitative targets.

Table 7-2. Report card symbols

Status Scores		Trend	
	We are making good progress. If there is a target, we are meeting the target.		Improving trend
	We anticipate difficulty; it is too early to assess; or there is too much variability to assess.		No change
	Progress is slow. If there is a target, we are not meeting the target. It is likely that the activity or target is not commensurate with the scope of the problems.		Declining trend

The Program Output report card (Table 7-3) is based on seven program output measures developed for high-priority programs and provides a qualitative assessment of the nutrient reduction trends over time (see Appendix F). The scores for program output measures are based on data provided by state and federal agencies and best professional judgment of agency experts. At this time, the Program Output Report card focuses on trend data, but can eventually assess progress against a specific nutrient reduction target set for a specific measure in the context of overall NRS goals and milestones. This format is similar to the Clean Water Fund Performance Report measure report card, allowing for consistency in reporting to promote cross-effort reporting when feasible. Using the program measures, it will be possible to see trends and track progress during NRS implementation. At this time, specific targets are not provided for programmatic measures. In the future targets should be added to the measures to provide a yardstick for whether the measure is making adequate progress that will have the necessary effect on nutrient load reductions.

Table 7-3. NRS report card, program output measures

Measures	Status	BMP Adoption Trend	Description
Program Output Measures			
Implementation of priority EQIP management practices and estimated nutrient load reductions	Residue management		Acreage enrolled under EQIP for these three priority practices has steadily declined since 2007–2010.
	Nutrient management		
	Forage and biomass planting		
Implementation of permanent conservation easements under RIM and estimated nutrient load reductions			Acreage under permanent conservation easements has increased since 2000, with an upward trend since 2008.
Implementation of nonpoint source BMPs tracked via eLink and estimated nutrient load reductions			Although funding has increased and there is a continued increase in practices being implemented, the total requests for projects were approximately three times greater than available funds.
Implementation of priority CRP conservation practices	Filter strips		The general trend since 2002 has been decline, but there are signs of increasing acreage under these practices. Although there isn't a target, it appears that progress is slow.
	Riparian buffers		
Implementation of conservation tillage funded through AgBMP Loans			The annual acreage associated with conservation tillage projects reported by borrowers under MDA's AgBMP Loan Program declining from 2006–2012. Less annual marginal gains under the program.

Measures	Status	BMP Adoption Trend	Description
Program Output Measures			
Implementation of nitrogen fertilizer BMPs	Application rate on corn following corn (surveyed fields)		Data from the 2010 Survey of Nitrogen Fertilizer Use on Corn in Minnesota only includes data point for three of four BMPs, so no trend data are available. Survey results, however, show that application rate on corn following corn are within the acceptable rates, although rates on the more common rotation of corn following legumes can in many cases be reduced. Nitrogen fertilizer timing is occurring in spring or as a sidedress, and inhibitor use increasing over time. The use of additives and specialty fertilizers is less than 9% on surveyed fields.
	Application rate on corn following legumes		
	Application timing of nitrogen (surveyed fields)		
	Nitrogen inhibitor use		
	Use of additives and specialty fertilizers (surveyed fields)		
Changes over time in municipal wastewater phosphorus discharges			Long-term ramp-up in requirements coupled with new Clean Water Fund investments are helping wastewater sources continue to reduce phosphorus discharges.

The Program Output Report card indicates some progress in program implementation. A majority of the measures indicate an improving trend. However, several of the measures indicate that sufficient progress is not being made or achievement of targets or goals is uncertain. The only measure that does not require additional attention is related to programs for reducing phosphorus in municipal wastewater on an overall, statewide basis, although there is still progress that can be made. The current report card demonstrates that all measures require attention during implementation. Overall, the current report card provides a starting point for implementation and can be used to track progress across multiple program measures over time.

The program progress included in the above tables does not provide the complete picture of progress, and additional tables, documents, and communication tools will need to be provided. It is also important to show progress status with non-governmental program BMP implementation and with water quality monitoring results.

7.3 Adjust Nutrient Reduction Strategy

The ultimate step of the adaptive management process is adjusting the NRS implementation activities based on the data collection and trend evaluation process to ensure progress toward the NRS goals and milestones. Adjustments to the NRS could include recommendations for adjusting implementation guided by the trends seen in the suite of programmatic measures. A formal update of the NRS will be completed in 2016. A second update would be expected prior to 2025 to incorporate updated milestones and recent progress.

In addition, adjustments to the NRS could include recommendations guided by research, additional planning details, BMP adoption progress, programmatic measures, in addition to new water quality modeling/monitoring information. It will be necessary to document the rationale for any adjustments to the NRS on the basis of progress evaluation, coordination with program management and water quality data compiled to support the NRS. Where adjustments are necessary, updated versions of the NRS will document the changes.

Chapter 8

References and Literature

Barr Engineering. 2004. *Detailed Assessment of Phosphorus Sources to Minnesota Watersheds.* Prepared for Minnesota Pollution Control Agency, by Barr Engineering Company, Minneapolis, MN. Accessed February 2013. http://www.pca.state.mn.us/index.php/water/water-monitoring-and-reporting/water-quality-and-pollutants/phosphorus/detailed-assessments-of-phosphorus-sources-to-minnesota-watersheds.html.

Barr Engineering. 2007. Detailed Assessment of Phosphorus Sources to Minnesota Watersheds – Atmospheric Deposition: 2007 Update. Technical Memorandum prepared for Minnesota Pollution Control Agency, by Barr Engineering Company, Minneapolis, MN. Accessed February 2014. http://www.pca.state.mn.us/index.php/view-document.html?gid=3958.

Bierman, P., C. Rosen, R. Venterea, and J. Lamb. 2011. Survey of Nitrogen Fertilizer Use on Corn in Minnesota. 27 pp.

Birr, A.S. and D.J. Mulla. 2001. Evaluation of the Phosphorus Index in Watersheds at the Regional Scale. *Journal of Environmental Quality* 30(6): 2018-2025.

Crites, R. and G. Tchobanoglous. 1998. Small and Decentralized Wastewater Management Systems. International Edition. McGraw-Hill, Boston.

Engstrom, D., J. Almendinger, and J. Wolin. 2009. Historical Changes in Sediment and Phosphorus Loading to the Upper Mississippi River: Mass-Balance Reconstructions from the Sediments of Lake Pepin. *Journal of Paleolimnology* 41 (4): 563-588.

EPA (United States Environmental Protection Agency). 2002. Onsite Wastewater Treatment Systems Manual. EPA/625/R-00/008. Prepared by the US EPA Office of Water, Office of Research and Development.

EPA (U.S. Environmental Protection Agency). 2009. *Nutrient Control Design Manual: State of Technology Review Report.* Office of Research and Development, National Risk Management Research Laboratory, Water Supply and Water Resources Division, January, 2009.

EPA (U.S. Environmental Protection Agency). 2010. *Nutrient Control Design Manual.* Office of Research and Development, National Risk Management Research Laboratory, Water Supply and Water Resources Division, August, 2010.

Gervino, N. 2013. Conservation Effects Assessment Project Minnesota Phosphorus Loading. Minnesota Pollution Control Agency.

Huang, W. 2002. Using Insurance to Enhance Nitrogen Fertilizer Application Timing to Reduce Nitrogen Losses. *Journal of Agricultural and Applied Economics* 34 (1): 131-148.

Iowa Department of Agriculture and Land Stewardship, Iowa Department of Natural Resources, and the Iowa State University College of Agriculture and Life Sciences. 2013. Iowa Nutrient Reduction Strategy.

Iowa State University. 2013. Iowa Science Assessment of Nonpoint Source Practices to Reduce Nitrogen and Phosphorus Transport in the Mississippi River Basin. Section 2 in *Iowa Nutrient Reduction Strategy*. Iowa Department of Agriculture and Land Stewardship, Iowa Department of Natural Resources, and Iowa State University College of Agriculture and Life Sciences, Ames, IA.

Jennings, G. D., D. Hoag, M. L. McFarland, and D. L. Osmond. 2012. Lessons Learned from the NIFA-CEAP: Effective Education to Promote Conservation Practice Adoption. NC State University, Raleigh, NC.

Lahti, Ll, B. Hansen, J. Nieber, and J. Magner. 2013. Lake Superior Streams Sediment Assessment: Phase I. Prepared for the Minnesota Pollution Control Agency, by the Department of Bioproducts and Biosystems Engineering, University of Minnesota, St. Paul, MN. http://www.pca.state.mn.us/index.php/view-document.html?gid=20382

Lazarus, W., G. Kramer, D. Mulla, and D. Wall. 2013. Watershed Nitrogen Reduction Planning Tool (NBMP.xlsm) for Comparing the Economics of Practices to Reduce Watershed Nitrogen Loads. University of Minnesota, St. Paul, MN. 54 pp. http://www.mda.state.mn.us/protecting/cleanwaterfund/gwdwprotection/~/media/Files/protecting/cwf/2009nitrocorn.ashx.

Lazarus, W., D. Mulla, and D. Wall. 2014. A Spreadsheet Planning Tool for Assisting a State Agency with Cost-effective Watershed Scale Surface Water Nitrogen Planning. Journal of Soil and Water Conservation, 69(2): 45A-50A.

Lehman, John T., Douglas W. Bell, and Kahli E. McDonald. 2009. "Reduced River Phosphorus Following Implementation of a Lawn Fertilizer Ordinance." *Lake and Reservoir Management* 25 (3): 307–12.

Lowe, Kathryn. 2009. Influent Constituent Characteristics of the Modern Waste Stream from Single Sources. Prepared by the Colorado School of Mines for the Water Environment Research Foundation.

Maryland Department of Agriculture, USDA-Maryland Natural Resources Conservation Service, Kent Soil and Water Conservation District, Queen Anne's Soil Conservation District, and Maryland Department of Natural Resources Forestry Service. 2011. *Upper Chester River Showcase Watershed Project Farm Assessment Report*. http://www.upperchester.com/UC_Assessment.pdf.

MDA (Minnesota Department of Agriculture). 2008. Sesquicentennial Agricultural History Timeline. Minnesota Department of Agriculture, St. Paul, MN.

MDA (Minnesota Department of Agriculture). 2011. 2009 Survey of Nitrogen Fertilizer Use on Corn in Minnesota, A Companion Report to the Full Report Prepared by the University of Minnesota Extension. Minnesota Department of Agriculture, St. Paul, MN. 25 pp.

MDA (Minnesota Department of Agriculture). 2012. Ethanol Program. Minnesota Department of Agriculture, St. Paul, MN. http://www.mda.state.mn.us/Ethanol.

MDA (Minnesota Department of Agriculture). 2013. *Nitrogen Fertilizer Management Plan* (DRAFT). Minnesota Department of Agriculture, St. Paul, MN.

MDA (Minnesota Department of Agriculture). 2014. Fertilizer and Manure Selection and Management Practices Associated with Minnesota's 2010 Corn and Wheat Production. Minnesota Department of Agriculture, St. Paul, MN.

Miller, T.P., J.R. Peterson, C.F. Lenhart, and Y. Nomura. 2012. *The Agricultural BMP Handbook for Minnesota*. Prepared for the Minnesota Department of Agriculture. www.eorinc.com/documents/AG-BMPHandbookforMN_09_2012.pdf.

Minnesota Climatology Working Group. 2013. Minnesota State-Averaged Annual Precipitation. State Climatology Office, Department of Natural Resources, Division of Ecological and Water Resources, University of Minnesota. Accessed February 2013. http://climate.umn.edu/pdf/minnesota_state_averaged_precipitation.pdf

Minnesota State Demographic Center. 2013. Census 2010. Accessed February 2013. http://www.demography.state.mn.us/.

Mississippi River/Gulf of Mexico Watershed Nutrient Task Force. 2008. *Gulf Hypoxia Action Plan 2008 for Reducing, Mitigating, and Controlling Hypoxia in the Northern Gulf of Mexico and Improving Water Quality in the Mississippi River Basin*. Accessed October 2012. http://water.epa.gov/type/watersheds/named/msbasin/actionplan.cfm.

Moncrief, J., P. Bloom, N. Hansen, D. Mulla, P. Bierman, A. Birr, and M. Mozaffari. 2006. *Minnesota Phosphorus Site Risk Index, Technical Guide*. Department of Soil, Water and Climate, University of Minnesota, St. Paul, MN.

MPCA (Minnesota Pollution Control Agency). 1989. Ground Water Contamination Susceptibility in Minnesota. (Posted announcement). Minnesota Pollution Control Agency, St. Paul, MN.

MPCA (Minnesota Pollution Control Agency). 2000. Phosphorus Strategy. Minnesota Pollution Control Agency, St. Paul, MN. http://www.pca.state.mn.us/index.php/water/water-monitoring-and-reporting/water-quality-and-pollutants/phosphorus/mpca-phosphorus-strategy.html.

MPCA (Minnesota Pollution Control Agency). 2004. *Lower Minnesota River Dissolved Oxygen Total Maximum Daily Load Report*. Minnesota Pollution Control Agency, St. Paul, MN. http://www.pca.state.mn.us/index.php/view-document.html?gid=7994.

MPCA (Minnesota Pollution Control Agency). 2013a. *Nitrogen in Minnesota Surface Waters, Conditions, Trends, Sources, and Reductions*. Minnesota Pollution Control Agency, St. Paul, MN. http://www.pca.state.mn.us/index.php/view-document.html?gid=19622.

MPCA (Minnesota Pollution Control Agency). 2013b. *The Condition of Minnesota's Groundwater, 2007–2011*. Minnesota Pollution Control Agency, St. Paul, MN. http://www.pca.state.mn.us/index.php/view-document.html?gid=19743.

NASS (National Agricultural Statistics Service). 2013. Cropland Data Layer. U.S. Department of Agriculture. http://nassgeodata.gmu.edu/CropScape/.

Robertson, D.M. and D. A. Saad. 2011. Nutrient Inputs to the Laurentian Great Lakes by Source and Watershed Estimated Using SPARROW Watershed Models. *Journal of the American Water Resources Association* 47:1011–1033.

Sands, G. 2010. Drainage Fact Sheet. University of Minnesota Extension Service.

Schueler, Tom, and C. Lane. 2013. *Recommendations of the Expert Panel to Define Removal Rates for Urban Nutrient Management*. Prepared by the Chesapeake Stormwater Network.

Simpson, T. and S. Weammert. 2009. *Developing Best Management Practice Definitions and Effectiveness Estimates for Nitrogen, Phosphorus and Sediment in the Chesapeake Bay Watershed: Final Report*. Chesapeake Bay Program, Annapolis, MD.

Singer, J., S. Nusser, and C. Alf. 2007. Are Cover Crops Being Used in the US Corn Belt? *Journal of Soil and Water Conservation* 62(5):353–358.

Tetra Tech. 2009. Upland Practice Identification for Agriculture, Lake Pepin Implementation Support. Memorandum prepared for Minnesota Pollution Control Agency and U.S. Environmental Protection Agency, Region 5, by Tetra Tech, Inc., Research Triangle Park, NC.

Thorson, R. 2011. Cost Estimates for Municipal Facilities using Chemical Phosphorus Removal to Meet a 1 mg/L Effluent Limit. Office Memorandum to Steve Heiskary, Minnesota Pollution Control Agency, St. Paul, MN. August 4, 2011.

University of Minnesota. 2011. Minnesota Water Sustainability Framework. Prepared by the University of Minnesota Water Resource Center, for the Minnesota State Legislature, St. Paul, MN.

U.S. Census Bureau. 2013. American Fact Finder. Accessed February 2013. http://factfinder2.census.gov/faces/nav/jsf/pages/index.xhtml.

USDA (United States Department of Agriculture). 2011. *State Agriculture Overview: Minnesota*. National Agricultural Statistics Service.

USDA (United States Department of Agriculture). 2012a. Assessment of the Effects of Conservation Practices on Cultivated Cropland in the Upper Mississippi River Basin. U.S. Department of Agriculture Natural Resources Conservation Service. Accessed February 2014. http://www.nrcs.usda.gov/Internet/FSE_DOCUMENTS/stelprdb1042093.pdf.

USDA (United States Department of Agriculture). 2012b. 2007 Census Volume 1, Chapter 1: State Level Data. Census of Agriculture. U.S. Department of Agriculture. Accessed February 2013. http://www.agcensus.usda.gov/Publications/2007/Full_Report/Volume_1,_Chapter_1_State_Level/Minnesota.

Vlach, Brian, John Barten, James Johnson, and Monica Zachay. 2010. "Case Study #9: Assessment of Source Reduction due to Phosphorus-Free Fertilizers." In *Optimizing Stormwater Treatment*

Practices: A Handbook of Assessment and Maintenance, edited by John S. Gulliver, Andrew J. Erickson, and Peter T. Weiss. University of Minnesota, St. Anthony Falls Laboratory. Minneapolis, MN.

Wright, C.K., and M.C. Wimberly. 2013. Recent Land Use Change in Western Corn Belt Threatens Grassland and Wetlands. In *Proceedings of the National Academy of Sciences*, Geographic Information Science Center of Excellence, South Dakota State University.

Appendix A: Statewide Buffer Analysis

Existing data on the presence of perennial vegetation in riparian areas are available from the Minnesota Center for Environmental Advocacy (MNCenter) and the Cannon River Watershed Partnership (CRWP) (Figure A-1). These data were used to calibrate an analysis of riparian vegetation using the 2012 Cropland Data Layer (CDL). The MnCenter and CRWP data were not able to be used directly because not all streams were evaluated and the buffer evaluated ranged from 50 – 300 feet.

Five geospatial (GIS) data sets served as the foundation of the statewide riparian buffer analysis:

1. The 8-digit Hydrologic Unit Code (HUC8) watershed boundaries provided as part of Minnesota Department of Natural Resources (MNDNR) "Level 08 (All Catchments)"
2. MNDNR 24K resolution stream GIS polylines
3. MNDNR Public Waters Inventory (PWI) Watercourse Delineations
4. Land Cover - Minnesota Land Cover Classification System (MLCCS)
5. The 2012 CDL 30-meter gridded coverage as provided by the USDA's National Agricultural Statistics Service (NASS)

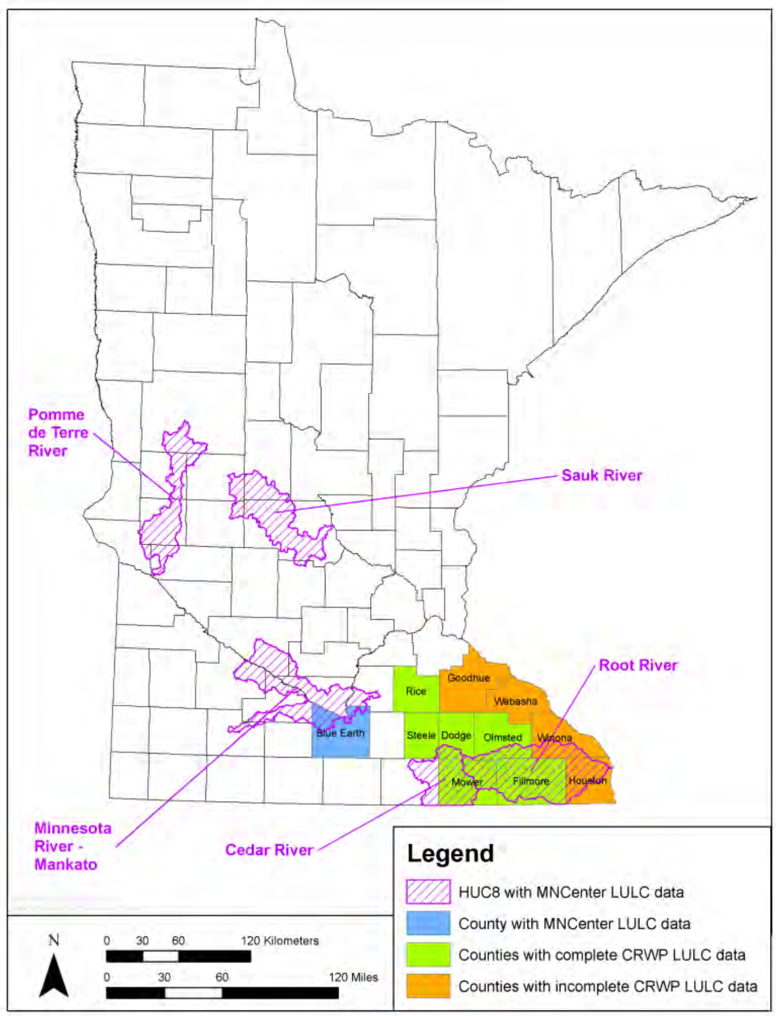


Figure A-1. Available high resolution data on riparian buffer vegetation

An initial analysis was conducted to compare riparian buffer land use and land cover (LULC) mapping outputs using high-resolution aerial imagery (MnCenter and CRWP data) to a GIS-based approach employing a lower-resolution, state-wide LULC dataset (2012 CDL).

The MnCenter data applied to a 50-foot riparian buffer of MNDNR's PWI stream polyline dataset with the exception of the Root River HUC8 which included data a 300-foot riparian buffer of the PWI dataset. The CRWP mapping outputs were all done for a 300-foot riparian buffer of the PWI dataset. Note that neither of the datasets applied to the DNR 24K streams, which is the basis of the Strategy buffer recommendations.

The area of perennial vegetation within the MnCenter and CRWP 50- and 300-foot buffers was extracted from the 2012 CDL. The following vegetation types were assumed to be perennial:

- Other Hay/Non Alfalfa
- Clovers/Wildflowers
- Sod/Grass Seed
- Switchgrass
- Fallow/Idle Cropland
- Deciduous Forest
- Evergreen Forest
- Mixed Forest
- Shrubland
- Grassland/Herbaceous
- Woody Wetlands
- Herbaceous Wetlands

A comparison of the MnCenter and CRWP data versus the CDL derived data are presented in Table A-1. An adjustment factor is provided based on this comparison for CDL data. A 30-meter riparian buffer from the MNDNR 24k resolution stream polyline dataset was then created, as described in Chapter 5 and the area of perennial vegetation in the buffer was tabulated by HUC8.

The first of the Average Adjustment Factors from Table A-1 (1.326) was used to modify (i.e., increase) the percent of the buffer in perennial vegetation which was derived from the 2012 CDL for the 30-meter buffer. This adjustment applied to all HUC8s with the exception of those HUC8s identified in Figure A-2 for which the second average adjustment factor (0.932) was applied. The Existing Adoption Rate, presented in Figure A-3, is based on the adjusted percent of the buffer that is in existing perennial vegetation. The assumptions applied in this analysis are rudimentary; however the analysis represents the best available data at the time of this analysis.

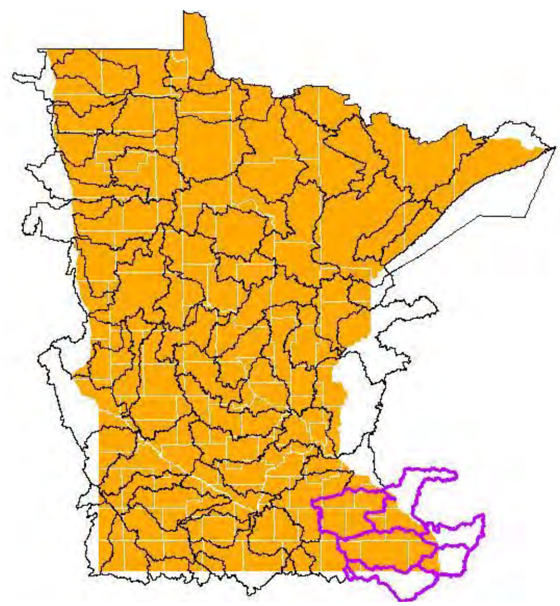


Figure A-2. An adjustment factor of 0.932 was applied to the HUC8s in purple

Table A-1. Buffer comparison results. Percentages represent percent of all land in the buffered area (agricultural and other lands).

Mapped Area (HUC8 or County)	High Resolution Data Source	Date of Imagery Used	Percent of Riparian Buffer Considered Perennially Vegetated		CDL 2012	Adjustment Factor	Average Adj. Factor
			Buffer Analysis Width (ft)	MNCenter/ CRWP Results			
Sauk River	MNCenter	2010	50	84.07	62.73	1.34	1.326
Pomme de Terre River	MNCenter	2010	50	87.97	65.74	1.34	
Minnesota River - Mankato	MNCenter	2010	50	83.00	47.54	1.75	
Root River	MNCenter	2009	300	76.14	75.00	1.02	
Cedar River	MNCenter	2009	50	77.30	72.59	1.06	
Blue Earth County	MNCenter	2009	50	88.30	60.74	1.45	
Mower County	CRWP	2009	50	82.20	79.19	1.04	0.932
Rice County	CRWP	2009	50	59.60	65.32	0.91	
Steele County	CRWP	2009	50	74.76	78.43	0.95	
Dodge County	CRWP	2009	50	80.81	78.34	1.03	
Olmsted County	CRWP	2009	50	77.51	82.84	0.94	
Fillmore County	CRWP	2009	50	59.28	82.41	0.72	
Goodhue County	***CRWP***	***2009***	***50***	***88.12***	***72.78***	***1.21***	***Not Used***
Wabasha County	***CRWP***	***2009***	***50***	***66.70***	***65.61***	***1.02***	
Houston County	***CRWP***	***2009***	***50***	***61.58***	***75.81***	***0.81***	
Winona County	***CRWP***	***2009***	***50***	***81.84***	***79.83***	***1.03***	

***** = missing buffered areas along River/State Boundary***

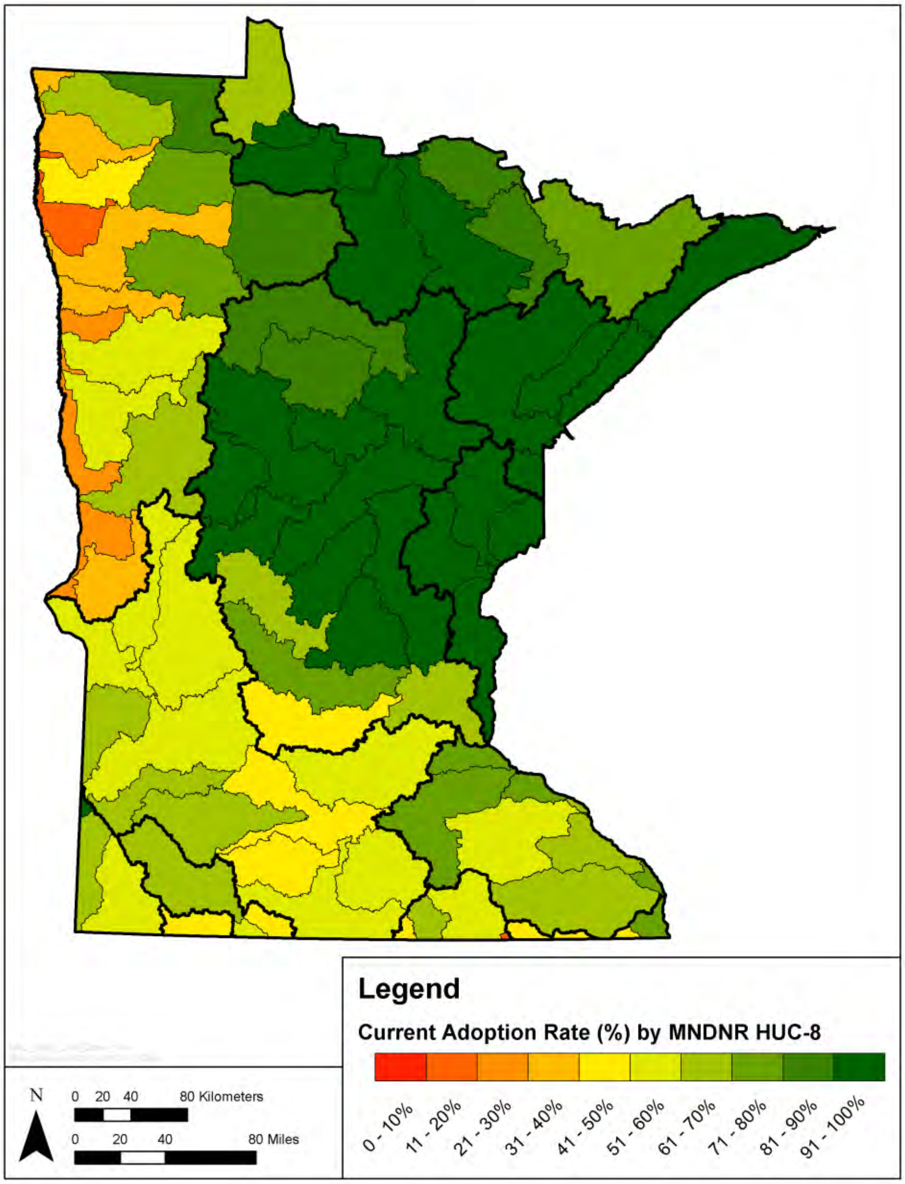


Figure A-3. Existing buffer adoption rate.

Appendix B: Progress Assessed through Program Quantification

Program quantification is intended to provide an assessment of the recent progress that has been achieved, in terms of nitrogen and phosphorus load reduction, through documented implementation of best management practices (BMPs) and wastewater treatment adopted in direct response to government programs. Many of the nutrient reducing programs (see Chapter 4) contain numerous structural and non-structural BMPs implemented as part of these programs. Not all programs had data that were able to be translated into spatially quantified nutrient load reductions. Program quantification therefore only addresses those programs with applicable data on a HUC8 scale.

Program quantification included the following indicator BMP categories:

- Nutrient management (NRCS EQIP)
- Forage and biomass planting (NRCS EQIP)
- Residue management (NRCS EQIP)
- Conservation easements (BWSR Reinvest in Minnesota [RIM])
- Nonpoint source BMPs (as reported in BWSR's eLINK, not including feedlot BMPs)
- Septic system improvements (MPCA Subsurface Sewage Treatment System Program)
- Feedlot projects (MPCA Feedlot Program)
- Phosphorus lawn fertilizer ban

Data for nutrient management, forage and biomass planting, and residue management were obtained from the EQIP program, while data for conservation easements were obtained from the BWSR RIM program. Data for nonpoint source BMPs were provided through the eLINK system, maintained by BWSR. The eLINK system only tracks and reports phosphorus load reductions associated with BMPs. Total acres (by HUC8) were tabulated for each BMP category with the exception of the nonpoint source BMPs from eLINK, for which total load reduction data (lbs/year) were provided for each HUC8, for phosphorus only. Feedlot phosphorus load reductions are tracked separately in eLINK, and are reported separate from other nonpoint source BMPs in this section based on data from Open Lot Agreements tracked by the MPCA's Feedlot Program. Phosphorus reductions from septic system improvements were based on the estimated number of septic systems that had been identified as an imminent threat to public health or safety (ITPHS) and had been brought into compliance. Reductions in phosphorus loading as a result of the statewide phosphorus fertilizer ban were compiled from various sources (Vlach et al. 2010, Lehman et al. 2009, and Schueler and Lane 2013); a 10 percent in phosphorus loading from urban areas was assumed.

Recent trends in point source loads (wastewater) were quantified based on SPARROW results. A more recent version of the SPARROW model is available which provides updated (2005–2006 for nitrogen and 2005–2009 for phosphorus) point source data. These updated results were compared to the original SPARROW results to calculate the relative percent change in phosphorus and nitrogen loading from point sources that has recently occurred.

Assumptions

A key assumption used in program quantification is that the SPARROW results approximate conditions prior to recent program efforts to increase BMP adoption. This assumption enables us to determine the loads reduced by existing BMPs by using SPARROW generated watershed loads combined with BMP load reduction efficiencies.

Cropland BMPs were applied to only the agricultural loads in SPARROW. SPARROW agricultural loads are the summed loads for manure, other agricultural sources, and atmospheric deposition (scaled by the proportion of the HUC8 that is agricultural).For phosphorus, it is important to note that approximately 15 percent of the load in the Mississippi River Basin is derived from streambank erosion (Barr Engineering 2004). SPARROW, however, does not separately account for streambank erosion as a source and the agricultural load portion of SPARROW accounts for both upland sources and sources associated with streambank erosion in agricultural areas. Accordingly, the phosphorus source allocation fraction estimated in the *Detailed Assessment of Phosphorus Sources to Minnesota Watersheds* (Barr Engineering 2004) was applied to the HUC8 phosphorus loads from SPARROW to identify the load derived from upland agricultural sources.

Source load reductions may not yet be fully realized at the instream stations near the Minnesota state line, particularly for phosphorus, due to lags in transport through the stream network, but are expected to be achieved over time.

BMP removal efficiencies were assigned to each indicator cropland BMP based on recent literature review efforts by the MPCA, MDA, and Iowa State University (Table B-1). Removal efficiencies were selected from these efforts with a focus on studies in the Midwest, with Minnesota-based studies receiving the highest priority. Chapter 5 includes additional discussion on available literature sources.

Table B-1. BMP removal efficiencies (see Chapter 5 for further discussion)

Indicator BMP Category	Nitrogen Removal (%)	Phosphorus Removal (%)	Sources
Residue Management	0	63	Miller et al. 2012; Iowa State University 2013; Simpson and Weammert 2009
Nutrient Management	16	24	MPCA 2013a ; Iowa State University 2013
Forage and Biomass Planting	95	59	Iowa State University 2013; MPCA 2013a
Conservation Easements	83	56	Iowa State University 2013; MPCA 2004; MPCA 2013a

Reductions for miscellaneous sources apply to phosphorus only and include septic system improvements, feedlots, and the phosphorus lawn fertilizer ban. Reductions in phosphorus from septic systems was estimated using MPCA program data based on the number of ITPHSs that had been brought into compliance. The average total phosphorus production per capita (2.3 lbs phosphorus produced per capita per year) was estimated from a septic system's average flow (60 gallons per capita per day; Lowe 2009), the average phosphorus concentration of septic tank effluent (12.5 mg/l phosphorus; EPA 2002; Crites and Tchobanoglous 1998), and the average number of people per dwelling (2.46 people per dwelling; 2010 U.S. Census). The percentage of phosphorus that reaches surface waters from ITPHS and conforming systems (Table B-2; Barr Engineering 2004) was then used to estimate the reduction of phosphorus loading to surface waters as a result of the upgrades. Permanent and seasonal residences were both taken into account, and it was assumed that 16 percent of all dwellings in the state are seasonal. Between 2002 and 2013, an estimated 27,710 ITPHSs were brought into compliance. The SPARROW attenuation factors were applied to the load reduction estimates.

Table B-2. Percent of phosphorus from septic systems that reaches surface waters (from Barr Engineering 2004)

Description	Percent of phosphorus that reaches surface waters from septic systems (%)
Permanent residence, conforming system	10
Permanent residence, failing system	30
Permanent residence, imminent threat to public health system	43
Seasonal residence, conforming system	20
Seasonal residence, failing system	43
Seasonal residence, imminent threat to public health system	43

The Open Lot Agreement is a provision in the Feedlot Rule (7020) in which eligible livestock producers can receive an extended time for making improvements to open feedlots for water quality issues. Between 2000 and 2010, there was an average of 141 additional feedlot fixes per year from open lot agreements and other efforts to reduce feedlot runoff. Another 108 feedlot closings per year occurred, on average. A typical MinnFARM model annual load reduction of 25 pounds of phosphorus reduced per project was used to determine total phosphorous load reductions by major basin. Basin or smaller scale data were not available. This estimate does not include manure application to cropland related reductions stemming from rule revisions made in 2000 or voluntary changes for livestock feed which reduced phosphorus in manure.

A 10 percent reduction in phosphorus loading from urban areas was assumed to have occurred as a result of the statewide phosphorus fertilizer ban. The Chesapeake Stormwater Network estimated that statewide phosphorus fertilizer bans in the Chesapeake Bay watershed have led to a load reduction from the overall urban stormwater sector of approximately 10 percent (Schueler and Lane 2013). The authors found that their results were consistent with research in Minnesota (Vlach et al. 2010) and Michigan (Lehman et al. 2009 [1]). A 10 percent phosphorus load reduction was applied to the average loads from urban runoff in the *Detailed Assessment of Phosphorus Sources to Minnesota Watersheds* (Barr Engineering 2004) to estimate the total load reductions that resulted from the phosphorus fertilizer ban.

The following key assumptions were also considered in the program quantification analysis:

- Existing BMPs are applied to mutually exclusive land areas. For example, nutrient management and residue management are not implemented on the same farms. In reality it is likely that these practices are implemented concurrently on the same fields.
- BMP efficiency is presumed to be the same for tiled versus non-tiled lands.

Cropland and Miscellaneous Source Results

Table B-3 and Table B-4 present a summary of non-wastewater program quantification results for nitrogen and phosphorus, respectively. The loads presented in these tables represent the loads generated within Minnesota by major basin or basin, delivered to the state line. The current conditions load presented in the tables (second column in each table) reflect the recent point source update to SPARROW.

[1] This study found higher percent reductions in a subset of the data. Their reported percent reductions (28%) represent an upper estimate of May through September monthly phosphorus concentration reductions in their study area.

The results of the program quantification analysis suggest that recent implementation of cropland BMPs has not achieved a significant nitrogen load reduction relative to conditions in 2000, as represented by SPARROW. For nitrogen, about a 1 percent reduction of nitrogen load statewide was estimated. For phosphorus, it appears that modest load reductions have recently been achieved (almost 8 percent reduction of the statewide phosphorus load).

Table B-3. Summary of recent progress for cropland nitrogen loads (total to state line)

Basin	Current Conditions N with Point Source Update (metric tons/ yr) [a]	N Reduced by Nutrient Mgmt. (metric tons/yr)	N Reduced by Forage and Biomass Planting (metric tons/yr)	N Reduced by Residue Mgmt. (metric tons/yr)	N Reduced by Conservation Easements (metric tons/yr)	Net N Reduction (metric tons/yr)	% of N Reduced by BMPs
Cedar River	6,918	16	1	0	53	70	1.0%
Des Moines River	4,507	36	1	0	36	73	1.6%
Lake Superior	3,656	0	0	0	0	0	0.0%
Mississippi River [b]	99,441	476	47	0	837	1,361	1.4%
Missouri River	5,208	34	3	0	16	52	1.0%
Rainy River	2,606	1	3	0	0	4	0.1%
Red River	16,822	90	30	0	40	159	0.9%
Total	**139,159**	**654**	**85**	**0**	**981**	**1,719**	**1.2%**

a. Loads calculated from SPARROW.

b. Loads for the Mississippi River basin are tabulated at De Soto, WI downstream of the MN/IA state line, using SPARROW.

Table B-4. Summary of recent progress for cropland and miscellaneous source phosphorus loads (total to state line)

<table>
<tr><th>Basin</th><th>Current Conditions P with Point Source Update (metric tons/yr) [a]</th><th>P Reduced by Nutrient Mgmt. (metric tons/yr)</th><th>P Reduced by Forage and Biomass Planting (metric tons/yr)</th><th>P Reduced by Residue Mgmt. (metric tons/yr)</th><th>P Reduced by Conservation Easements (metric tons/yr)</th><th>P Reduced by BMPs tracked in eLINK [c] (metric tons/yr)</th><th>P Reduced by Septic System BMPs (metric tons/yr)</th><th>P Reduced by Feedlot Projects (metric tons/yr)</th><th>P Reduced by Urban Fertilizer Ban (metric tons/yr)</th><th>Net P Reduction (metric tons/yr)</th><th>% of P Reduced by BMPs</th></tr>
<tr><td>Lake Superior</td><td>255</td><td>0</td><td>0</td><td>0</td><td>0</td><td>2</td><td>0.7</td><td>0.1</td><td>2.3</td><td>5</td><td>2%</td></tr>
<tr><td>Cedar River</td><td>242</td><td>0</td><td>0</td><td>1</td><td>1</td><td>3</td><td>0.6</td><td rowspan="5">30.5</td><td>0.4</td><td rowspan="5">556</td><td rowspan="5">9%</td></tr>
<tr><td>Des Moines River</td><td>251</td><td>1</td><td>0</td><td>1</td><td>1</td><td>7</td><td>0.6</td><td>0.2</td></tr>
<tr><td>Mississippi River [b]</td><td>5,553</td><td>18</td><td>1</td><td>28</td><td>13</td><td>395</td><td>13</td><td>23.4</td></tr>
<tr><td>Missouri River</td><td>290</td><td>1</td><td>0</td><td>1</td><td>0</td><td>11</td><td>0.7</td><td>0.2</td></tr>
<tr><td>Rainy River</td><td>204</td><td>0</td><td>1</td><td>1</td><td>0</td><td>4</td><td>0.2</td><td>0.2</td></tr>
<tr><td>Red River</td><td>949</td><td>4</td><td>0</td><td>6</td><td>1</td><td>28</td><td>1.3</td><td>0.7</td><td>1.1</td><td>49</td><td>4%</td></tr>
<tr><td>Total</td><td>7,742</td><td>24</td><td>2</td><td>39</td><td>15</td><td>450</td><td>17</td><td>31</td><td>28</td><td>610</td><td>8%</td></tr>
</table>

a. Loads calculated from SPARROW.

b. Loads for the Mississippi River basin are tabulated at De Soto, WI downstream of the MN/IA state line, using SPARROW.

c. eLINK loads do not include feedlot projects.

Wastewater Source Results

Table B-5 presents recent trends in wastewater point source loads. Point source data (as loads generated within Minnesota and transported to the state line) were summarized in two different SPARROW models representing progress between the early and late 2000s. These data do not reflect the most up-to-date monitoring information, but are adequate to quantify progress. The data contained in the SPARROW models were derived from point source discharge monitoring records. The difference in wastewater loads from 2002 and 2005–2006 for nitrogen and 2005–2009 for phosphorus were used to calculate the change in phosphorus and nitrogen loading from point sources that has recently occurred. In general, there have been treatment improvements (especially for phosphorus in the Minnesota River, part of the Mississippi Major Basin), but also offsetting increases in discharge volumes. Wastewater phosphorus reductions in the Mississippi River Major Basin account for a 24 percent reduction in monitored baseline loads.

Table B-5. Summary of recent trends in point sources

Major basin	Nitrogen		Phosphorus	
	Recent Change in Point Source (metric tons/yr)	Percent Change in Baseline Loads	Recent Change in Point Source (metric tons/yr)	Percent Change in Baseline Loads
Lake Superior	+411	+13%	+7	undetermined
Mississippi River	+1,492	+2%	-1,113	-24%
Lake Winnipeg	-55	0%	-4	-0.3%

Appendix C: Agricultural BMPs

In addition to the BMPs presented in Chapter 5, additional BMPs can be used to achieve nutrient reductions including the following (NRCS Technical Practice number precedes the BMP name):

Core Practices

AVOIDING

328 - Conservation Crop Rotation
340 - Cover Crop
528 - Prescribed Grazing
590 - Nutrient Management
633 - Waste Utilization

CONTROLLING

329 - Residue and Tillage Management - No Till/Strip Till
330 - Contour Farming
345 - Residue and Tillage Management - Mulch Till
346 - Residue and Tillage Management - Ridge Till
412 - Grassed Waterway
512 - Pasture and Hayland Planting
554 - Drainage Water Management
585 - Stripcropping
600 - Terrace

TRAPPING

332 - Contour Buffer Strips
390 - Riparian Herbaceous Cover
391 - Riparian Forest Buffer
393 - Filter Strip
601 - Vegetative Barriers
635 - Vegetated Treatment Area
656 - Constructed Wetland
657 - Wetland Restoration

658 - Wetland Creation
659 - Wetland Enhancement
747 - Denitrifying Bioreactor

Supporting Practices

AVOIDING

313 - Waste Storage Facility
317 - Composting Facility
327 - Conservation Cover
381 - Silvopasture Establishment
382 - Fence
472 - Access Control
511 - Forage Harvest Management
558 - Roof Runoff Structure
561 - Heavy Use Area Protection
612 - Tree and Shrub Planting
632 - Solid/Liquid Waste Separation Facility
634 - Waste Transfer

CONTROLLING

324 - Deep Tillage
342 - Critical Area Planting
362 - Diversion
386 - Field Border
410 - Grade Stabilization Structure
430 - Irrigation Water Conveyance
447 - Tailwater Recovery
449 - Irrigation Water Management
468 – Lined Waterway or Outlet
484 - Mulching
533 - Pumping Plant
587 - Structure for Water Control
606 - Subsurface Drainage
607 - Surface Drainage

620 - Underground Outlet

638 - Water & Sediment Control Basin

TRAPPING

342 - Critical Area Planting

350 - Sediment Basin

356 - Dike

436 - Irrigation Storage Reservoir

490 - Forest Site Preparation

533 - Pumping Plant

587 - Structure for Water Control

629 - Waste Treatment

638 - Water and Sediment Control Basin

646 - Shallow Water Development and Management

Appendix D: Conservation Effects Assessment Project Summary

The USDA NRCS Conservation Effects Assessment Project (CEAP) estimated the benefits of the 2002 Farm Bill's increase in conservation funding at a national, regional, and watershed scale. The Upper Mississippi River Basin (UMB) was one of 13 basins studied by CEAP. Two nutrient loading scenarios in the CEAP study dealt with increasing treatment for undertreated areas and, more specifically, simulated the effects of structural conservation practices, residue and tillage management, and nutrient management. Similar to the NRS load reduction estimates, the practices used for simulation were selected as example practices that represent the broader range of practices available to operators. Using different analysis methods from this NRS, the CEAP study showed considerable room for improvement in reducing cropland nutrient transport to waters in Minnesota and neighboring states. By treating critical undertreated areas, the CEAP study estimated a 6 percent reduction of overall phosphorus loss to waters from all sources (12 percent reduction of the cropland only losses).By treating all undertreated areas the CEAP study estimated that phosphorus losses to water could be reduced by 17 percent or more (30 percent reduction in the cropland only losses).

The NRS goal of reducing Mississippi River phosphorus by 7.5 percent through cropland BMPs is within the 6 to 17 percent reduction range that the CEAP study determined possible through BMP adoption on some or all of the undertreated areas. The CEAP Study supports the achievability of this NRS's recommendations for additional phosphorus loss reductions in the Mississippi River using traditional cropland conservation BMPs.

The simulated practices included terraces, contouring or strip cropping, riparian buffers, filter strips, nutrient management, and efficiency of irrigation water conveyances and water application. In reality, tillage or residue management and cover crops may be used instead of the simulated structural practices, and drainage water management or cover crops may be used instead of strict nutrient management practices (USDA 2012a).

USDA NRCS conducted an extensive survey of current farming practices to estimate the load reduction being achieved through conserving practices. The farm–scale Agricultural Policy/ Environmental Extender simulation model was used to estimate weighted average yields of surface water delivery, sediment, nutrients, and pesticides. These results were multiplied by the area of cultivated cropland obtained from the Hydrologic Unit Model for the United States database and entered into the Soil and

Water Assessment Tool (SWAT) watershed model for each 8-digit HUC. The SWAT model was used to simulate nonpoint source loadings from land uses other than cropland and aggregate HUC8 loading results for all land uses to the HUC4 scale (Gervino 2013).

While the majority of the modeling steps were specific to the HUC8 scale, the results were reported at the HUC4 level. Seven HUC4 UMB watersheds intersect with Minnesota (Gervino 2013):

- Mississippi Headwaters HUC4 0701: 100 percent within Minnesota
- Minnesota River HUC4 0702: 81 percent in Minnesota
- St. Croix HUC4 0703 and Black–Root HUC4 0704: intersected by the Minnesota-Wisconsin border, relatively large portions within Minnesota
- HUC4s 0706, 0708, and 0710: small portions are located in Minnesota, intersecting at the Minnesota-Iowa border

Since CEAP results at the HUC8 scale are not available, the Mississippi Headwaters 0701 and the Minnesota River 0702 provide the best means of comparison between the NRS and CEAP load reduction results. These watersheds combined represent 74 percent of the UMB within Minnesota (Gervino 2013).

Table D-1 compares the land area assumptions and load reduction results, in terms of percent, between the NRS (Minnesota only, all Mississippi River drainage) and the CEAP study (Mississippi Headwaters and Minnesota River HUC4s). The geographic areas are not the same but they overlap considerably. The relative percentages provide a means of comparison between the NRS and CEAP approaches. Both approaches consider a similar percentage of cultivated land compared to the total land within the study areas. While the simulated BMPs differed, as well as the assumptions, the percent of new treated area is similar between the NRS and the CEAP scenarios. Comparing the CEAP undertreated areas scenario to the NRS, the CEAP results estimate is twice the phosphorus load reduction compared to the NRS (17 percent versus 7.5 percent). The other CEAP scenario shown in Table D-1, treating critical undertreated areas only, simulates a much smaller treated area compared to all undertreated areas but is estimated to achieve a reasonably large percentage of load reduction compared to its treated area.

Underlying both the NRS and CEAP study results are many detailed assumptions and decision rules regarding the extent and type of increased treatment. While the percent of total cultivated land estimates are similar, the source of data on current practices also differs between CEAP and the NRS. Finally, both methods used an uncalibrated approach for estimating pollutant load reductions from practices. When two efforts conduct large scale, uncalibrated loading estimations, a difference in results is expected. While the methods differed considerably, CEAP provides an additional line of evidence for major nutrient load reductions that can be achieved through additional conserving practices on cultivated land.

Table D-1. Comparison between NRS and CEAP land areas and load reduction results

	Percent of land that is cultivated [a]	Percent of cultivated land simulated with additional treatment	Percent load reduction estimated as a percent of all sources
MN NRS [b]	46%	62%	7.5%
CEAP, Treatment of Critical Undertreated Areas [c]	48%	13%	6%
CEAP, Treatment of All Undertreated Areas [c]	48%	57%	17%

a. CEAP cropland estimates include Conservation Reserve Program land.
b. Represents Minnesota portion of Mississippi Basin, 2012 CDL.
c. Represents mostly Minnesota area with some area in adjacent states; limited to HUC4 0701 (Mississippi Headwaters) and 0702 (Minnesota River).

Appendix E: HUC8 Watershed Loads and Reductions

Chapter 6 includes a strategy for nutrient reduction which calls for achieving nutrient reductions within the 8-digit hydrologic unit code (HUC8) major watersheds which will cumulatively achieve the downstream goals and Mississippi River nitrogen milestone. The watershed restoration and protection strategy (WRAPS) for each major watershed includes such elements as timelines, interim milestones, and responsible governmental units for achieving the needed pollutant reductions. The WRAPS and associated local water management plan (e.g., One Watershed One Plan) should be developed to not only have the goal of protecting and restoring water resources within the watershed, but to also contribute to nutrient reductions needed for downstream waters (in-state and out-of-state).

A set of HUC8 nutrient reduction targets is provided in this appendix as a guide to provide an estimate of the magnitude of individual HUC8 reductions which will collectively reach NRS goals and milestones (Table E-1). One approach in this appendix is based on reducing a common percentage of SPARROW-modeled loads for each HUC8 watershed outlet in the major basin (i.e. 20 percent for the Mississippi nitrogen milestone reduction for each HUC8 in the Mississippi Basin). This approach, as shown in Table E-2, includes loads from all sources and takes into consideration recent progress as documented in Chapter 4. If other watershed monitoring and modeling is available (e.g., calibrated HSPF watershed model), the major basin reduction needs in Table E-1 could instead be applied to the modeled existing condition load to estimate the needed HUC8 load reduction.

Table E-1. Summary of new reductions needed

Major Basin	Phosphorus			Nitrogen		
	Goal Reduction	Recent Progress Reduction	Remaining Reduction Needed	Goal/ Milestone Reduction	Recent Progress Reduction	Remaining Reduction Needed
Mississippi River	45%	33%	**12%**	20%	0%	**20%**
Lake Winnipeg	10%	4.3%	**5.7%**	13%	0%	**13%**

A different approach provided in this appendix is based on estimated HUC8 watershed nutrient reduction needs from cropland sources only. Table E-3 shows estimates for HUC8 load reductions that would collectively achieve the cropland nutrient reduction goals and milestones. The BMP adoption targets are predicted to be sufficient to meet environmental milestones and goals for nitrogen and phosphorus loading, if adopted on the suitable acres as described in Chapter 5. The cropland load reduction approximations are summarized from the NBMP tool and the phosphorus analysis, which considers the amount of land that is suitable and available for the various agricultural BMPs in each watershed. Individual HUC8 watershed modeling and planning should be used along with information in the NRS to determine the best scenario for HUC8 nutrient reductions and the associated BMP adoption to achieve both local and downstream milestones and goals.

In addition to these watershed nutrient reduction guidelines and scenarios, TMDLs will inform watershed and point source reductions needed to address specific water body impairments. In cases where downstream TMDLs require large reductions, interim implementation targets consistent with these reduction targets may be considered, but in all cases TMDLs are applicable and this NRS is not intended to supersede any regulatory requirements. Of particular importance are the reductions needed for those HUC8s that drain to lakes with approved TMDLs such as Lake St. Croix and in the future Lake Pepin. Chapter 2 of the NRS summarizes key eutrophication-impaired lakes with large watersheds in Minnesota that are in need of phosphorus load reductions to meet water quality standards.

Table E-2. SPARROW modeled loads at HUC8 outlets from all sources to collectively achieve goals and nitrogen milestone when each watershed in the major basin is reduced by the same percentage according to Table E-1.

Note: The reduction targets in this table indicate the general magnitude of reductions needed. Additional monitoring and modeling information should be used determine watershed reduction goal planning.

HUC8 Number	HUC8 Name	Basin	Major Basin	Phosphorus		Nitrogen	
				Load [a] (MT/year)	Reduction (MT/year) [b]	Load [a] (MT/year)	Reduction (MT/year) [b]
07080102	Upper Wapsipinicon River	Cedar	Mississippi	2.8	0.3	80.4	16.1
07080201	Cedar River	Cedar	Mississippi	169.3	20.3	4,660.9	932.2
07080202	Shell Rock River	Cedar	Mississippi	57.6	6.9	1,359.4	271.9
07080203	Winnebago River	Cedar	Mississippi	12.2	1.5	817.5	163.5
07100001	Des Moines River - Headwaters	Des Moines	Mississippi	199.3	23.9	3,709.3	741.9
07100002	Lower Des Moines River	Des Moines	Mississippi	19.2	2.3	246.0	49.2
07100003	East Fork Des Moines River	Des Moines	Mississippi	32.1	3.9	552.1	110.4
10170202	Upper Big Sioux River	Missouri	Mississippi	6.9	0.8	124.4	24.9
10170203	Lower Big Sioux River	Missouri	Mississippi	83.6	10.0	1,504.5	300.9
10170204	Rock River	Missouri	Mississippi	147.6	17.7	2,655.4	531.1
10230003	Little Sioux River	Missouri	Mississippi	51.4	6.2	924.2	184.8
07010101	Mississippi River - Headwaters	Upper Mississippi	Mississippi	15.7	1.9	181.3	36.3
07010102	Leech Lake River	Upper Mississippi	Mississippi	7.2	0.9	79.4	15.9
07010103	Mississippi River - Grand Rapids	Upper Mississippi	Mississippi	123.2	14.8	982.1	196.4

HUC8 Number	HUC8 Name	Basin	Major Basin	Phosphorus		Nitrogen	
				Load [a] (MT/year)	Reduction (MT/year) [b]	Load [a] (MT/year)	Reduction (MT/year) [b]
07010104	Mississippi River - Brainerd	Upper Mississippi	Mississippi	111.7	13.4	1,611.4	322.3
07010105	Pine River	Upper Mississippi	Mississippi	6.0	0.7	89.3	17.9
07010106	Crow Wing River	Upper Mississippi	Mississippi	53.9	6.5	905.2	181.0
07010107	Redeye River	Upper Mississippi	Mississippi	39.9	4.8	806.7	161.3
07010108	Long Prairie River	Upper Mississippi	Mississippi	52.6	6.3	733.6	146.7
07010201	Mississippi River - Sartell	Upper Mississippi	Mississippi	115.1	13.8	1,847.7	369.5
07010202	Sauk River	Upper Mississippi	Mississippi	149.8	18.0	2,076.6	415.3
07010203	Mississippi River - St. Cloud	Upper Mississippi	Mississippi	106.0	12.7	1,783.7	356.7
07010204	North Fork Crow River	Upper Mississippi	Mississippi	173.3	20.8	3,287.1	657.4
07010205	South Fork Crow River	Upper Mississippi	Mississippi	296.0	35.5	5,811.2	1162.2
07010206	Mississippi River - Twin Cities	Upper Mississippi	Mississippi	291.5	35.0	5,108.6	1021.7
07010207	Rum River	Upper Mississippi	Mississippi	103.4	12.4	1,647.2	329.4
07020001	Minnesota River - Headwaters	Minnesota	Mississippi	42.0	5.0	512.9	102.6
07020002	Pomme de Terre River	Minnesota	Mississippi	135.2	16.2	1,643.4	328.7
07020003	Lac Qui Parle River	Minnesota	Mississippi	117.3	14.1	1,705.0	341.0
07020004	Minnesota River - Yellow Medicine River	Minnesota	Mississippi	435.7	52.3	6,910.6	1382.1
07020005	Chippewa River	Minnesota	Mississippi	234.4	28.1	3,882.9	776.6
07020006	Redwood River	Minnesota	Mississippi	199.3	23.9	1,998.5	399.7
07020007	Minnesota River - Mankato	Minnesota	Mississippi	299.4	35.9	8,245.0	1649.0
07020008	Cottonwood River	Minnesota	Mississippi	261.0	31.3	5,305.0	1061.0
07020009	Blue Earth River	Minnesota	Mississippi	376.5	45.2	8,022.1	1604.4
07020010	Watonwan River	Minnesota	Mississippi	192.0	23.0	4,176.2	835.2
07020011	Le Sueur River	Minnesota	Mississippi	351.8	42.2	7,067.9	1413.6
07020012	Lower Minnesota River	Minnesota	Mississippi	338.4	40.6	9,249.1	1849.8
07030001	Upper St. Croix River	St. Croix	Mississippi	19.5	2.3	377.6	75.5
07030003	Kettle River	St. Croix	Mississippi	53.2	6.4	777.3	155.5
07030004	Snake River	St. Croix	Mississippi	63.5	7.6	911.2	182.2
07030005	Lower St. Croix River	St. Croix	Mississippi	66.9	8.0	1,428.8	285.8
07040001	Mississippi River - Lake Pepin	Lower Mississippi	Mississippi	97.1	11.7	1,735.4	347.1
07040002	Cannon River	Lower Mississippi	Mississippi	248.0	29.8	6,265.3	1253.1

HUC8 Number	HUC8 Name	Basin	Major Basin	Phosphorus		Nitrogen	
				Load [a] (MT/year)	Reduction (MT/year) [b]	Load [a] (MT/year)	Reduction (MT/year) [b]
07040003	Mississippi River - Winona	Lower Mississippi	Mississippi	161.0	19.3	1,744.0	348.8
07040004	Zumbro River	Lower Mississippi	Mississippi	314.6	37.8	5,575.3	1115.1
07040006	Mississippi River - La Crescent	Lower Mississippi	Mississippi	30.0	3.6	412.4	82.5
07040008	Root River	Lower Mississippi	Mississippi	322.5	38.7	5,821.4	1164.3
07060001	Mississippi River - Reno	Lower Mississippi	Mississippi	30.5	3.7	404.7	80.9
07060002	Upper Iowa River	Lower Mississippi	Mississippi	25.1	3.0	677.7	135.5
09020101	Bois de Sioux River	Red	Winnipeg	35.2	2.1	471.8	47.2
09020102	Mustinka River	Red	Winnipeg	155.7	9.3	1,653.3	165.3
09020103	Otter Tail River	Red	Winnipeg	116.7	7.0	1,569.1	156.9
09020104	Upper Red River of the North	Red	Winnipeg	69.6	4.2	684.8	68.5
09020106	Buffalo River	Red	Winnipeg	98.8	5.9	1,687.3	168.7
09020107	Red River of the North - Marsh River	Red	Winnipeg	27.9	1.7	552.9	55.3
09020108	Wild Rice River	Red	Winnipeg	104.9	6.3	2,214.1	221.4
09020301	Red River of the North - Sandhill River	Red	Winnipeg	39.0	2.3	963.0	96.3
09020302	Upper/Lower Red Lake	Red	Winnipeg	2.4	0.1	21.6	2.2
09020303	Red Lake River	Red	Winnipeg	86.2	5.2	1,689.6	169.0
09020304	Thief River	Red	Winnipeg	14.3	0.9	255.4	25.5
09020305	Clearwater River	Red	Winnipeg	53.0	3.2	964.3	96.4
09020306	Red River of the North - Grand Marais Creek	Red	Winnipeg	47.9	2.9	809.4	80.9
09020309	Snake River	Red	Winnipeg	43.2	2.6	1,079.4	107.9
09020311	Red River of the North - Tamarac River	Red	Winnipeg	44.3	2.7	1,160.2	116.0
09020312	Two Rivers	Red	Winnipeg	79.0	4.7	1,532.1	153.2
09020314	Roseau River	Red	Winnipeg	54.7	3.3	1,033.6	103.4

a. Load delivered to HUC8 outlet derived from SPARROW, results reflect point source update. Note that these loads are higher than the loads delivered to De Soto (state line) due to attenuation.
b. Load reduction is proportional based on Major Basin reduction milestones, at the HUC8 outlet (Table E-1).

Table E-3. HUC8 loading results and reductions from new agricultural BMPs.

BMP adoption scenarios are based on the levels of adoption described Chapter 5. Total loads are at HUC8 outlets. The cropland load reduction indicates the general magnitude of reductions needed from cropland to collectively achieve goals and nitrogen milestone. Additional monitoring and modeling information where available and appropriate should be used to complete a watershed-specific nutrient reduction planning process.

HUC8 Number	HUC8 Name	Basin	Major Basin	Phosphorus		Nitrogen	
				Load [a] (MT/year)	Cropland Load Reduction (MT/year) [b]	Load [a] (MT/year)	Cropland Load Reduction (MT/year)[b]
07080102	Upper Wapsipinicon River	Cedar	Mississippi	2.8	0.2	80.4	7.4
07080201	Cedar River	Cedar	Mississippi	169.3	12.7	4,660.9	435.2
07080202	Shell Rock River	Cedar	Mississippi	57.6	3.1	1,359.4	123.4
07080203	Winnebago River	Cedar	Mississippi	12.2	1.6	817.5	31.7
07100001	Des Moines River - Headwaters	Des Moines	Mississippi	199.3	20.7	3,709.3	581.4
07100002	Lower Des Moines River	Des Moines	Mississippi	19.2	2.4	246.0	52.7
07100003	East Fork Des Moines River	Des Moines	Mississippi	32.1	4.2	552.1	123.0
10170202	Upper Big Sioux River	Missouri	Mississippi	6.9	1.5	124.4	13.8
10170203	Lower Big Sioux River	Missouri	Mississippi	83.6	8.7	1,504.5	171.0
10170204	Rock River	Missouri	Mississippi	147.6	13.7	2,655.4	304.9
10230003	Little Sioux River	Missouri	Mississippi	51.4	5.5	924.2	139.4
07010101	Mississippi River - Headwaters	Upper Mississippi	Mississippi	15.7	1.0	181.3	--
07010102	Leech Lake River	Upper Mississippi	Mississippi	7.2	0.3	79.4	--
07010103	Mississippi River - Grand Rapids	Upper Mississippi	Mississippi	123.2	1.3	982.1	33.6
07010104	Mississippi River - Brainerd	Upper Mississippi	Mississippi	111.7	4.6	1,611.4	139.6
07010105	Pine River	Upper Mississippi	Mississippi	6.0	0.1	89.3	--
07010106	Crow Wing River	Upper Mississippi	Mississippi	53.9	2.3	905.2	--
07010107	Redeye River	Upper Mississippi	Mississippi	39.9	3.1	806.7	125.0
07010108	Long Prairie River	Upper Mississippi	Mississippi	52.6	3.8	733.6	129.7
07010201	Mississippi River - Sartell	Upper Mississippi	Mississippi	115.1	9.1	1,847.7	121.7
07010202	Sauk River	Upper Mississippi	Mississippi	149.8	17.4	2,076.6	144.9
07010203	Mississippi River - St. Cloud	Upper Mississippi	Mississippi	106.0	6.9	1,783.7	219.7
07010204	North Fork Crow River	Upper Mississippi	Mississippi	173.3	17.7	3,287.1	480.7
07010205	South Fork Crow River	Upper Mississippi	Mississippi	296.0	33.9	5,811.2	682.8
07010206	Mississippi River - Twin Cities	Upper Mississippi	Mississippi	291.5	13.5	5,108.6	288.6
07010207	Rum River	Upper	Mississippi	103.4	6.3	1,647.2	122.2

HUC8 Number	HUC8 Name	Basin	Major Basin	Phosphorus		Nitrogen	
				Load [a] (MT/year)	Cropland Load Reduction (MT/year) [b]	Load [a] (MT/year)	Cropland Load Reduction (MT/year)[b]
		Mississippi					
07020001	Minnesota River - Headwaters	Minnesota	Mississippi	42.0	3.1	512.9	109.3
07020002	Pomme de Terre River	Minnesota	Mississippi	135.2	15.7	1,643.4	280.7
07020003	Lac Qui Parle River	Minnesota	Mississippi	117.3	12.5	1,705.0	408.1
07020004	Minnesota River - Yellow Medicine River	Minnesota	Mississippi	435.7	47.0	6,910.6	1,038.4
07020005	Chippewa River	Minnesota	Mississippi	234.4	22.5	3,882.9	572.1
07020006	Redwood River	Minnesota	Mississippi	199.3	12.5	1,998.5	334.2
07020007	Minnesota River - Mankato	Minnesota	Mississippi	299.4	32.5	8,245.0	790.7
07020008	Cottonwood River	Minnesota	Mississippi	261.0	24.6	5,305.0	691.0
07020009	Blue Earth River	Minnesota	Mississippi	376.5	52.8	8,022.1	976.8
07020010	Watonwan River	Minnesota	Mississippi	192.0	22.7	4,176.2	649.4
07020011	Le Sueur River	Minnesota	Mississippi	351.8	50.9	7,067.9	897.2
07020012	Lower Minnesota River	Minnesota	Mississippi	338.4	25.5	9,249.1	1,023.4
07030001	Upper St. Croix River	St. Croix	Mississippi	19.5	0.8	377.6	77.9
07030003	Kettle River	St. Croix	Mississippi	53.2	1.1	777.3	96.2
07030004	Snake River	St. Croix	Mississippi	63.5	3.2	911.2	27.7
07030005	Lower St. Croix River	St. Croix	Mississippi	66.9	2.9	1,428.8	134.6
07040001	Mississippi River - Lake Pepin	Lower Mississippi	Mississippi	97.1	4.9	1,735.4	209.5
07040002	Cannon River	Lower Mississippi	Mississippi	248.0	20.3	6,265.3	743.1
07040003	Mississippi River - Winona	Lower Mississippi	Mississippi	161.0	9.8	1,744.0	340.6
07040004	Zumbro River	Lower Mississippi	Mississippi	314.6	37.7	5,575.3	982.0
07040006	Mississippi River - La Crescent	Lower Mississippi	Mississippi	30.0	0.5	412.4	26.8
07040008	Root River	Lower Mississippi	Mississippi	322.5	33.1	5,821.4	913.6
07060001	Mississippi River - Reno	Lower Mississippi	Mississippi	30.5	0.9	404.7	67.4
07060002	Upper Iowa River	Lower Mississippi	Mississippi	25.1	3.3	677.7	143.1
09020101	Bois de Sioux River	Red	Winnipeg	35.2	1.2	471.8	32.1
09020102	Mustinka River	Red	Winnipeg	155.7	3.6	1,653.3	54.6
09020103	Otter Tail River	Red	Winnipeg	116.7	2.6	1,569.1	158.2
09020104	Upper Red River of the North	Red	Winnipeg	69.6	2.9	684.8	21.7
09020106	Buffalo River	Red	Winnipeg	98.8	3.2	1,687.3	82.0
09020107	Red River of the North - Marsh River	Red	Winnipeg	27.9	1.1	552.9	13.2
09020108	Wild Rice River	Red	Winnipeg	104.9	3.7	2,214.1	70.7

HUC8 Number	HUC8 Name	Basin	Major Basin	Phosphorus		Nitrogen	
				Load [a] (MT/year)	Cropland Load Reduction (MT/year) [b]	Load [a] (MT/year)	Cropland Load Reduction (MT/year)[b]
09020301	Red River of the North - Sandhill River	Red	Winnipeg	39.0	1.5	963.0	34.2
09020302	Upper/Lower Red Lake	Red	Winnipeg	2.4	0.1	21.6	
09020303	Red Lake River	Red	Winnipeg	86.2	2.9	1,689.6	40.6
09020304	Thief River	Red	Winnipeg	14.3	0.4	255.4	19.9
09020305	Clearwater River	Red	Winnipeg	53.0	1.4	964.3	65.7
09020306	Red River of the North - Grand Marais Creek	Red	Winnipeg	47.9	2.1	809.4	19.4
09020309	Snake River	Red	Winnipeg	43.2	1.6	1,079.4	90.1
09020311	Red River of the North - Tamarac River	Red	Winnipeg	44.3	1.9	1,160.2	29.5
09020312	Two Rivers	Red	Winnipeg	79.0	2.4	1,532.1	23.4
09020314	Roseau River	Red	Winnipeg	54.7	1.3	1,033.6	--

a. Load delivered to HUC8 outlet derived from SPARROW, results reflect point source update. Note that these loads are higher than the loads delivered to De Soto (state line) due to attenuation.
b. Load reduction is from new agricultural BMPs, as summarized in Chapter 5, at the HUC8 outlet.

Appendix F: Program Metadata Worksheets

Implementation of Nonpoint Source (NPS) Best Management Practices (BMPs) Tracked via eLink and Estimated Nutrient Load Reductions

Measure Background

Visual Depiction

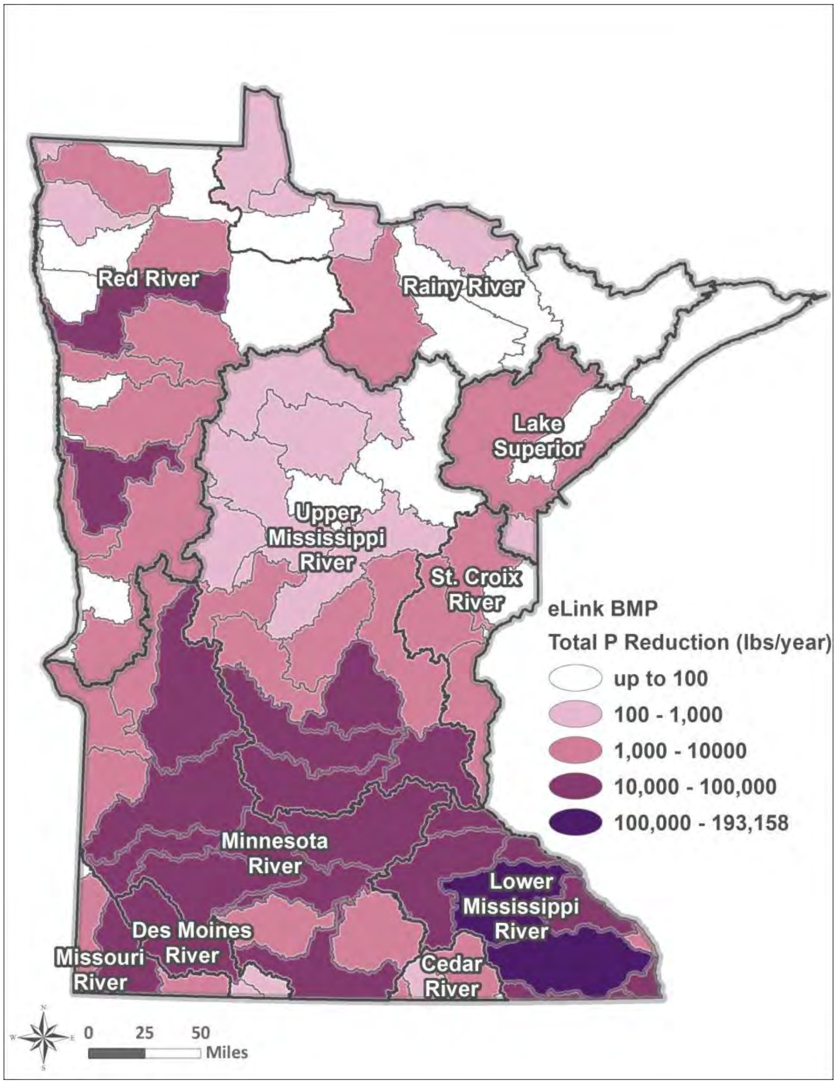


Figure 1. TP load reductions as reported in eLINK, data retrieved March 2013.

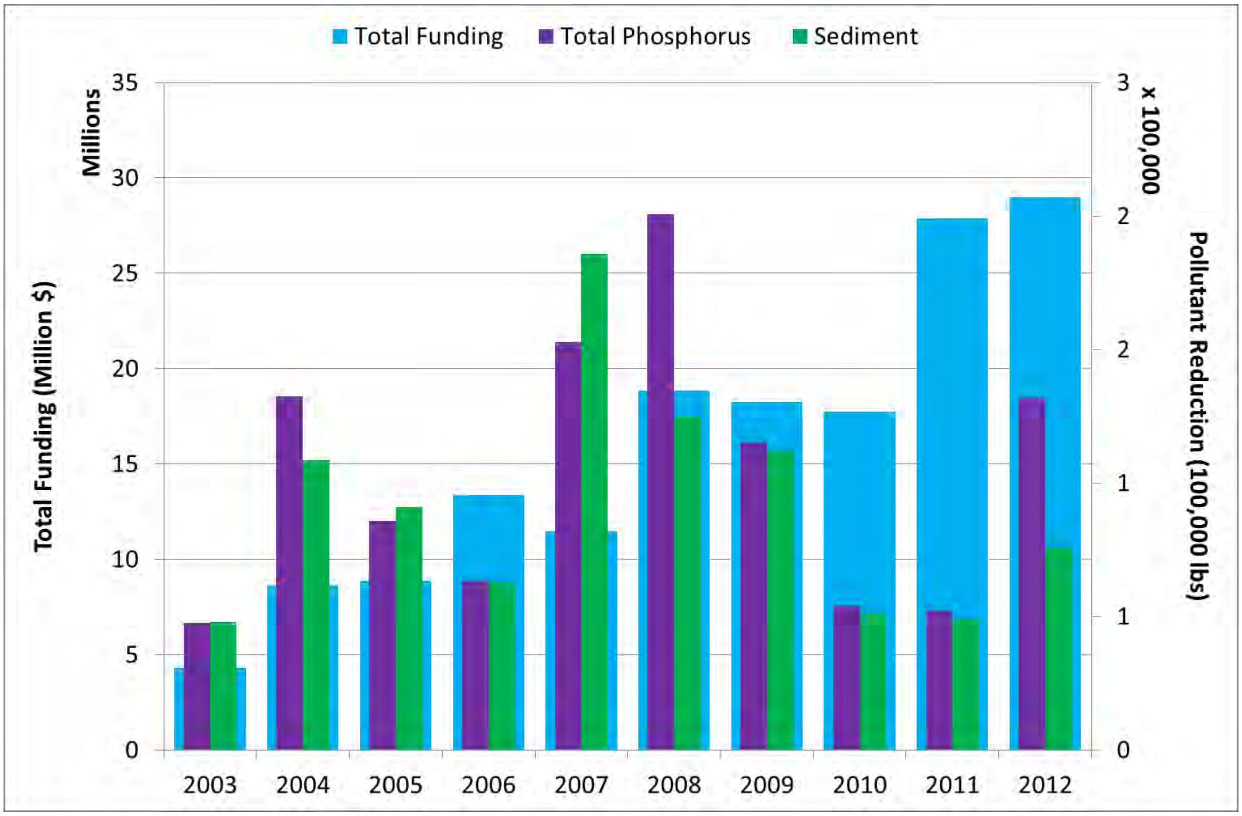


Figure 2. Annual total funding for NPS projects, as reported in eLINK, 2003- 2012.
Note – Annual total funding is a combination of multiple fund sources including Federal and local dollars, dates are based on the project year included in the database. Any other reported years were ignored in Figure 2, although they are included in Figure 1.

Measure Description

This measure communicates the phosphorus reduction and number of nonpoint source (NPS) best management practices (BMPs) implemented through a variety of key programs administered by several agencies and tracked through eLINK. Figure 1 describes the phosphorus load reductions by 8-digit HUC for projects included in the eLINK database (data retrieved March 2013). Figure 2 illustrates the total funding associated with these BMPs from 2003-2012, as well as associated reductions in total phosphorus, sediment, and soil. According to Figure 2, funding for NPS projects as tracked in eLINK has increase significantly over time. In 2007, Clean Water Legacy Act funding became available. In 2009, funding associated with the passage of the Clean Water Land and Legacy Amendment began to be tracked.

The eLINK database, which is presented in summary above, is the result of self-reported load reductions, calculated in a variety of ways. A review of the eLINK database identified anomalies and potential missing data as related to pollutant load reductions; however no efforts were made to further investigate. One outlier was removed in 2010.

Funding for NPS projects tracked in this database has clearly increased. The dollars spent per load of pollutant removed has increased as well in recent years. The cause of this is unknown.

This measure is an indirect or surrogate measure of environmental response. It does not provide information on watershed health, but does provide information on efforts to reduce pollutant loads over time.

Associated Terms and Phrases

To better understand this measure, it is necessary to understand a few program specific terms and phrases.

BMPs: Conservation practices that improve or protect water quality in agricultural, forested, and urban areas.

Phosphorus: In this measure, we report the estimated reduction in the amount of total phosphorus reaching surface waters as a result of runoff or soil erosion (sheet, rill, gully erosion, or steam channel).

Sediment Loss: The estimated amount of sediment reaching the nearest surface water body as a result of soil erosion from water (sheet, rill, gully erosion, or stream channel).

Target

There is no specific numeric target for this measure to date.

Baseline

2003-2012

Geographical Coverage

Spatial data points associated with each eLINK project.

Data and Methodology

Methodology for Measure Calculation

This measure represents NPS BMPs implemented through a number of state grant and loan programs. To calculate this measure, state agencies collect data on the NPS BMPs implemented by multiple programs including BWSR State Cost-Share and BWSR Clean Water Fund, amongst others.

Pollutant estimates are entered into the Minnesota Board of Water and Soil Resources' (BWSR's) web-based grant reporting and tracking tool, eLINK, by grant recipients when entering BMP data. The State of Minnesota does not require a specific methodology for developing pollutant load estimates. Pollutant load reductions using existing models developed for estimating pollutant load are acceptable. BWSR provides several pollution reduction calculators that can be used at http://www.bwsr.state.mn.us/outreach/eLINK/index.html. In the past, BQSR has provided pollutant estimators for eLINK based on soil erosion (sheet, rill, gully and stream channel). Sediment reduction estimates in eLINK were based on the distance to the nearest surface waters and soil loss calculations using USDA's Revised Universal Soil Loss Equation (RUSLE2). Phosphorus reduction estimates were derived from sediment reduction estimates.

For programs administered by BWSR, local grant recipients are required to enter BMP data in eLINK. More information on eLINK is available at http://www.bwsr.state.mn.us/outreach/eLINK/index.html.

Data Source

Minnesota Board of Water and Soil Resources

Data Collection Period

For Figure 1, as explained below in Caveats and Limitations, there is a lag time between grants being awarded and BMPs being fully implemented and recorded. The dataset will be complete once all of the BMPs funded are fully implemented and recorded. Until then, the dataset for this measure only provides a snapshot in time.

For Figure 2, the data collection period was 2003 through 2012.

Data Collection Methodology and Frequency

BWSR staff extracts the data by summarizing all BMPs in the database. Local grant recipients enter BMP information into eLINK every six months, recording only those BMPs that are fully implemented at that time. BMP data are analyzed by the fiscal year the grant was awarded rather than the calendar year the BMP was installed.

Supporting Data Set

Table 1. eLINK database summary, March 2013 data pull

HUC8	eLINK P Reduction	eLINK Count of BMPs	HUC8	eLINK P Reduction	eLINK Count of BMPs
04010101	96	50	07040006	3,752	54
04010102	1,799	49	07040008	118,219	1,199
04010201	1,778	50	07060001	10,444	239
04010202	1	6	07060002	80,598	140
04010301	368	43	07080102	0	0
04020300	143	2	07080201	5,758	132
07010101	209	78	07080202	280	61
07010102	116	18	07080203	1,073	6
07010103	49	89	07100001	14,977	1,346
07010104	752	214	07100002	257	35
07010105	34	51	07100003	197	97
07010106	337	361	09020101	14	111
07010107	666	569	09020102	1,190	201
07010108	1,495	418	09020103	5,027	634
07010201	4,329	431	09020104	7,949	264
07010202	8,124	469	09020106	19,582	814
07010203	16,324	550	09020107	0	84
07010204	81,786	529	09020108	6,722	402
07010205	13,801	552	09020301	1,890	99
07010206	13,094	293	09020302	43	22
07010207	2,277	169	09020303	10,822	353
07020001	1,769	278	09020304	2,520	146

HUC8	eLINK P Reduction	eLINK Count of BMPs	HUC8	eLINK P Reduction	eLINK Count of BMPs
07020002	3,308	269	09020305	1,471	195
07020003	6,309	588	09020306	0	111
07020004	27,247	2,428	09020309	39	119
07020005	24,362	1,123	09020311	147	77
07020006	41,260	926	09020312	4,093	187
07020007	10,839	462	09020314	81	136
07020008	12,073	1,384	09030001	0	2
07020009	69,187	655	09030002	0	1
07020010	5,871	789	09030003	237	15
07020011	8,330	576	09030004	188	5
07020012	26,716	1,970	09030005	19	12
07030001	2	9	09030006	8,806	47
07030003	1,092	38	09030007	0	2
07030004	2,974	90	09030008	716	75
07030005	1,419	232	09030009	158	101
07040001	22,107	175	10170202	64	37
07040002	23,976	925	10170203	5,553	334
07040003	82,823	458	10170204	14,641	528
07040004	705,504	684	10230003	4,314	152

Caveats and Limitations

There is lag time between when grant funds are awarded and when BMPs are fully implemented and recorded in eLINK. This measure reports only BMPs that are fully implemented; it does not report on those that are planned or in progress.

Pollution reductions entered into eLINK are calculated at the field scale, not the watershed scale.

Not all projects have associated pollutant load reductions for phosphorus in the database. No effort was made to assign a phosphorus load reduction for these projects.

Potential Double-Counting of BMPs: An individual BMP may be co-funded by several implementation programs tracked through eLink. For example, a gully/grade stabilization structure might be funded 75% through a BWSR grant and 25 percent by an AgBMP loan—with both programs counting the same structure in their respective databases. In another example, a BWSR grant might provide financial incentives for a farmer to switch to no-till, while an AgBMP loan finances the farmers' purchase of a no-till drill —again, both programs might record the same structure. Until a method is developed to identify such projects and coordinate the way they are recorded, it is necessary to report eLINK-entered data in total, noting potential data overlaps.

eLINK does not request nitrogen removal associated with BMPs being recorded.

Future Improvements

Improvements to this measure will be made over time. The type of pollutant reductions estimated in eLINK will expand in the short-term; therefore, this measure will track additional estimated pollutant load reductions associated with NPS BMPs.

Ideally this measure will be able to compare estimated pollutant load reductions in a particular watershed with pollutant load reduction targets established through TMDLs and other plans. However, accurate comparisons would require tracking all BMPs in a watershed, not just those reported in eLINK, as well as point source pollutant load reductions.

The inclusion of nitrogen reductions as part of required eLINK reporting would allow tracking of this pollutant. In addition, ensuring pollutant load reductions are associated with each project is critical to tracking progress over time.

Financial Considerations

Contributing Agencies and Funding Sources

eLINK tracks a large universe of grant funded BMPs funded through a wide array of funding sources.

Measure Points of Contact

Agency Information

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Implementation of Permanent Easements and Associated Nutrient Load Reductions

Measure Background

Visual Depiction

The map in Figure 1 shows the percentage of agricultural area in permanent conservation easements made through the Reinvest in Minnesota (RIM) easement program, administered by the Minnesota Board of Water and Soil Resources (BWSR), in each 8 digit-HUC. Figure 2 shows the aggregated annual acreage of permanent conservation easements and annual RIM costs associated with permanent easements from 2000-2012.

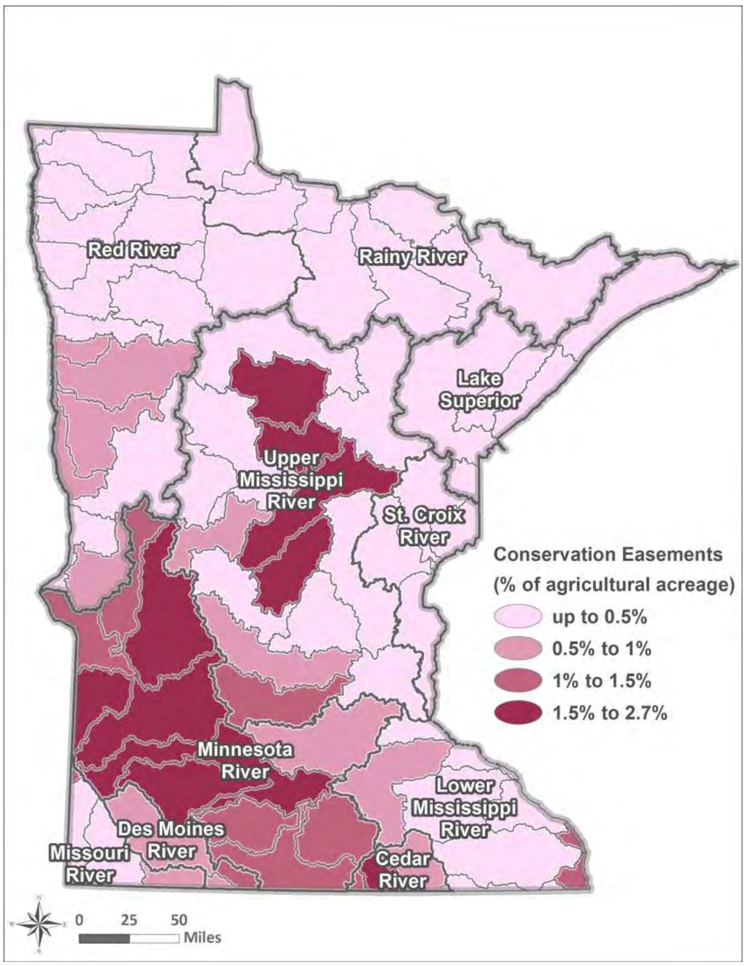

Figure 1. Percentage of permanent conservation easements of total agricultural acreage by 8-digit HUC.

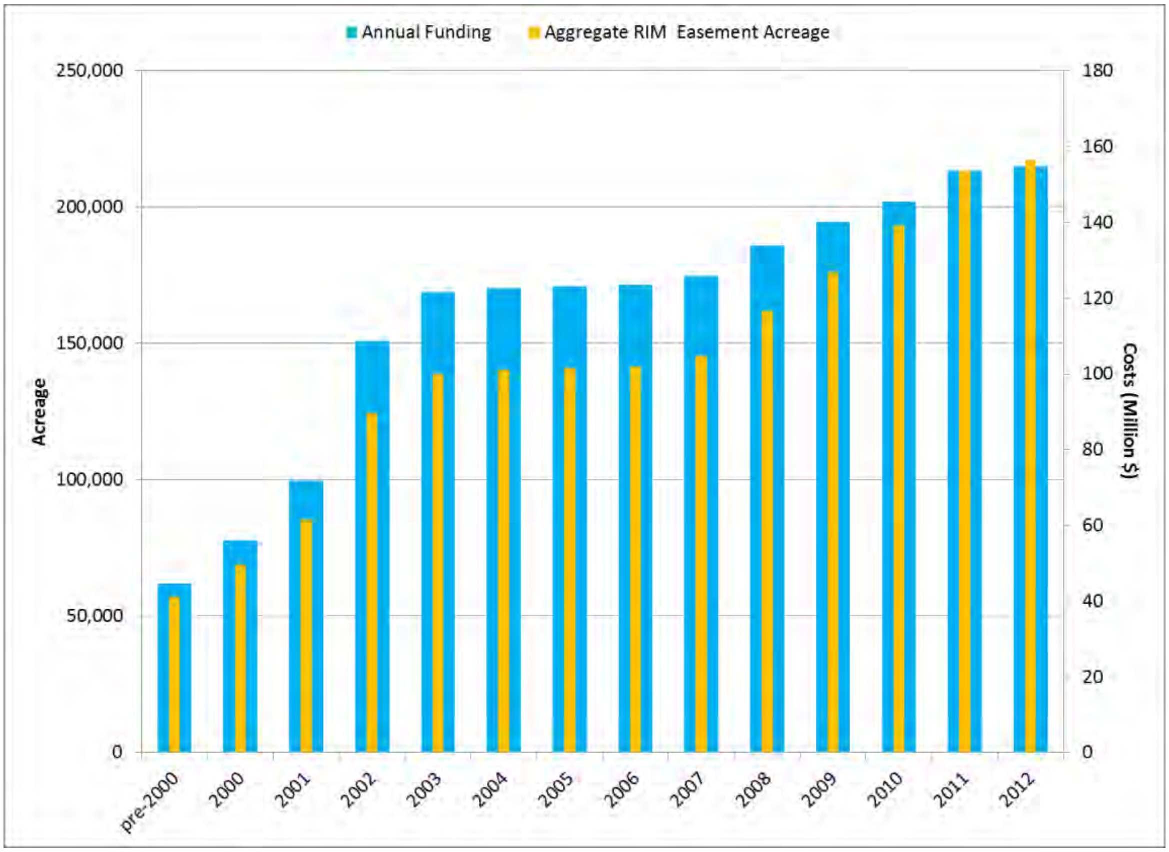

Figure 2. Aggregated annual RIM permanent conservation easement acreage and annual RIM funding.

Measure Description

This measure focuses on implementation trends for permanent easements on eligible agricultural land acquired through RIM. Agricultural land eligible for RIM easements are defined in the RIM Eligibility Handbook (http://www.bwsr.state.mn.us/easements/handbook/rimeligibility.pdf)

Figure 1 shows the percent of agricultural acreage within each 8-digit HUC that has permanent easements through the RIM program. The 8-digit HUCs with the highest percentages of agricultural land acquired for permanent easements through RIM are located in the Upper Mississippi River basin (primarily due to the small amount of agricultural land) and the Minnesota River basin. According to Figure 2, the aggregate acreage of permanent conservation easements through RIM increased from 2000-2003, but remained relatively steady until 2007, when an increase in acreage occurred until present. This increase has been primarily due to funding secured through the Legacy Amendment and increases in Capitol Investment (bonding). The trends in funding mirror the trends in acreage.

Table 1 below shows the estimated percent nitrogen and phosphorus removal associated with permanent conservation easements.

Table 1. Estimated nutrient removal efficiencies for conservation easements

Best Management Practice	Phosphorus Removal (%)	Nitrogen Removal (%)
Conservation easements[a]	56	83

a. Iowa State, 2013; MPCA, 2013; MPCA, 2004

Associated Terms and Phrases

To better understand this measure, it is necessary to understand a few program specific terms and phrases.

The Reinvest in Minnesota (RIM) Resources Law of 1986, Minnesota Statutes, sections 103F.501 to 103F.531, as amended, states: " It is the purpose of [the program] to keep certain marginal agricultural land out of crop production to protect soil and water quality and support fish and wildlife habitat. It is state policy to encourage the retirement of marginal, highly erodible land, particularly land adjacent to public waters, drainage systems, wetlands, and locally designated priority waters, from crop production and to reestablish a cover of perennial vegetation."

Definitions used in this measure are as follows:

Agricultural Land: According to the RIM Eligibility Handbook, agricultural land means land devoted for use as pasture or hayland or to the production of horticultural, row, close grown, introduced pasture, or introduced hayland crops, or to growing nursery stocks, or for pasturing domestic livestock or dairy animals, or for use as animal feedlots, and may include contiguous land associated with the production of the above.

Conservation Easements: the acquisition of limited rights in land for conservation purposes. Landowners who offer the state a conservation easement receive a payment to stop cropping and/or grazing the land, and in turn the landowners establish conservation practices such as native grass and forbs, trees or wetland restorations. The easement is recorded on the land title with the county recorder and transfers with the land when the parcel is sold. Most easements purchased by the state are perpetual (forever). Some eligible lands may be enrolled under limited duration easements (not less than 20 years), depending on programs available. The focus of this measure is on permanent/perpetual conservation easements.

Marginal Agricultural Cropland Area: Land with crop history that is composed of class IIIe, Ive, V, VI, VII, or VIII land as identified in the land capability classification system of the United States Department of Agriculture.

Target

There is no specific numeric target for this measure to date.

Baseline

Covers pre-2000-2013 data

Geographical Coverage

Statewide, major basin, 8-digit HUC

Data and Methodology

Methodology for Measure Calculation

BWSR manages a RIM program database to track specific information related to RIM land acquisitions over time. A variety of RIM reports are made available on the BWSR RIM website http://maps.bwsr.state.mn.us/rimonline/.

To develop the map for this measure (Figure 1), data from BWSR's RIM Spatial Dataset derived from the RIM database were downloaded from the RIM website. Using this data, information on permanent conservation easements were isolated from other easement types, including the associated acreage, location, cost, and start date. This information was then compiled by 8-digit HUC and compared to the total agricultural acreage in each HUC, derived using NLCD land use/land cover data, focusing on coverages for pasture/hay and cultivated crops. This information was then mapped using GIS to show total conservation easement acreage in each 8-digit HUC as a percentage of the total agricultural acreage by 8-digit HUC within each major basin.

To develop the bar graph (Figure 2), data on acreage and funding associated with permanent conservation easements from BWSR's RIM database were downloaded from the RIM website. This information was placed into an Excel spreadsheet and graphed.

Data Source

Minnesota Board of Water and Soil Resources

Data Collection Period

2000 through 2012. (data in the Spatial Dataset spans 1986-2012)

Data Collection Methodology and Frequency

Using the RIM database, BWSR staff track the following information: type of easement, acreage, county, start date (i.e., date the easement is recorded at the courthouse), and funding source (i.e., paid or donated). Data from the RIM database is uploaded to the RIM website twice yearly in May and September.

Supporting Data Set

Table 2 contains the acreage under permanent conservation easements through RIM by 8-digit HUC, as well as the total agricultural acreage by 8-digit HUC derived through the NLCD dataset.

Table 2. Acreage under permanent conservation easement through RIM and total agricultural acreage from NLCD by 8-digit HUC to derive percent agricultural acreage under conservation easements within each 8-digit HUC

HUC8	NLCD 2006 Pasture/Hay (acres)	NLCD 2006 Cultivated Crops (acres)	Total NLCD Agriculture	BWSR Conservation Easements (acres)	Percent Conservation Easements
04010101	251	346	597	0	0.00%
04010102	8,088	656	8,744	0	0.00%
04010201	64,220	5,999	70,219	1	0.00%
04010202	4,546	493	5,038	0	0.00%
04010301	17,309	1,799	19,109	0	0.00%
04020300	6	2	9	0	0.00%
07010101	71,996	13,773	85,769	184	0.21%
07010102	29,768	4,334	34,102	538	1.58%
07010103	54,101	11,026	65,127	83	0.13%
07010104	161,571	108,288	269,859	5,202	1.93%
07010105	20,738	7,696	28,434	773	2.72%
07010106	143,492	126,483	269,975	1,175	0.44%
07010107	116,519	145,759	262,278	605	0.23%
07010108	118,441	150,375	268,816	2,588	0.96%
07010201	207,373	190,071	397,444	6,681	1.68%
07010202	161,108	333,713	494,821	1,660	0.34%
07010203	126,728	280,122	406,850	839	0.21%
07010204	134,538	525,184	659,722	5,164	0.78%
07010205	78,360	592,556	670,917	8,810	1.31%
07010206	65,082	52,434	117,517	286	0.24%
07010207	164,848	183,675	348,524	1,516	0.43%
07020001	30,780	328,027	358,807	4,701	1.31%
07020002	36,536	352,347	388,883	4,430	1.14%
07020003	34,307	365,658	399,965	7,625	1.91%
07020004	47,850	1,066,063	1,113,913	23,548	2.11%
07020005	104,517	913,106	1,017,623	22,614	2.22%
07020006	13,924	351,114	365,038	6,700	1.84%
07020007	22,222	656,913	679,134	13,698	2.02%
07020008	14,443	713,427	727,870	14,513	1.99%
07020009	5,966	643,771	649,737	8,456	1.30%
07020010	2,965	484,237	487,203	7,211	1.48%
07020011	9,881	586,803	596,684	8,341	1.40%
07020012	122,496	671,582	794,078	7,272	0.92%
07030001	23,976	7,517	31,494	1	0.00%

HUC8	NLCD 2006 Pasture/Hay (acres)	NLCD 2006 Cultivated Crops (acres)	Total NLCD Agriculture	BWSR Conservation Easements (acres)	Percent Conservation Easements
07030003	86,858	14,955	101,813	28	0.03%
07030004	124,826	54,365	179,192	441	0.25%
07030005	130,037	137,247	267,284	48	0.02%
07040001	43,927	156,210	200,137	382	0.19%
07040002	90,883	568,985	659,868	5,459	0.83%
07040003	70,721	123,252	193,973	738	0.38%
07040004	104,136	507,351	611,488	1,358	0.22%
07040006	14,186	2,201	16,387	194	1.18%
07040008	216,226	436,022	652,248	2,553	0.39%
07060001	27,875	20,885	48,760	714	1.46%
07060002	17,517	88,797	106,315	455	0.43%
07080102	75	7,009	7,083	38	0.54%
07080201	6,950	367,602	374,552	2,956	0.79%
07080202	2,964	107,888	110,852	1,701	1.53%
07080203	957	35,630	36,587	476	1.30%
07100001	11,857	647,304	659,161	6,463	0.98%
07100002	144	46,181	46,324	393	0.85%
07100003	306	109,092	109,399	1,376	1.26%
09020101	5,220	304,792	310,013	1,293	0.42%
09020102	7,817	465,522	473,339	2,502	0.53%
09020103	173,649	330,788	504,437	1,855	0.37%
09020104	5,641	268,935	274,576	1,513	0.55%
09020106	49,221	476,923	526,144	3,093	0.59%
09020107	3,133	199,060	202,193	1,531	0.76%
09020108	68,341	555,010	623,351	4,665	0.75%
09020301	16,610	293,147	309,756	659	0.21%
09020302	70,785	10,170	80,956	56	0.07%
09020303	46,450	507,434	553,884	855	0.15%
09020304	47,405	241,516	288,921	353	0.12%
09020305	158,421	288,569	446,990	574	0.13%
09020306	1,055	345,832	346,887	244	0.07%
09020309	14,917	392,096	407,013	321	0.08%
09020311	11,220	445,939	457,159	327	0.07%
09020312	34,669	448,266	482,936	226	0.05%
09020314	58,441	213,920	272,361	37	0.01%
09030001	358	129	487	0	0.00%

HUC8	NLCD 2006 Pasture/Hay (acres)	NLCD 2006 Cultivated Crops (acres)	Total NLCD Agriculture	BWSR Conservation Easements (acres)	Percent Conservation Easements
09030002	2,522	577	3,099	0	0.00%
09030003	2,302	1,709	4,011	0	0.00%
09030004	8,148	4,619	12,767	0	0.00%
09030005	18,390	6,281	24,672	0	0.00%
09030006	22,767	3,072	25,839	0	0.00%
09030007	6,124	5,839	11,963	7	0.06%
09030008	12,308	13,892	26,200	0	0.00%
09030009	30,224	48,459	78,683	5	0.01%
10170202	1,990	16,237	18,228	271	1.49%
10170203	22,960	252,756	275,716	960	0.35%
10170204	22,021	465,294	487,315	1,445	0.30%
10230003	798	166,435	167,233	887	0.53%

Caveats and Limitations

- Acquisition of agricultural land for conservation easements through RIM is dependent on available funding.
- BWSR does not track nutrient load reductions associated with easements under RIM, although BWSR is interested in doing so in the future.
- Not all agricultural lands are eligible for conservation easements under RIM. Specific eligibility criteria are contained in the RIM Eligibility Handbook. This measure assumes that all agricultural lands within an 8-digit HUC are eligible for purposes of the analysis, due to the challenge in spatially defining marginal agricultural land because this definition is based on land productivity. Therefore, the percent of agricultural land under conservation easements within each 8-digit HUC are likely lower than if the measure were to assess the percent of eligible agricultural land under conservation easements within each 8-digit HUC.
- There is the possibility for a small overlap between agricultural land reflected in the CRP program indicators and this measure for RIM. However, BWSR has stated that this overlap is not significant.

Future Improvements

Improvements to this measure will be made over time.

Ideally this measure will be able to focus on RIM eligible agricultural lands within each 8-digit HUC rather than all agricultural acreage to assess implementation trends. In addition, it would be helpful for BWSR to incorporate a mechanism for estimated nutrient load reductions associated with RIM conservation easements as part of the RIM database. BWSR is considering doing this in a future version of the RIM database.

Financial Considerations

Contributing Agencies and Funding Sources

This measure tracks the annual funding associated with permanent conservation easements acquired under RIM. BWSR establishes payment rates on an annual basis. Payment rates vary for land with a crop history versus land without a crop history. The basis for BWSR's payment rates are described in the RIM Eligibility Handbook (http://www.bwsr.state.mn.us/easements/handbook/rimeligibility.pdf)

References

Iowa State University. 2013. *Iowa Science Assessment of Nonpoint Source Practices to Reduce Nitrogen and Phosphorus Transport in the Mississippi River Basin*. May 2013. Section 2 of the Iowa Nutrient Reduction Strategy developed by Iowa Department of Agriculture and Land Stewardship, Iowa Department of Natural Resources, and Iowa State University College of Agriculture and Life Sciences.

MPCA. 2004. Detailed Assessment of Phosphorus Sources to Minnesota Watersheds. Minnesota Pollution Control Agency, St. Paul, MN. 280 pp + appendices.

MPCA. 2013. D1 Nitrogen Sources to Land and Waters - Results Overview. DRAFT 2013 (Dave Wall, David J. Mulla, and Steve Weiss, MPCA).

Measure Points of Contact

Agency Information

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Implementation of Nitrogen Fertilizer Management BMPs

Measure Background

Visual Depiction

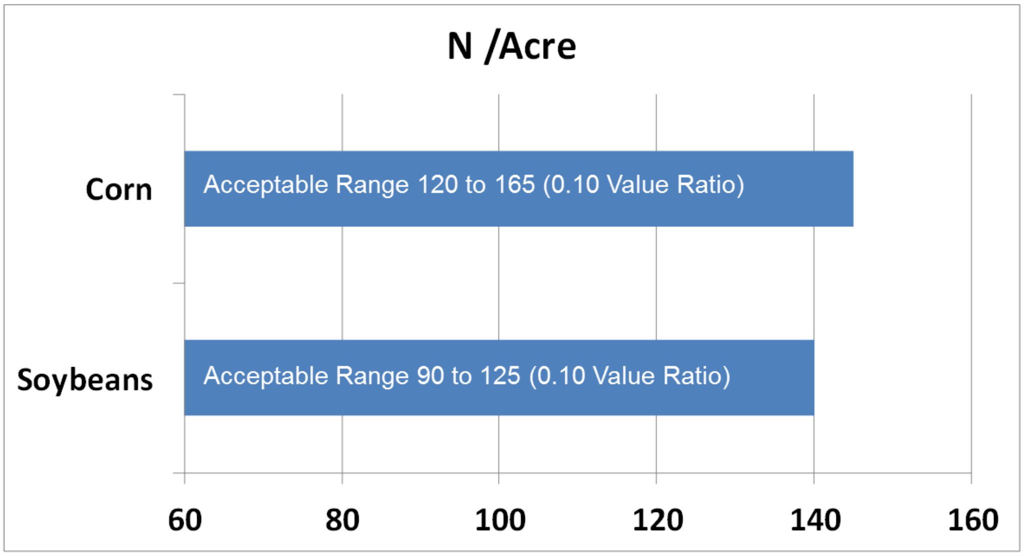

Figure 1. Nitrogen fertilizer application rates on non-manured corn following different crops in 2009 by surveyed farmers reporting on an average field

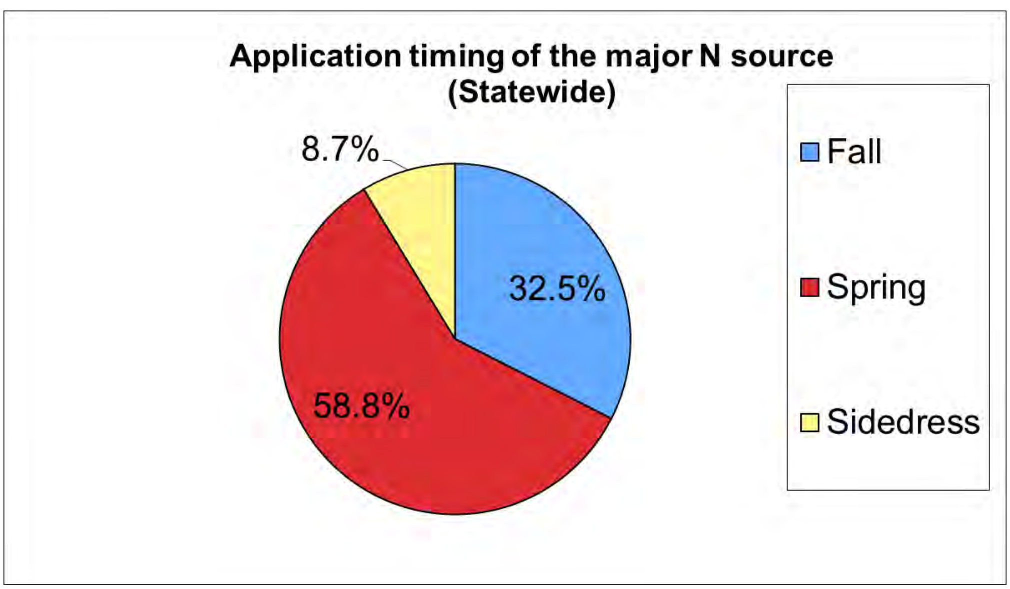

Figure 2. Statewide 2009 nitrogen fertilizer application timing on corn

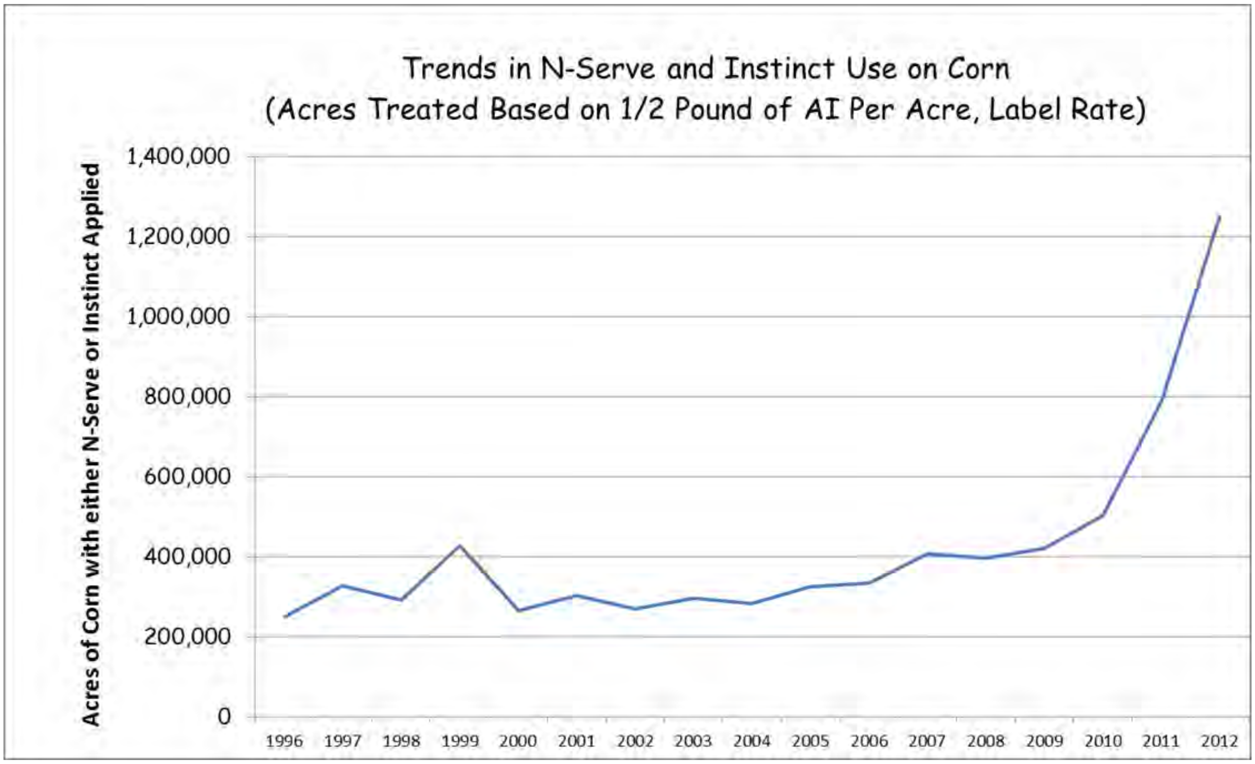

Figure 3. Statewide trends in nitrogen inhibitor use on corn

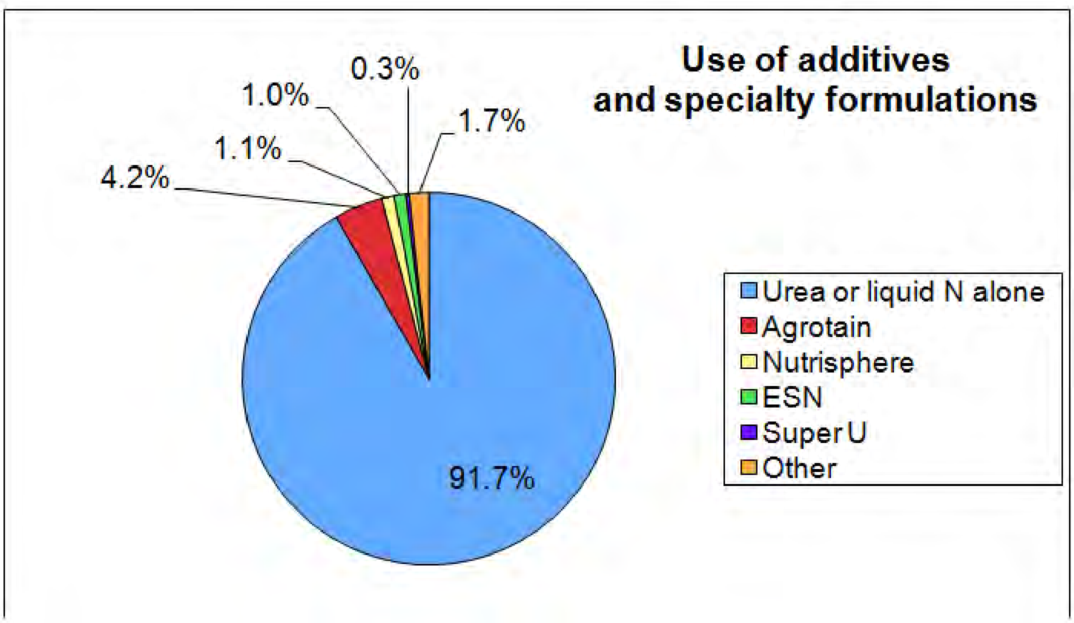

Figure 4. Use of additive and specialty formulations of urea and liquid nitrogen fertilizers applied to corn in 2009 by surveyed farmers reporting on average farm fields.

Measure Description

This measure is intended to communicate voluntary nitrogen fertilizer best management practices (BMPs) promoted through the Minnesota Department of Agriculture's (MDA) Nitrogen Fertilizer Management Plan (NFMP). The key voluntary nitrogen fertilizer BMPs are nitrogen fertilizer application rates on corn, nitrogen fertilizer application timing on corn, nitrogen inhibitor use on corn, and use of additive and specialty formulations of urea and liquid nitrogen fertilizers applied to corn.

Nitrogen Fertilizer Application Rates. Figure 1 shows the nitrogen fertilizer application rates on non-manured corn following different crops in 2009 by surveyed farmers reporting on average farm fields. According to Figure 1, nitrogen fertilizer application rates on corn following corn in 2009 fall within the acceptable nitrogen application rate range of 120-165 pounds (lbs)/acre of nitrogen. For corn following soybean, the nitrogen application rates exceed the acceptable range of 95-120 lbs/acre of nitrogen.

Nitrogen Fertilizer Application Timing. Figure 2 shows the nitrogen fertilizer application timing on corn in 2009 by surveyed farmers reporting on average farm fields, with 58.8 percent of surveyed farmers applying nitrogen fertilizer during the spring and 8.7 percent of surveyed farmers applying as a sidedress; both of these practices are better than fall applications.

Nitrogen Inhibitor Use. Figure 3 shows the statewide trends in nitrogen inhibitor use on corn from 1996-2012, with a steady increase in use over time.

Use of Additive and Specialty Formulations. Figure 4 shows the use of additive and specialty formulations of urea and liquid nitrogen fertilizers applied to corn in 2009 by surveyed farmers reporting on average farm fields, indicating that 91.7 percent of surveyed farmers use urea or liquid nitrogen fertilizer alone.

Table 1 below shows the estimated percent nitrogen and phosphorus removal associated with the nitrogen fertilizer BMPs presented in this measure. These efficiencies were derived from a comprehensive literature review.

Table 1. Estimated nutrient removal efficiencies for key nitrogen fertilizer BMPs

Best Management Practice	Nitrogen Removal (%)	Phosphorus Removal (%)
	Average[a]	Average[b]
Fertilizer Application Rates [From existing rates down to rates providing the maximum return to nitrogen value (133 lb/acre corn-soybean and 190 lb/acre on corn-corn)]	10	17
Fertilizer Application Timing		
From fall to spring pre-plant	6	NA
From fall to spring pre-plant/sidedress 40-60 split	5	NA
From pre-plant application to sidedress	7	NA
From pre-plant to sidedress – soil test based	4	NA
Nitrogen Inhibitor Use (From fall applied without inhibitor to fall applied with Nitrapyrin)	9	NA
Use of Additive and Specialty Formulations	Unknown	NA

a. MPCA, 2013
b. Iowa State University, 2013

Associated Terms and Phrases

To better understand this measure, it is necessary to understand a few program specific terms and phrases.

Nitrogen Fertilizer Application Timing: By moving application timing closer to the actual use of the crop reduces the potential for nitrogen fertilizer loss. Spring application is better than fall, and side-dress is better than spring.

Nitrogen Fertilizer Rate: University of Minnesota recommended fertilizer rates strive to maximize nitrogen use efficiency. They are also based to utilize carry-over nitrogen from previous crops (soybeans, alfalfa) and manure.

Nitrogen Fertilizer Variable Rate: Precision agriculture, through the use of GPS technology, can adjust nitrogen fertilizer application rates according to soil type within a field or crop condition in order to increase nitrogen use efficiency.

Inhibitors: Nitrification inhibitor delay the conversion of ammonia, an immobile form of nitrogen, to nitrate, which can move freely with soil water, or be lost to the atmosphere.

Nitrogen Fertilizer Formulations: Some urea nitrogen fertilizers are formulated to release nitrogen slowly so it is available closer to when the crop needs it.

Sidedress: Fertilizer application technique where fertilizer is applied beside the row after plant emergence; a better nitrogen fertilizer application practice than spring or fall application

Target

There is no specific numeric target for this measure to date.

Baseline

1996-2012 (nitrogen inhibitor only); statewide data reported during 2010 survey to reflect 2009 growing season

Geographical Coverage

Statewide

Data and Methodology

Methodology for Measure Calculation

These measures are based on information from the *2010 Survey of Nitrogen Fertilizer Use on Corn in Minnesota*.

Data Source

Minnesota Department of Agriculture

Data Collection Period

2010 for 2009 growing season (Figures 1, 2, 4)

1996-2012 (Figure 3)

Data Collection Methodology and Frequency

The MDA has partnered with the USDA National Agricultural Statistic Service (NASS) and University of Minnesota researchers to collect information about fertilizer use and farm management at the statewide level. Partners have pioneered a survey tool for characterizing fertilizer use and associated management on a regional and statewide scale. Surveys are conducted over the phone. The statewide fertilizer use survey will alternate every other year. Much of the focus will be on corn production, where 70 percent of the commercial inputs are used. The first attempt using this technique was in 2010. NASS enumerators surveyed approximately 1,500 corn farmers from across the state to gather information about commercial fertilizer use.

Project personnel collaborated with the Minnesota Department of Agriculture (MDA) to develop survey questions and MDA worked with the USDA National Agricultural Statistics Service (NASS), Minnesota Field Office to conduct the survey.

Farmers in the survey were from a database of the Minnesota Field Office of NASS. An initial pool of 7,000 farmers was randomly selected by NASS from their database of about 31,000 Minnesota farmers who have recently grown corn. The survey was carried out through phone interviews conducted at the North Dakota Field Office of NASS in Fargo. Interview staff were the same experienced interviewers that are routinely used to perform the regular surveys conducted by NASS. The survey consisted of 42 questions and it took about one-half hour to complete the interview with farmers who were able to finish the entire survey. Interviews and follow-up calls necessary to clarify some of the responses were conducted between February and June of 2010.

Interviewers were able to contact 4,461 of the initial pool of 7,000 farmers. Those not contacted were called more than once, but failed to answer the phone. Of the farmers contacted, 3,358 grew corn in 2009. The 2,769 farmers who continued the interview grew corn on 656,312 acres in 2009. Manure had been applied to 32% of these acres in the previous five years. The focus of the survey was use of manufactured N fertilizers, so to avoid the complicating effects of previous manure application on N fertilizer rates the farmers were asked to report on an average field with no manure applied in the last five years. The 866 farmers who did not have a field where no manure had been applied in the last five years were eliminated. Also eliminated were 407 of the remaining farmers who did not have a field where they knew the total amount of N applied per acre. This left 1,496 farmers, who grew corn on 482,812 acres in 2009. The survey results reported below are from this subsample of Minnesota corn farmers.

Supporting Data Set

Table 1. Nitrogen fertilizer rates on corn following different crops in 2009 by surveyed farmers reporting on an average field (Bierman et al. 2011).

Crop	N rate (lbs/acre)
Corn	145
Soybean	140

Caveats and Limitations

- The survey was restricted to nitrogen management on corn because corn is the most widely grown crop in Minnesota that requires nitrogen application and the majority of the nitrogen fertilizer applied in the state is used in corn production.
- Responses of individual farmers in this survey represent their “average” or “typical” nitrogen management practices. In some cases farmers may have strayed from the “average field”

restriction, especially as the interview progressed, and some of their answers may have reflected the entire range of the nitrogen management options they employed.

- The average size of the corn fields reported on by farmers in this survey was 81 acres.
- Information reported in the survey report broke Minnesota into BMP regions by groups of counties. Although the final survey report did report number of fields by county, it did not provide acreage associated with the number of fields captured in the survey. Therefore, it is difficult to analyze survey results at the 8-digit HUC scale.
- MDA does not track nitrogen load reductions associated with implementation of nitrogen BMPs.

Future Improvements

According to MDA, the next statewide nutrient fertilizer survey will include not only number of fields by county, but also the associated acreage. This will allow nitrogen fertilizer survey results to be further analyzed at the 8-digit HUC scale and included in an updated Strategy analysis.

Financial Considerations

Contributing Agencies and Funding Sources

This survey was supported by the MDA using dollars provided by the Clean Water Fund (from the Clean Water, Land and Legacy Amendment).

References

Iowa State University. 2013. *Iowa Science Assessment of Nonpoint Source Practices to Reduce Nitrogen and Phosphorus Transport in the Mississippi River Basin*. May 2013. Section 2 of the Iowa Nutrient Reduction Strategy developed by Iowa Department of Agriculture and Land Stewardship, Iowa Department of Natural Resources, and Iowa State University College of Agriculture and Life Sciences.

MPCA. 2013. D1 Nitrogen Sources to Land and Waters - Results Overview. DRAFT 2013 (Dave Wall, David J. Mulla, and Steve Weiss, MPCA).

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Implementation of Priority CRP Conservation Practices and Estimated Nutrient Load Reductions

Measure Background

Visual Depiction

The bar graphs below show the acreage and number of occurrences for two conservation practices funded through the Conservation Reserve Program (CRP) in Minnesota administered by the U.S. Department of Agriculture (USDA) Farm Service Agency (FSA). The two highlighted management practices (filter strips and riparian buffers) are considered priority water quality practices.

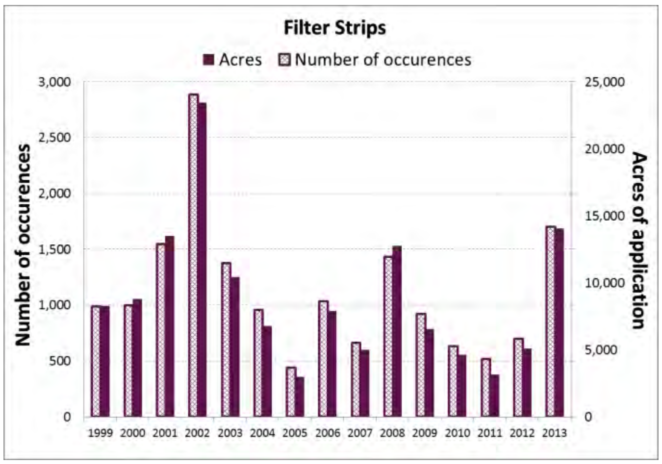

Figure 2. Number of occurrences and acres of application for filter strips funded by CRP from 1999-2013

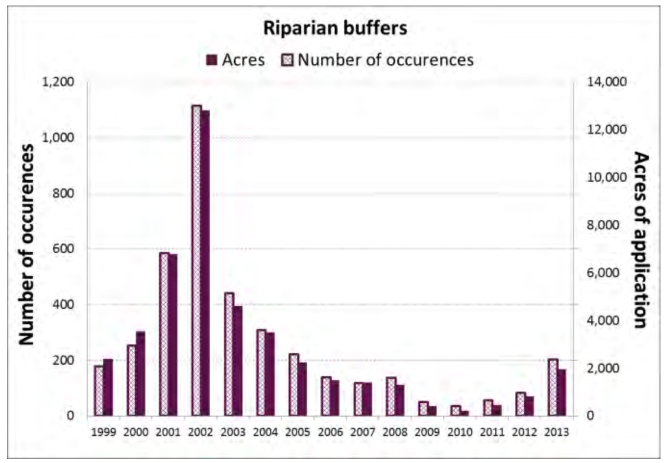

Figure 1. Number of occurrences and acres of application for riparian forested buffers funding by CRP from 1999-2013

Measure Description

This measure focuses on implementation trends for two key conservation practices funded by through CRP administered by FSA, as well as the estimated associated reduction in nutrients through implementation. It is an indirect or surrogate measure for the overall CRP program in Minnesota, focusing on conservation practices identified by FSA as key to reducing nutrient contributions from agricultural land eligible to receive funding through CRP.

Figure 1 shows the number and acreage of filter strips implemented through CRP in Minnesota from 1999-20013. As shown in Figure 1, the number and acreage associated with filter strips from 1999-2013 peaked in 2002, with a decline until 2006. In 2007, the number and acreage declined again, but rose in 2008. The number and acreage of filter strips declined during 2009-2011, with small gains made in 2012. During 2013, the number and acreage of filter strips exceeded 2008 levels, but have not achieved the 2002 peak year quantities.

Figure 2 shows the number and acreage of riparian forested buffers implemented through CRP in Minnesota. According to Figure 2, the number and acreage of riparian forested buffers peaked in 2002 and steadily declined until a slight uptick in 2008, with further decline in 2009 and 2010. The number and acreage of riparian forested buffers funded through CRP increased slightly in 2011 and 2012, with a return to 2005 levels in 2013.

Table 1 below shows the estimated percent nitrogen and phosphorus removal associated with these practices.

Table 1. Estimated nutrient removal efficiencies for two key CRP practices

Best Management Practice	Phosphorus Removal (%)	Nitrogen Removal (%)
Filter Strips[1]	65	27
Riparian Buffers[2]	95	58

[1] Miller et al., 2012
[2] MPCA 2013; Iowa State, 2013

Associated Terms and Phrases

To better understand this measure, it is necessary to understand a few specific terms and phrases. Definitions used in this measure are as follows:

Conservation Reserve Program (CRP): a land conservation program administered by the Farm Service Agency (FSA). In exchange for a yearly rental payment, farmers enrolled in the program agree to remove environmentally sensitive land from agricultural production and plant species that will improve environmental health and quality. Contracts for land enrolled in CRP are 10-15 years in length. The long-term goal of the program is to re-establish valuable land cover to help improve water quality, prevent soil erosion, and reduce loss of wildlife habitat.

Filter strips: an area of permanent herbaceous vegetation used to reduce sediment, organics, nutrients, pesticides, and other contaminant loadings in runoff. Filter strips provide a buffer between fields and water bodies and allow for settling out of suspended soil particles, infiltration of runoff and soluble pollutants, adsorption of pollutants on soil and plant surfaces, and uptake of soluble pollutants by plants. Conservation Practice 21/Minn. NRCS Conservation Practice Standard (393). More information on the design standards is available at http://efotg.sc.egov.usda.gov/references/public/MN/393mn.pdf

Riparian buffers: an area of trees and shrubs located adjacent to streams, lakes, ponds, or wetlands. Riparian forest buffers of sufficient width intercept sediment, nutrients, pesticides, and other materials in surface runoff and reduce nutrients and other pollutants in shallow subsurface water flow. Buffers are located along or around permanent or intermittent streams, lakes, ponds, wetlands, or seeps. Conservation Practice 22/Minn. NRCS Conservation Practice Standard (391). More information on the design standards is available at http://efotg.sc.egov.usda.gov/references/public/MN/391mn.pdf

Target

There is no specific numeric target for this measure to date.

Baseline

Covers 1999-2013 (through May)

Geographical Coverage

Statewide

Data and Methodology

Methodology for Measure Calculation

FSA tracks specific information related to CRP implementation and sign-ups over time. A variety of CRP reports are made available on the FSA CRP website https://arcticocean.sc.egov.usda.gov/CRPReport/monthly_report.do?method=selectMonthlyReport&report=May-2013

To calculate this measure, information on annual practice acres and practice occurrences for CP-21 and CP-22 were extracted from FSA's CRP report entitled SUMMARY OF ACTIVE CONTRACTS BY PROGRAM YEAR BY STATE CRP - MONTHLY CONTRACTS REPORT for Minnesota . This information was placed into an Excel spreadsheet to generate the bar graphs shown in Figures 1 and 2.

Data Source

USDA-FSA Minnesota State Office

Data Collection Period

1999 through 2013

Data Collection Methodology and Frequency

FSA is in the process of transferring to a new data management system for CRP information. Information from October 2012 to present is contained in the new data management system. Information prior to October 2012 remains in the old system. Eventually, all data will be housed in the new data management system.

Supporting Data Set

Table 2 provided below contains practice acreage and number of occurrences for filter strips (CP-21) and riparian buffers (CP-22) from 1999-2013 as available in FSA's CRP report entitled SUMMARY OF ACTIVE CONTRACTS BY PROGRAM YEAR BY STATE CRP - MONTHLY CONTRACTS REPORT for Minnesota.

Table 2. Practice acreage and number of occurrences for filter strips (CP-21) and riparian buffers (CP-22) funded by FSA through the CRP program by year

Year	Practice	Acres	Number of Occurrences
1999	Filter strips	8,275.10	991
2000	Filter strips	8,775.50	998
2001	Filter strips	13,500.20	1547
2002	Filter strips	23,433.90	2884
2003	Filter strips	10,442.40	1374
2004	Filter strips	6,756.10	958
2005	Filter strips	2,996.50	442
2006	Filter strips	7,869.60	1034
2007	Filter strips	4,990.30	665
2008	Filter strips	12,740.10	1435
2009	Filter strips	6,535.70	920
2010	Filter strips	4,609.20	634
2011	Filter strips	3,166.00	518
2012	Filter strips	5,105.60	698
2013	Filter strips	14,071.10	1700
1999	Riparian buffers	2,394.60	178
2000	Riparian buffers	3,545.50	253
2001	Riparian buffers	6,789.10	586
2002	Riparian buffers	12,811.50	1116
2003	Riparian buffers	4,600.70	442
2004	Riparian buffers	3,510.20	308
2005	Riparian buffers	2,246.10	221
2006	Riparian buffers	1,492.00	140
2007	Riparian buffers	1,391.70	118
2008	Riparian buffers	1,295.80	137
2009	Riparian buffers	418.7	51
2010	Riparian buffers	207.6	35
2011	Riparian buffers	470.4	57
2012	Riparian buffers	814.9	84
2013	Riparian buffers	1,968.20	204

Caveats and Limitations

- This measure only tracks two priority management practices funded by FSA through CRP conservation payments.
- Implementation of these management practices are largely determined by the amount of funding available annually through Minnesota's CRP program.
- FSA does not track nutrient load reductions associated with management activities implemented under CRP.
- Land enrolled in other conservation programs is eligible under CRP provided CRP does not pay for the same practice on the same land as any other USDA program. As a result, acreage captured under this measure might also be captured under other program indicators.
- The use of two data management systems creates challenges for easily reporting practice information by county. Current county-specific CRP reports provided by FSA do not specify individual practice acreages and occurrences. Lack of county-specific information for each practice over time does not allow the acreage information to be incorporated into the Strategy's 8-digit HUC analysis of implementation.

Future Improvements

Improvements to this measure will be made over time. Ideally this measure will be able to report on implementation of the two key practices by 8-digit HUC, as well as compare estimated nutrient load reductions. It would be helpful for FSA to incorporate a mechanism for estimated nutrient load reductions associated with CRP practices as part of programmatic tracking, possibly through CRP reporting requirements. However, this would require a national change in approach because CRP is a federal program.

Financial Considerations

Contributing Agencies and Funding Sources

This measure only tracks the two priority management practices identified by FSA funded using CRP to make conservation payments. Payment rates for each management practice vary annually.

References

Iowa State University. 2013. *Iowa Science Assessment of Nonpoint Source Practices to Reduce Nitrogen and Phosphorus Transport in the Mississippi River Basin*. May 2013. Section 2 of the Iowa Nutrient Reduction Strategy developed by Iowa Department of Agriculture and Land Stewardship, Iowa Department of Natural Resources, and Iowa State University College of Agriculture and Life Sciences.

Miller, T.P., J.R. Peterson, C.F. Lenhart, and Y. Nomura. 2012. The Agricultural BMP Handbook for Minnesota. Minnesota Department of Agriculture. Accessed June 2013. http://www.eorinc.com/documents/AG-BMPHandbookforMN_09_2012.pdf

MPCA. 2013. D1 Nitrogen Sources to Land and Waters - Results Overview. DRAFT 2013 (Dave Wall, David J. Mulla, and Steve Weiss, MPCA).

Waidler, D., M. White, E. Steglich, S. Wang, J. Williams, C.A. Jones, and R. Srinivasan. 2009. Conservation Practice Modeling Guide for SWAT and APEX. USDA Agricultural Research Service, Blackland, TX.

Measure Points of Contact

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Implementation of Priority EQIP Management Practices and Estimated Nutrient Load Reductions

Measure Background

Visual Depiction

The maps and charts below provide a representative summary of the extent of implementation of key management practices through the Environmental Quality Incentives Program (EQIP) administered by the U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS). The three management practices (nutrient management, residue management, and forage and biomass (pasture/hayland) planting) are considered priority practices for nutrient reductions in Minnesota by NRCS. The maps show the percentage of eligible agricultural acreage in each county (by major basin) enrolled in the three management practices. The bar graphs show the annual number of EQIP contracts for each practice and the associated acreage.

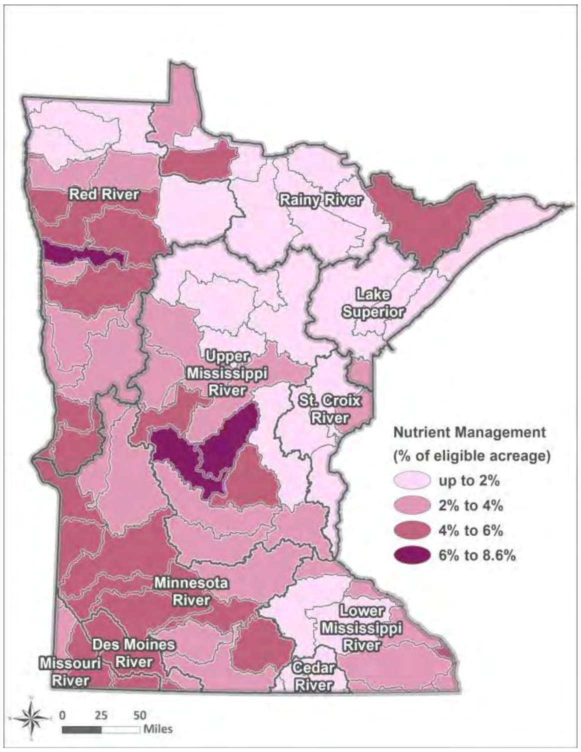

Figure 1. Percent of eligible acreage implementing nutrient management through EQIP by 8-digit HUC

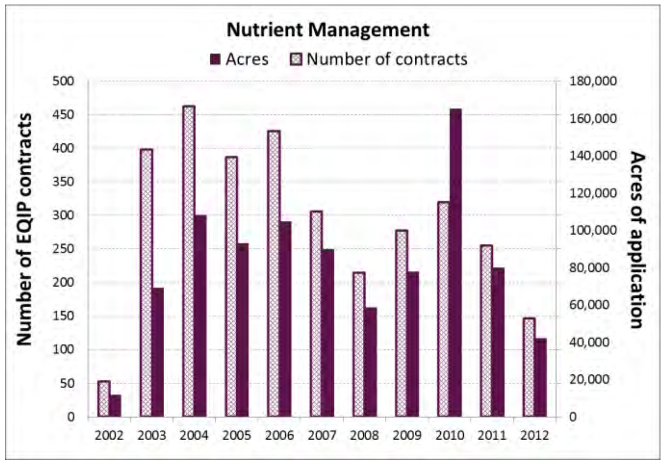

Figure 2. Annual trends in nutrient management implementation through EQIP by acres of application and number of EQIP contracts

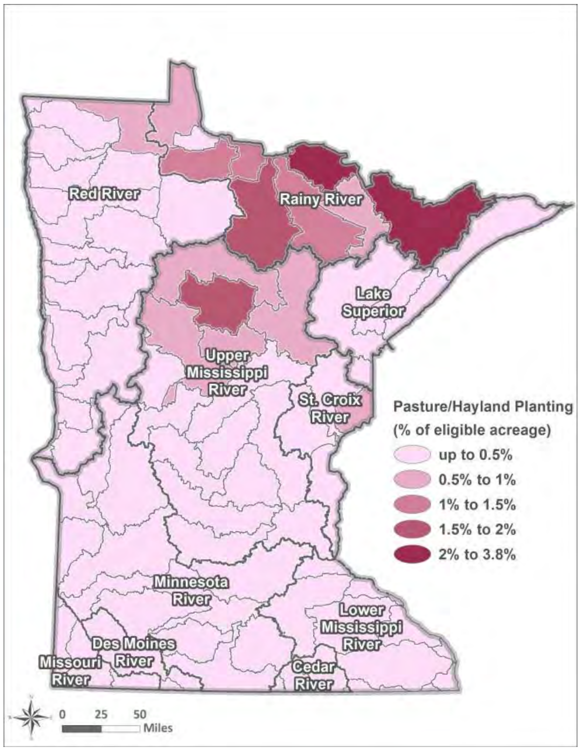

Figure 4. Percent of eligible acreage implementing forage and biomass (pasture/hayland) planting through EQIP by 8-digit HUC

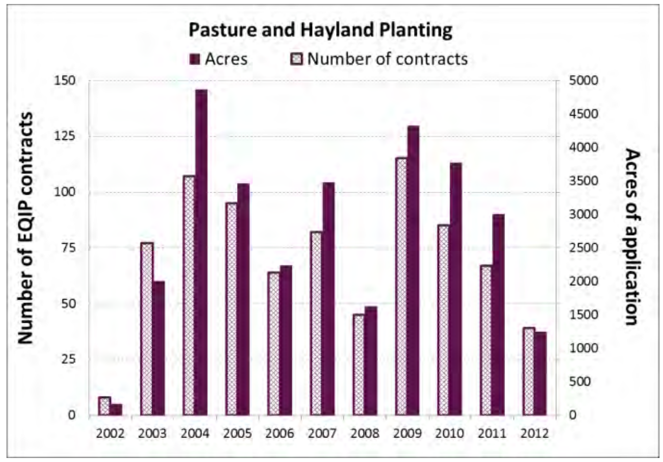

Figure 5. Annual trends in forage and biomass (pasture/hayland) planting implementation through EQIP by acres of application and number of EQIP contracts

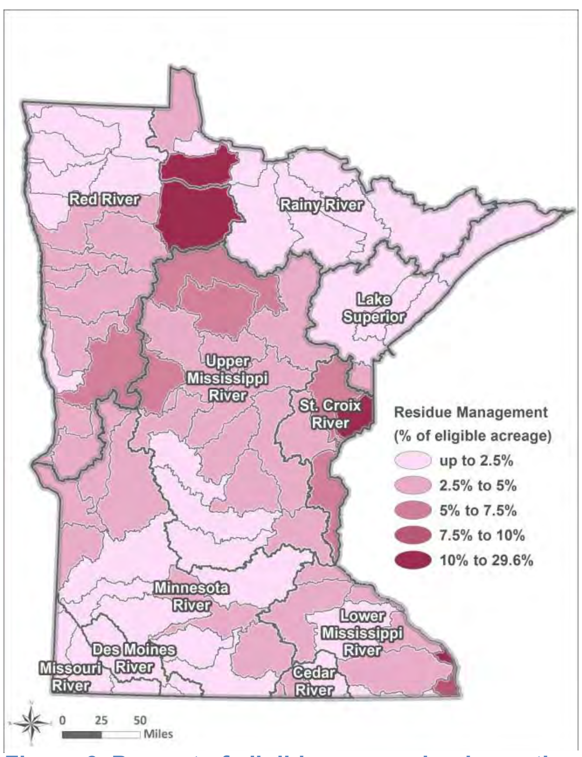

Figure 6. Percent of eligible acreage implementing residue management through EQIP by 8-digit HUC

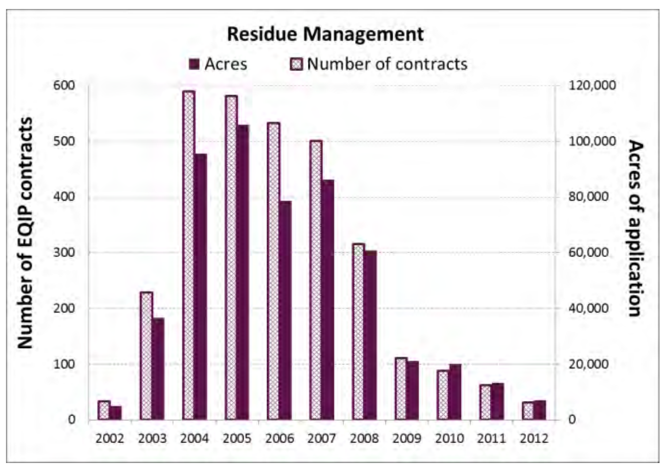

Figure 3. Annual trends in residue management implementation through EQIP by acres of application and number of EQIP contracts

Measure Description

This measure focuses on the extent of implementation of three priority management practices within Minnesota's 8 digit HUCs funded by NRCS under EQIP, the annual enrollment trends for these management practices, and the estimated associated reduction in nutrients through implementation. It is an indirect or surrogate measure for the overall EQIP program in Minnesota, focusing on management practices identified by NRCS as key to reducing nutrient contributions from agricultural land eligible to receive funding through EQIP. The analysis of the measures for each priority management practice is provided below.

Nutrient Management. Figure 1 shows the percentage of eligible agricultural acreage on which nutrient management funded through EQIP is being implemented by 8-digit HUC. According to this figure, only three 8-digit HUCs have between 6-8 percent of eligible agricultural acreage with nutrient management implementation through EQIP. The 8-digit HUCs in the southwest portion of the state have between 2-6 percent of eligible agricultural acreage under nutrient management via EQIP. Figure 2 shows the annual acreage enrolled in EQIP for nutrient management has vacillated since 2000, with a spike in enrolled acreage in 2010. Since that spike, acreage has declined.

Forage and Biomass (Pasture/Hayland) Planting. Figure 4 shows the percentage of eligible agricultural acreage on which forage and biomass planting funded through EQIP is being implemented by 8-digit HUC. According to this figure, forage and biomass planting is occurring in northern 8-digit HUCs, with up to 0.5 percent occurring in a majority of the state. Figure 5 shows a spike in enrolled acreage for this practice in 2004, with a decline until 2007, a significant drop off in acreage in 2008, and despite an increase in 2009, a steady decline through 2012.

Residue Management. Figure 6 shows the percentage of eligible agricultural acreage on which residue management funded through EQIP is being implemented by 8-digit HUC. According to this figure, three 8-digit HUCs have 10-29.6 percent of eligible acreage enrolled in contracts for residue management under EQIP. A majority of 8-digit HUCs in the state have between 5-7.9 percent of eligible agricultural land enrolled in contracts under EQIP for residue management. According to Figure 3, the amount of acreage enrolled in residue management spiked in 2005, declined in 2006, and spiked again in 2007. From 2007, the total acreage enrolled in this management practice under EQIP contracts steadily declined.

Table 1 shows the estimated percent nitrogen and phosphorus removal associated with these practices. These efficiencies were derived from a comprehensive literature review.

Table 1. Estimated nutrient removal efficiencies for three key EQIP practices

Best Management Practice	Subcategory (if applicable)	Nitrogen Removal (%)	Phosphorus Removal (%)
Residue Management[a]	Cover Crops	51	29
	Conservation Tillage	0	63
Nutrient Management[b]		16	24
Forage and Biomass Planting[b]		95	59

a. Miller et al 2012; MPCA Nitrogen Study, 2013; Iowa Nutrient Reduction Strategy, 2013; Simpson and Weammert, 2009
b. MPCA Nitrogen Study, 2013; Iowa Nutrient Reduction Strategy, 2013

Associated Terms and Phrases

To better understand this measure, it is necessary to understand a few specific terms and phrases. Definitions used in this measure are as follows:

Eligible agricultural land: Pasture/hay and cultivated crops on one of the three practices that could be implemented under EQIP contracts

Residue management: According to the NRCS Conservation Practice Standard, this management activity (Codes 329, 329A, 329B, 329C, 345, 346) is defined as managing the amount, orientation, and distribution of crop and other plant residue on the soil surface year-round, while limiting the soil disturbing activities used to grow crops in systems where the entire field surface is tilled prior to planting. This practice is intended to reduce sheet and rill erosion; wind erosion; soil particulate emissions; and maintain or improve soil condition. It applies to all cropland. More information on the practices that fall under this category from the Minnesota NRCS Field Office Technical Guide (FOTG) is available at http://efotg.sc.egov.usda.gov/treemenuFS.aspx

Nutrient management: According to the NRCS Conservation Practice Standard, this management activity (Code 590) is defined as managing the amount, source, placement, form, and timing of the application of nutrients and soil amendments. The criteria for this practice are intended to minimize nutrient entry into surface water, groundwater, and atmospheric resources while maintaining and improving the physical, chemical, and biological condition of the soil. The standard for this conservation practice applies to all fields where plant nutrient sources and soil amendments are applied during the course of a rotation. More information on this conservation practice from the Minnesota NRCS FOTG is available at http://efotg.sc.egov.usda.gov/references/public/MN/590mn.pdf

Forage and biomass (pasture/hayland) planting: According to the NRCS Conservation Practice Standard, this management activity (Codes 512) is defined as establishing adapted and/or compatible species, varieties, or cultivars of herbaceous species suitable for pasture, hay, or biomass production. This practice is intended to reduce soil erosion and improve soil and water quality. This practice applies to all lands suitable to the establishment of annual, biennial or perennial species for forage or biomass production. This practice does not apply to the establishment of annually planted and harvested food, fiber, or oilseed crops. More information on this conservation practice from the Minnesota NRCS FOTG is available at http://efotg.sc.egov.usda.gov/references/public/MN/512mn.pdf

Target

There is no specific numeric target for this measure to date.

Baseline

Covers 2000-2012 EQIP data

Geographical Coverage

Statewide, by major basin, by 8-digit HUC

Data and Methodology

Methodology for Measure Calculation

NRCS tracks specific information related to EQIP implementation and participation over time. Information tracked includes type of management practice, county, acreage treated, enrollment date, and contract length, in addition to associated financial information such as payment rate and payment schedules.

To calculate this measure, NRCS compiled information on the acreage treated under residue management, nutrient management, and forage and biomass (pasture/hayland) planting practices by county. The county information was then mapped according to 8-digit HUC. This information was then compared to the total acreage in each 8-digit HUC that is potentially eligible for these management practices under EQIP. Potentially eligible acreage for each 8-digit HUC was derived using NLCD land use/land cover data, focusing on coverages for pasture/hay and cultivated crops. This information was then mapped using GIS to show implementation of each management practice as a percentage of the total eligible acreage within each 8-digit HUC by major basin. Table 1 under Supporting Data Set presents the breakdown of treated acreage for each management practice by 8-digit HUC, as well as total eligible acreage, used to derive the maps for this measure. Table 2 presents the annual number of contracts and acreage for each management practice.

Data Source

- Minnesota USDA-NRCS State Agronomist
- NLCD for agricultural land use/land cover

Data Collection Period

2000 through 2012.

Data Collection Methodology and Frequency

The data presented in the measure is reported by NRCS field offices once the BMP implementation has been certified. Data are obtained directly from NRCS as provided in http://prohome.nrcs.usda.gov.

Each county field office is responsible to verify and certify that each practice has been completed to NRCS standards and specifications. Once certified the practice is entered into our payment software and producer is paid for the practice. Practice is considered planned and certified and becomes available for querying of data.

Supporting Data Set

Table 2 contains treated acreage by county tracked by NRCS for the three priority management practices, as well as the potential eligible agricultural acreage derived through the NLCD dataset. Table 3 presents the data on an annual basis.

Table 2. Acreage treated by three priority management practices funded through EQIP (2000-2012) and total eligible agricultural lands by 8-digit HUC used to derive percent implementation

HUC8	NLCD 2006 Pasture/ Hay (acres)	NLCD 2006 Cultivated Crops (acres)	Total NLCD Agriculture	EQIP Nutrient Management (acres)	EQIP Forage and Biomass Plantings (acres)	EQIP Residue Management (acres)	Percent Nutrient Management	Percent Pasture/Hay	Percent Residue Management
04010101	251	346	597	0	0	0	0.00%	0.00%	0.00%
04010102	8,088	656	8,744	7	5	0	0.08%	0.05%	0.00%
04010201	64,220	5,999	70,219	401	124	36	0.57%	0.18%	0.60%
04010202	4,546	493	5,038	21	14	0	0.42%	0.27%	0.00%
04010301	17,309	1,799	19,109	466	69	77	2.44%	0.36%	4.28%
04020300	6	2	9	0	0	0	0.02%	0.01%	0.00%
07010101	71,996	13,773	85,769	570	610	882	0.66%	0.71%	6.40%
07010102	29,768	4,334	34,102	571	608	319	1.67%	1.78%	7.36%
07010103	54,101	11,026	65,127	240	467	403	0.37%	0.72%	3.66%
07010104	161,571	108,288	269,859	9,077	531	5,042	3.36%	0.20%	4.66%
07010105	20,738	7,696	28,434	97	231	205	0.34%	0.81%	2.66%
07010106	143,492	126,483	269,975	6,003	1,355	3,453	2.22%	0.50%	2.73%
07010107	116,519	145,759	262,278	8,523	631	7,977	3.25%	0.24%	5.47%
07010108	118,441	150,375	268,816	12,571	485	5,553	4.68%	0.18%	3.69%
07010201	207,373	190,071	397,444	29,638	278	9,346	7.46%	0.07%	4.92%
07010202	161,108	333,713	494,821	42,492	303	7,301	8.59%	0.06%	2.19%
07010203	126,728	280,122	406,850	18,585	215	7,486	4.57%	0.05%	2.67%
07010204	134,538	525,184	659,722	25,173	336	11,687	3.82%	0.05%	2.23%
07010205	78,360	592,556	670,917	26,264	293	9,934	3.91%	0.04%	1.68%
07010206	65,082	52,434	117,517	2,590	45	2,567	2.20%	0.04%	4.90%
07010207	164,848	183,675	348,524	6,680	515	7,766	1.92%	0.15%	4.23%
07020001	30,780	328,027	358,807	19,036	82	10,610	5.31%	0.02%	3.23%
07020002	36,536	352,347	388,883	8,170	217	11,204	2.10%	0.06%	3.18%

HUC8	NLCD 2006 Pasture/ Hay (acres)	NLCD 2006 Cultivated Crops (acres)	Total NLCD Agriculture	EQIP Nutrient Management (acres)	EQIP Forage and Biomass Plantings (acres)	EQIP Residue Management (acres)	Percent Nutrient Management	Percent Pasture/Hay	Percent Residue Management
07020003	34,307	365,658	399,965	18,606	81	9,591	4.65%	0.02%	2.62%
07020004	47,850	1,066,063	1,113,913	56,735	326	23,661	5.09%	0.03%	2.22%
07020005	104,517	913,106	1,017,623	24,885	577	25,820	2.45%	0.06%	2.83%
07020006	13,924	351,114	365,038	19,655	205	5,125	5.38%	0.06%	1.46%
07020007	22,222	656,913	679,134	27,273	206	18,347	4.02%	0.03%	2.79%
07020008	14,443	713,427	727,870	31,898	268	15,957	4.38%	0.04%	2.24%
07020009	5,966	643,771	649,737	13,622	233	8,026	2.10%	0.04%	1.25%
07020010	2,965	484,237	487,203	18,052	50	10,966	3.71%	0.01%	2.26%
07020011	9,881	586,803	596,684	24,218	172	18,308	4.06%	0.03%	3.12%
07020012	122,496	671,582	794,078	31,205	237	14,781	3.93%	0.03%	2.20%
07030001	23,976	7,517	31,494	1,103	274	804	3.50%	0.87%	10.69%
07030003	86,858	14,955	101,813	1,745	394	896	1.71%	0.39%	5.99%
07030004	124,826	54,365	179,192	1,704	326	1,402	0.95%	0.18%	2.58%
07030005	130,037	137,247	267,284	939	485	10,031	0.35%	0.18%	7.31%
07040001	43,927	156,210	200,137	5,492	244	5,360	2.74%	0.12%	3.43%
07040002	90,883	568,985	659,868	13,193	423	22,405	2.00%	0.06%	3.94%
07040003	70,721	123,252	193,973	6,209	298	4,503	3.20%	0.15%	3.65%
07040004	104,136	507,351	611,488	10,985	476	11,866	1.80%	0.08%	2.34%
07040006	14,186	2,201	16,387	965	41	652	5.89%	0.25%	29.62%
07040008	216,226	436,022	652,248	22,685	443	13,284	3.48%	0.07%	3.05%
07060001	27,875	20,885	48,760	1,312	91	1,835	2.69%	0.19%	8.79%
07060002	17,517	88,797	106,315	3,106	41	1,765	2.92%	0.04%	1.99%
07080102	75	7,009	7,083	176	0	110	2.49%	0.00%	1.57%
07080201	6,950	367,602	374,552	7,382	50	7,787	1.97%	0.01%	2.12%
07080202	2,964	107,888	110,852	509	40	3,491	0.46%	0.04%	3.24%

HUC8	NLCD 2006 Pasture/ Hay (acres)	NLCD 2006 Cultivated Crops (acres)	Total NLCD Agriculture	EQIP Nutrient Management (acres)	EQIP Forage and Biomass Plantings (acres)	EQIP Residue Management (acres)	Percent Nutrient Management	Percent Pasture/Hay	Percent Residue Management
07080203	957	35,630	36,587	146	11	973	0.40%	0.03%	2.73%
07100001	11,857	647,304	659,161	37,601	157	9,841	5.70%	0.02%	1.52%
07100002	144	46,181	46,324	1,978	22	561	4.27%	0.05%	1.21%
07100003	306	109,092	109,399	3,024	49	901	2.76%	0.04%	0.83%
09020101	5,220	304,792	310,013	13,146	36	7,943	4.24%	0.01%	2.61%
09020102	7,817	465,522	473,339	19,543	118	13,069	4.13%	0.02%	2.81%
09020103	173,649	330,788	504,437	19,772	919	20,858	3.92%	0.18%	6.31%
09020104	5,641	268,935	274,576	8,291	20	5,652	3.02%	0.01%	2.10%
09020106	49,221	476,923	526,144	12,361	301	12,137	2.35%	0.06%	2.54%
09020107	3,133	199,060	202,193	7,337	48	6,084	3.63%	0.02%	3.06%
09020108	68,341	555,010	623,351	35,055	854	15,791	5.62%	0.14%	2.85%
09020301	16,610	293,147	309,756	19,266	321	9,311	6.22%	0.10%	3.18%
09020302	70,785	10,170	80,956	75	221	1,239	0.09%	0.27%	12.18%
09020303	46,450	507,434	553,884	29,146	1,572	14,536	5.26%	0.28%	2.86%
09020304	47,405	241,516	288,921	8,839	708	4,153	3.06%	0.24%	1.72%
09020305	158,421	288,569	446,990	26,186	2,146	12,209	5.86%	0.48%	4.23%
09020306	1,055	345,832	346,887	17,409	391	8,186	5.02%	0.11%	2.37%
09020309	14,917	392,096	407,013	10,337	730	4,391	2.54%	0.18%	1.12%
09020311	11,220	445,939	457,159	6,850	1,090	6,593	1.50%	0.24%	1.48%
09020312	34,669	448,266	482,936	5,021	1,713	8,036	1.04%	0.35%	1.79%
09020314	58,441	213,920	272,361	4,628	1,656	4,745	1.70%	0.61%	2.22%
09030001	358	129	487	28	18	0	5.84%	3.78%	0.00%
09030002	2,522	577	3,099	35	23	0	1.13%	0.73%	0.00%
09030003	2,302	1,709	4,011	65	124	10	1.61%	3.08%	0.60%
09030004	8,148	4,619	12,767	70	172	16	0.55%	1.35%	0.35%

HUC8	NLCD 2006 Pasture/ Hay (acres)	NLCD 2006 Cultivated Crops (acres)	Total NLCD Agriculture	EQIP Nutrient Management (acres)	EQIP Forage and Biomass Plantings (acres)	EQIP Residue Management (acres)	Percent Nutrient Management	Percent Pasture/Hay	Percent Residue Management
09030005	18,390	6,281	24,672	139	289	31	0.56%	1.17%	0.49%
09030006	22,767	3,072	25,839	177	446	68	0.69%	1.73%	2.20%
09030007	6,124	5,839	11,963	512	154	647	4.28%	1.29%	11.08%
09030008	12,308	13,892	26,200	292	43	286	1.11%	0.17%	2.06%
09030009	30,224	48,459	78,683	1,904	514	1,897	2.42%	0.65%	3.91%
10170202	1,990	16,237	18,228	667	9	402	3.66%	0.05%	2.47%
10170203	22,960	252,756	275,716	10,364	215	5,224	3.76%	0.08%	2.07%
10170204	22,021	465,294	487,315	22,400	233	11,005	4.60%	0.05%	2.37%
10230003	798	166,435	167,233	7,436	61	3,026	4.45%	0.04%	1.82%

Table 3. Annual number of EQIP contracts for key management practices and associated acreage (2002-2012)

Year	Key EQIP Management Practices					
	Nutrient Management		Residue Management		Forage and Biomass Plantings	
	Contracts	Acreage	Contracts	Acreage	Contracts	Acreage
2002	53	11,924	33	5,077	8	171
2003	398	69,065	229	36,645	77	2,005
2004	463	108,405	590	95,498	107	4,866
2005	387	93,183	581	105,893	95	3,468
2006	426	105,022	533	78,553	64	2,241
2007	306	90,129	501	86,265	82	3,481
2008	215	58,814	316	60,742	45	1,629
2009	278	77,981	111	21,133	115	4,326
2010	320	165,510	88	20,059	85	3,779
2011	255	79,988	62	13,168	67	3,007
2012	147	42,264	31	7,004	39	1,246

Caveats and Limitations

- This measure only tracks three priority management practices funded by NRCS through EQIP conservation payments.
- Implementation of these management practices are largely determined by the amount of funding available annually through Minnesota's EQIP program.
- NRCS tracks information by county, not by 8-digit HUC. Providing data by 8-digit HUC requires additional analysis.
- NRCS does not track nutrient load reductions associated with management activities implemented under EQIP.
- Treated acreage is reported by EQIP applicants.
- Land enrolled in other conservation programs is eligible under EQIP provided EQIP does not pay for the same practice on the same land as any other USDA program. As a result, acreage captured under this measure might also be captured under other program indicators.
- Contact length versus implementation timeframe

Future Improvements

Improvements to this measure will be made over time.

Ideally this measure will be able to compare estimated nutrient load reductions for more EQIP conservation practices that affect nutrient loads. In addition, it would be helpful for NRCS to incorporate a mechanism for estimated nutrient load reductions associated with EQIP conservation practices as part of programmatic tracking, possibly through EQIP reporting requirements. However, this would require a national change in approach because EQIP is a federal program.

Financial Considerations

Contributing Agencies and Funding Sources

This measure only tracks the three priority management practices identified by NRCS funded using EQIP to make conservation payments. Payment rates for each management practice vary annually.

References

Haith, D.A., R. Mandel, and R.S. Wu. 1992. GWLF, Generalized Watershed Loading Functions, Version 2.0, User's Manual. Dept. of Agricultural & Biological Engineering, Cornell University, Ithaca, NY.

HRWCI. 2005. Agricultural Phosphorus Management and Water Quality in the Midwest. Heartland Regional Water Coordination Initiative. Iowa State University, Kansas State University, the University of Missouri, the University of Nebraska–Lincoln and the USDA Cooperative State Research, Education and Extension Service.

Miller, T.P., J.R. Peterson, C.F. Lenhart, and Y. Nomura. 2012. The Agricultural BMP Handbook for Minnesota. Minnesota Department of Agriculture. Accessed June 2013. http://www.eorinc.com/documents/AG-BMPHandbookforMN_09_2012.pdf

MPCA. 2013. Draft Nitrogen Study.

Measure Points of Contact

Agency Information

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Implementation of Conservation Tillage Funded through AgBMP Loans

Measure Background

Visual Depiction

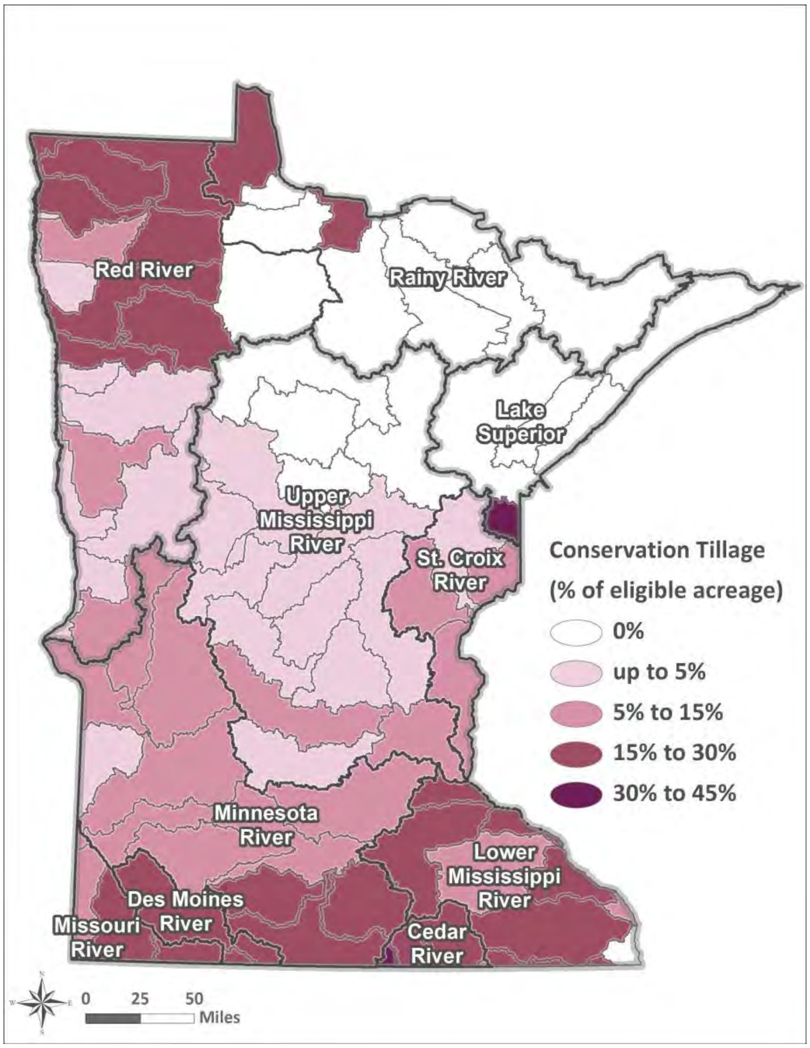

Figure 1. Percentage of agricultural acreage under conservation tillage funded through the AgBMP Loan Program by 8-digit HUC

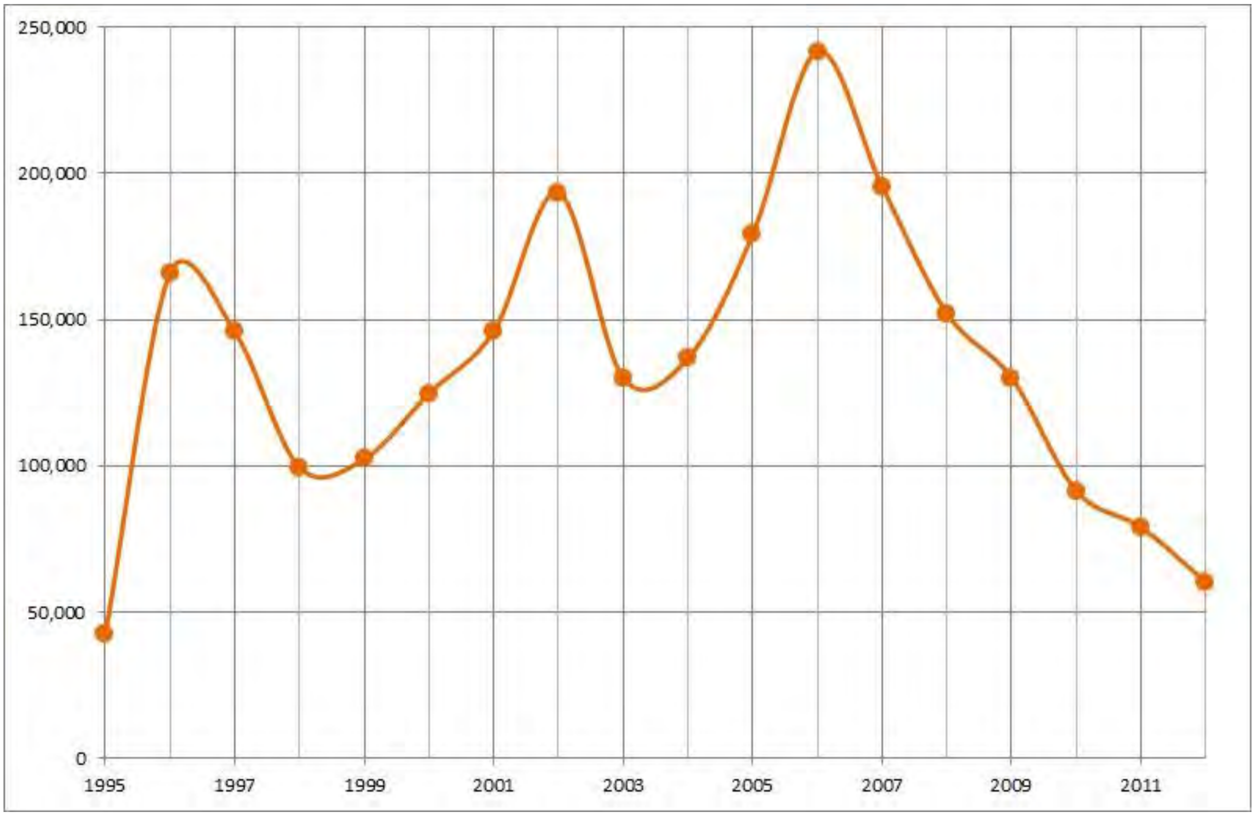

Figure 2. Acreage of agricultural land in Minnesota under conservation tillage through AgBMP Loan Program by year

Measure Description

This measure communicates the acreage of agricultural land under conservation tillage as reported by borrowers receiving loans through the Minnesota Department of Agriculture's (MDA's) AgBMP Loan Program. Acreage under conservation tillage in Figure 1 is shown by 8-digit HUC. According to Figure 1, higher percentages of agricultural acreage is under conservation tillage through the AgBMP Loan Program in northwest and southern Minnesota.

Figure 2 shows the new acreage reported to be under conservation tillage annually through the MDA's AgBMP Loan Program from 1995 through 2012. According to Figure 2, acreage under conservation tillage as reported by borrowers declined annually from 1996 to 1998, with an increasing trend from 2000 to 2002. In 2006, the acreage reported under conservation tillage spike, declined, with acreage reported during 2012 nearly equivalent to the acreage reported in 1995.

It is an indirect or surrogate measure of environmental response. It does not provide information on nutrient reduction, but does provide information on efforts to reduce pollutant loads over time that are likely to reduce nutrients.

Table 1 below shows the estimated percent nitrogen and phosphorus removal associated with conservation tillage. These efficiencies were derived from a comprehensive literature review.

Table 1. Estimated nutrient removal efficiencies for conservation tillage

Best Management Practice	Nitrogen Removal (%)	Phosphorus Removal (%)
Conservation Tillage[a]	0	63

a. Miller et al. 2012; Iowa State University 2013; Simpson and Weammert 2009

Associated Terms and Phrases

To better understand this measure, it is necessary to understand a few program specific terms and phrases.

Conservation Tillage: The category of *conservation tillage* for the AgBMP Loan program means any loan for a piece of equipment that can be used for conservation tillage. Each loan is placed in one of the following categories with conservation tillage:

CON-TILL - CHISEL PLOW
CON-TILL - CULTIVATOR
CON-TILL - DISK
CON-TILL - EQUIPMENT
CON-TILL - MULCHER
CON-TILL - PLANTER
CON-TILL - RIPPER
CON-TILL - SOIL FINISHER
CON-TILL - STRIP/RIDGE TILL
CON-TILL - CONSERVATION CHOPPER HEAD
CON-TILL - VERTICAL TILL

Target

There is no specific numeric target for this measure to date.

Baseline

2000-2012

Geographical Coverage

Statewide, major basin, 8-digit HUC

Data and Methodology

Methodology for Measure Calculation

This measure represents the agricultural acreage under conservation tillage as reported by agricultural operators receiving AgBMP Loan funding for equipment. To calculate this measure, MDA extracted data from the AgBMP Loan database “conservation tillage acres after project” and “total acres farmed” for all funded projects within each 8-digit HUC across the state from 1995-20013.

Data Source

Minnesota Department of Agriculture

Data Collection Period

1995-2013

Data Collection Methodology and Frequency

All data in the AgBMP Loan Program database reflects information as reported by the local government agency responsible for the oversight of the projects. All loan information is entered by MDA staff prior to disbursal. Projects are entered into the AgBMP Loan Program database as they are submitted for disbursal. Participants provide basic information about the project, which includes basic borrower information and loan terms. In addition, the program currently collects additional data that serves as an indicator of program trends and environmental benefits. This additional data currently includes information regarding what is being constructed or purchased, project location, farm size (animal units or acres), and type of crop or animals managed. AgBMP project data is reported by the calendar year the loan is issued.

Supporting Data Set

Table 2 contains the acreage of agricultural land under conservation tillage as reported annually by borrowers to MDA by 8-digit HUC for 1995-2012.

Table 2. AgBMP program data, acres enrolled under conservation tillage

HUC_8	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	Grand Total
4010101																			
4010102																			
4010201																			
4010202																			
4010301													800						800
7010101																			
7010102																			
7010103																			
7010104				800			1,500		250						225				2,775
7010105																			
7010106									150				800						950
7010107									525	250									775
7010108			450	800						200			800		1,250				3,500
7010201		150	800			800		230	426	800	200	2,200	370		300				6,276
7010202		800	100					600	423	750	850	800	2,175	350	1,025	250			8,123
7010203		350	1,500	360	550	800	650		920		2,025	800	645	800					9,400
7010204		4,600	6,600	150	1,280	2,215		1,040	3,882	2,616	4,540	4,743	800	1,400	544	1,400	300	100	36,210
7010205	157	5,797	1,400	200	800	2,488	240	400	1,550	1,200	4,815	850	1,200	600					21,697
7010206		3,150	800	300	667		275	713			570	375							6,849
7010207				800					998	800			2,100	41			1,400		6,139
7020001			3,530	350	1,000	1,500	3,000	4,372	690			2,150	2,000		480	1,000	450		20,522
7020002			1,700	2,300	800			1,367	405				5,140	1,450	3,840	1,175	1,885		20,062
7020003	800	1,420	3,192	479				550	2,100	2,500		600	1,600	1,466					14,707
7020004	3,551	6,586	6,661	1,802	3,976	1,680	3,150	11,698	6,195	2,000	5,000	5,684	2,852	7,947	3,825			2,675	75,281
7020005		1,100	8,650	4,850		1,263	3,780	8,600	6,502	4,250	2,930	2,020	11,490	8,250	2,733	1,050	1,391	1,700	70,559
7020006	800	4,866	950	1,000	2,200	1,201	3,850	500	3,505		2,550	5,775	3,566	2,683	448		320	1,175	35,389
7020007	2,903	9,083	6,427	1,666	1,510	1,577	8,896	1,800	1,395	3,721	4,900	9,987	11,941	4,130	1,627	4,385	985	2,180	79,112

HUC_8	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	Grand Total
7020008	923	8,741	5,218	2,885	900	10,951	12,742	2,793	5,484	6,780	8,367	5,168	6,319	3,417	4,030	3,525	3,090	1,000	92,332
7020009	7,999	9,663	3,330	3,283	8,800	8,792	772	11,927	3,300	9,238	8,886	10,535	2,012	9,864	5,948				104,348
7020010	8,042	14,209	7,174		8,801	2,643	6,331	9,870	1,641	7,659	8,769	20,399	13,365	3,775	9,546	5,082	3,775	5,500	136,579
7020011	4,633	14,647	7,385	783	2,200	3,433	4,838	12,068	6,290	5,899	6,511	15,445	12,299	18,974	15,427	6,195	6,645	1,200	144,872
7020012	240	6,557	5,551	3,618	2,282	3,572	1,550	2,209	1,485	6,468	14,608	6,702	5,195	1,600	1,470	3,667	4,165		70,939
7030001										675									675
7030003				375															375
7030004		146	1,950	900	200	650	102					450	600	210					5,208
7030005		1,700	1,250	2,400			800				600		330	1,000					8,080
7040001		128	648	1,880	385	1,320	1,059	2,500	459		5,452	8,600	273	3,700	1,425	2,000	3,950		33,779
7040002	6,930	6,180	7,113	2,517	1,967	3,500	3,180	4,271	4,809	8,478	8,393	7,512	5,497	11,911	2,571	1,368	2,990		89,185
7040003	535	1,865	2,568	243	2,693	850		3,500	1,795	356	1,106		1,950	2,330	200				19,991
7040004	814	5,144	8,320	925	2,895	2,271	3,330	11,093	4,875	2,840	3,765	3,410	6,575	2,150	405	2,268	2,775		63,853
7040006															135				135
7040008	1,598	925	2,200	4,438	4,150	6,678	5,974	14,375	5,825	1,050	4,555	7,485	2,300	3,800	450	1,878			67,681
7060001																			
7060002		3,433					400	2,500	1,440	500	3,017		1,900	400					13,590
7080102															583				583
7080201		1,600	3,200	800	1,937	3,453	3,341	4,660	8,065	1,815	8,905	10,948	3,500	1,180	6,268	500	1,675	7,145	68,992
7080202		1,800	550	1,640	430	2,500	7,530			4,100	1,500	1,326	2,235						23,611
7080203		2,150	1,550				1,400	2,000		1,500	800				1,200	1,060			11,660
7100001		14,531	12,415	8,999	17,649	11,567	16,721	9,375	8,260	19,535	20,133	14,906	11,630	7,933	4,442	5,048	4,283	4,188	191,614
7100002		1,088			750	1,760	1,083			2,700		250	1,000	1,267				2,033	11,931
7100003		2,447							7,665	230	1,730	2,325	1,800	1,000		5,817	2,400		25,413
9020101				565											2,000		5,350		7,915
9020102			1,300	4,100	5,350	2,788	3,050			700		3,000	2,712	3,910	2,571	2,100		2,222	33,803
9020103			2,400	3,100					700		1,100			700				70	8,070
9020104				800			1,650	1,100											3,550

HUC_8	1995	1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012	Grand Total
9020106				800	1,267	1,600	5,700	500	2,050	2,500	5,500	6,440	4,420	2,600		1,200		250	34,827
9020107												4,500							4,500
9020108					800				827		4,000	46	2,500	6,950	1,500				16,623
9020301			1,800	3,727	1,825		6,000	6,600	4,744	1,500	700	18,619	10,000		1,275	3,000		700	60,490
9020302																			
9020303		2,100	800	1,800		8,155	2,800	6,400		1,875	11,900	14,789	4,800	1,250	13,200	1,250	7,500	11,100	89,719
9020304				2,530	1,683			7,800	1,800	2,750	400	2,262	8,242	7,000	700	7,800	2,400		45,366
9020305		800		2,400	800		1,100	5,133	2,800	1,950	1,736		4,600	9,120	3,000	8,500	4,500		46,439
9020306							1,100	7,000	1,550			2,863	1,500		2,500				16,513
9020309		3,200	800	800	3,070	8,225	5,557	3,100		1,000	800	3,600	3,000		6,647	3,801		3,543	47,143
9020311		2,038	2,300		3,500	800	800	10,923	600	7,208	300	12,405	5,422	3,577	10,067	4,650	4,625	3,775	72,989
9020312		14,440	12,611	7,962		11,600	6,200	12,170	9,100	5,480	2,600	9,950	10,090	4,440	7,000	6,460	1,700	5,333	127,137
9020314				8,350	3,150	2,600	1,600	1,700	4,010			5,100	1,560	3,625		1,200	3,590		36,485
9030001																			
9030002																			
9030003																			
9030004																1,000			1,000
9030005																			
9030006																			
9030007																			
9030008																			
9030009			800							4,300		650	2,300	800		1,500	1,650		12,000
10170202	700		766									750							2,216
10170203	1,200	1,156	1,099		3,844		2,025	2,300	1,550	850		1,250	300		2,000		1,000	800	19,374
10170204	800	1,680	4,735	6,750	8,267	4,578	10,210	2,050	5,464	5,003	7,975	2,595	5,783	1,860	3,240	1,244	2,709	3,511	78,454
10230003		5,765	3,243	4,200		6,967	1,800	1,600	3,549	2,835	6,663	1,450	1,212	2,630	4,000		1,500		47,413

Caveats and Limitations

Loan vs. Producer: A loan is different than an individual producer in that any individual can have multiple loans with the program. This is important to note when MDA reports conservation tillage acres because a single farmer may receive a loan for a cultivator one day and a planter the next. Therefore, MDA reports only the first loan for a borrower and uses the borrower's average acreage for all of their subsequent loans.

BMPs vs. Projects: The Minnesota Department of Agriculture's AgBMP Loan Program database does not record BMPs implemented per se, but rather loan projects completed. MDA collects information on "conservation tillage acres after project" and "total acres farmed" for all projects.

Voluntary information: The information provided by borrowers on conservation tillage acres after project is voluntary, but the numbers are generally provided for conservation tillage projects. If acreage isn't provided, MDA used 800 acres, which is the mode for all conservation tillage equipment loans with the AgBMP Loan Program.

Potential Double-Counting of BMPs: There could be any other number of state, local, federal, non-profit, or private dollars going towards a project. There are several barriers that make it difficult to avoid double-counting:

- Privacy/fairness issues associated with recipients of federal funds, MDA is not supposed to ask loan participants about their other sources of funds. MDA does report the total project cost when available. Loan funds are often used as the borrower cost share portion of grant funds, it sometimes makes sense to report dollars as opposed to number of projects because rather than reporting the same project twice, the cumulative cost is reported.
- There is not an easy unique identifier for MDA to use to identify projects between programs. Location can be used to some effect. MDA collects project location, but the accuracy varies (i.e., did the borrower report the exact project site, nearest 40, center of their farm, their home?). AgBMP loans are in the name of the borrower, but the project might include many people or organizations. As a result, other funding contributors (e.g., NRCS) might have a different contact person for the project.

Quantifying Environmental Benefits: MDA does not require extensive monitoring and reporting for projects because the AgBMP Loan Program is based on implementing recognized and demonstrated BMPs recommended in environmental plans such as the Local Comprehensive Water Management Plans, Total Maximum Daily Load (TMDL) Implementation Plans, and the State 319 Nonpoint Source Management Plan. These practices have been shown to be effective by researchers, University Extension, state & federal agencies, and industry research and development. Since it is a loan program, and the borrower has to repay the funds, MDA is satisfied with the approval from the local government that the project will have a water quality benefit. Because of this approach, MDA has been able to keep the program as simple and cost effective as possible – ensuring that more practices are completed. It is important to note that any environmental benefits are theoretical.

Future Improvements

Future improvements to this indicator would include a method for avoiding double-counting among other funding programs and a mechanism to verify the actual acreage under conservation tillage as a result of the loan.

Future iterations of the measure for the AgBMP Loan Program would also include AgWaste projects that relate to nutrient management on feedlots. To date, inclusion of AgWaste projects is challenging because MDA tracks a wide variety of equipment and approaches under the AgWaste category, including manure pumping and application equipment, manure basins, or feedlot upgrades such as a monoslope roof over a previously open feedlot. Below is a list of the practice categories that MDA uses under the AgWaste category:

FDLT - COMPOSTING
FDLT - ENGINEERING ASSISTANCE
FDLT - FEEDLOT IMPROVEMENTS
FDLT - FILTER and BUFFER STRIPS
FDLT - LANDSCAPING and DIVERSIONS
FDLT - LIVESTOCK EXCLUSION
FDLT - MORTALITY MANAGEMENT
FDLT - ROOF RUNOFF CONTROL
FDLT PRACTICE - GENERAL PRACTICE - Not Specified
MANURE AGITATION,PUMPING, LOADING - Liquid
MANURE APPLICATION EQUIPMENT- Not Specified
MANURE CUSTOM APPLICATION SERVICE
MANURE HANDLING and LOADING EQUIPMENT - Dry
MANURE HAULING and SPREADING EQUIPMENT
MANURE IRRIGATION EQUIPMENT
MANURE TREATMENT and PROCESSING
MILKHOUSE WASTE MANAGEMENT
NUTRIENT MANAGEMENT PLANS
ROTATIONAL GRAZING PRACTICES
STORAGE - BEDDING MANAGEMENT
STORAGE - HOOP BARNS
STORAGE - SLURRYSTORE
STORAGE - STACKING PAD
STORAGE BASIN - CONCRETE
STORAGE BASIN - EARTHEN
STORAGE BASIN - GEOTEXTILE LINER
STORAGE BASIN - TYPE UNKNOWN
STORAGE BASIN ABANDONMENT

For these projects, MDA collects the number of animal units that the borrower reports and the type of animals, which is essentially nutrients managed as opposed to nutrients reduced.

Financial Considerations

Contributing Agencies and Funding Sources

NA

References

Czapar, G.F., J.M. Laflen, G.F. McIsaac, D.P. McKenna. 2006. *Effects of Erosion Control Practices on Nutrient Loss*, University of Illinois.

Gold, A.J, and T.L. Loudon. 1989. Tillage effects on surface runoff water quality from artificially drained cropland. *Transactions of the American Society of Agricultural Engineers*, 32(4): 1329-1334.

Iowa State University. 2013. *Iowa Science Assessment of Nonpoint Source Practices to Reduce Nitrogen and Phosphorus Transport in the Mississippi River Basin*. May 2013. Section 2 of the Iowa Nutrient Reduction Strategy developed by Iowa Department of Agriculture and Land Stewardship, Iowa Department of Natural Resources, and Iowa State University College of Agriculture and Life Sciences.

Miller, T.P., J.R. Peterson, C.F. Lenhart, and Y. Nomura. 2012. *The Agricultural BMP Handbook for Minnesota*. Minnesota Department of Agriculture. Accessed June 2013. http://www.eorinc.com/documents/AG-BMPHandbookforMN_09_2012.pdf

Simpson, T. and S. Weammert. 2009. Developing Best Management Practice Definitions and Effectiveness Estimates for Nitrogen, Phosphorus and Sediment in the Chesapeake Bay Watershed: Final Report. December 2009, Chesapeake Bay Program, Annapolis, MD.

USEPA. 2003. National Management Measures to Control Nonpoint Source Pollution from Agriculture. EPA 841-B-03-004, July 2003.

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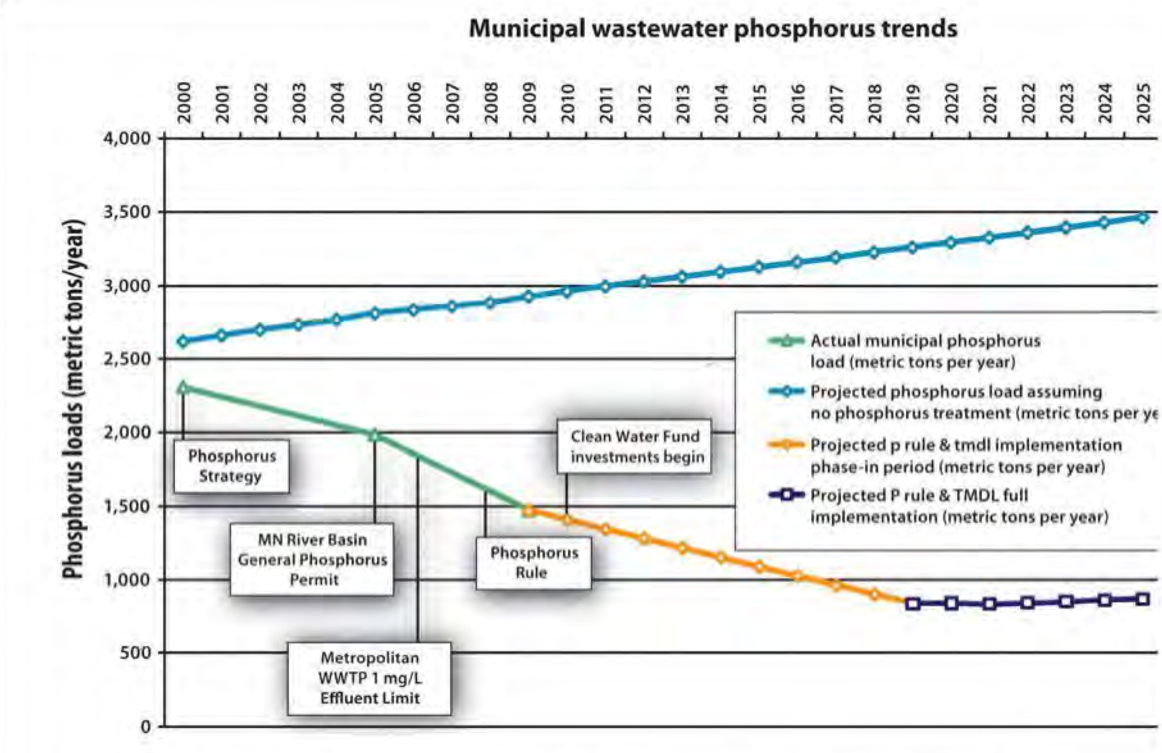
Municipal Wastewater Phosphorus Trends (excerpt from the Clean Water Fund Report)

Measure Background

Visual Depiction

This graph represents estimated statewide municipal wastewater treatment facility phosphorus reductions since the year 2000, projects future reductions based on the implementation of current permitting policies and contrasts them to anticipated increases in phosphorus loading that would have resulted from the perpetuation of previous permitting policies.



Estimated statewide reductions in phosphorus from municipal wastewater treatment facilities since the year 2000 and projections of future reductions based on current permitting policies, implementation of Total Maximum Daily Load (TMDL) requirements, and Clean Water Fund investments.

Measure Description

Statewide municipal wastewater treatment facility phosphorus trends and projections assume a 1 percent per year population growth rate:

- The **red line** assumes pre-2000 business as usual with effluent phosphorus concentrations of 4 mg/L.
- The **yellow line** represents DMR data reported for 2000, 2005 and 2009.
- The **blue line** (Projected Phosphorus Rule and TMDL Implementation Phase-In Period) simply joins the actual to the projected loads assuming a 10-year period.

- The **green line** represents full implementation of the phosphorus rule and continued phosphorus concentration declines from small municipal WWTPs.

Actual wastewater loads based on discharge monitoring report data. Projected phosphorus rule and TMDL implementation phase-in period assumes a 10-year period to achieve full implementation. TMDL requirements and operational margins of safety will likely reduce future phosphorus loads beyond projected values.

Associated Terms and Phrases

- The Phosphorus Strategy was a permitting approach adopted by the MPCA in 2000. It established policies to assign 1 mg/L effluent phosphorus permit limits for municipal wastewater treatment facilities that had the potential to discharge annual phosphorus loads in excess of 1,800 lbs/year to specific watersheds and waterbodies. Municipal wastewater treatment facilities that were not assigned effluent phosphorus limits were required to monitor influent and effluent phosphorus and develop phosphorus management plans.
- The Minnesota River Basin General Phosphorus permit was issued in 2005 to implement the wasteload allocations established by the Lower Minnesota River Dissolved Oxygen TMDL. It established baseline load and pollutant load reduction requirements for the 39 largest continuously discharging municipal and industrial wastewater dischargers in the 8 major watersheds of the Minnesota River basin.
- The Metropolitan WWTP is the largest wastewater treatment facility in Minnesota with an average annual design flow of 251 MGD.
- The "phosphorus rule" refers to Minnesota Rules Chapter 7053.0255. It codifies the phosphorus strategy but extends its requirements to all Minnesota watersheds.

Target

There is no specific numeric target for this measure to date.

Baseline

Baseline year: 2000

Baseline load: 2,305 MT per year

Geographical Coverage

Statewide

Data and Methodology

Methodology for Measure Calculation

- The projections are based on a 1 % per year population growth estimate.
- All municipal ("city") populations are used to calculate municipal flow. All rural ("township") populations are assumed to be outside municipal service boundaries.

- 92 percent of the flow and load are assumed to be from cities with populations ≥ 2000.
- Loads from municipalities with populations ≥ 2000 are estimated based on flow projections and a 1 mg/L concentration. Loads from municipalities with populations < 2000 are estimated based on flow projections and effluent concentrations that decline gradually based on the reductions shown in the 2000 to 2009 effluent data. They bottom out at 1 mg/L around 2020.
- TMDLs and operational margins of safety push actual future loads below the projections.

<u>About the graph:</u>

The red line assumes pre-2000 business as usual with effluent phosphorus concentrations of 4 mg/L.

The yellow line represents DMR data reported for 2000, 2005 and 2009.

The blue line (Projected Rule and TMDL Implementation Phase-In Period) simply joins the actual to the projected loads assuming a 10-year period.

The green line represents full implementation of the P rule and continued phosphorus concentration declines from small municipal WWTPs.

Actual wastewater loads based on discharge monitoring report data.

Projected P Rule and TMDL Implementation Phase-In Period assumes a 10-year period to achieve full implementation.

The year 2000 discrepancy between “Actual Municipal Phosphorus Load” and “Projected Phosphorus Load Assuming Non Phosphorus Treatment” reflects pre-2000 implementation of phosphorus effluent limits.

Data Source

WQ Delta database discharge monitoring report data and State demographic center population estimates

Data Collection Period

2000, 2005, 2009

Data Collection Methodology and Frequency

Supporting Data Set

	Domestic						
	Flow (MG/y)	Conc. (mg/L)	TP Load (MT/y)	Project TP Load @ 2000 Conc (MT/y)	No of Permits		No. of Permits with P Limits
2000	178,106	3.42	2,305	2,305	511		80
2005	210,756	2.49	1,985	2,727	552		100
2009	160,932	2.41	1,471	2,082	573		119

Year	City Population	City > 2000 Population	City > 2000 Pop as % of Tot. City Pop	City < 2000 Pop as % of Tot. City Pop	Actual Municipal Wastewater Flow (MG/y)	Actual Municipal Phosphorus Load (MT/y)	Projected Average Municipal Wastewater Flow (MG/y)	Projected Phosphorus Load Assuming No Phosphorus Treatement (MT/year)	City > 2000 Projected P Rule Implementation Load (MT/year)	City < 2000 Projected P Load (MT/year)	Projected P Rule & TMDL Implementation Phase-In Period MT/year)	Projected P Rule & TMDL Full Implementation (MT/year)
2000	4,257,328	3,900,753	92%	8%	178,106	2,305	172,848	2,617	599	187		
2001	4,324,100	3,964,161	92%	8%			175,558	2,658	609	183		
2002	4,387,230	4,022,758	92%	8%			178,122	2,697	618	175		
2003	4,444,786	4,077,722	92%	8%			180,458	2,732	627	174		
2004	4,500,777	4,129,621	92%	8%			182,732	2,767	635	169		
2005	4,567,652	4,191,489	92%	8%	210,756	1,985	185,447	2,808	644	165		
2006	4,607,356	4,220,005	92%	8%			187,059	2,832	648	164		
2007	4,648,222	4,259,669	92%	8%			188,718	2,857	655	157		
2008	4,686,816	4,294,835	92%	8%			190,285	2,881	660	152		
2009	4,762,705	4,365,483	92%	8%	160,932	1,471	193,366	2,928	671	147	1,471	
2010	4,816,929	4,415,002	92%	8%			195,567	2,961	678	142	1,407	
2011	4,871,153	4,464,520	92%	8%			197,769	2,994	686	137	1,344	
2012	4,925,377	4,514,039	92%	8%			199,970	3,028	694	131	1,280	
2013	4,979,601	4,563,557	92%	8%			202,172	3,061	701	125	1,216	
2014	5,033,825	4,613,076	92%	8%			204,373	3,094	709	120	1,153	
2015	5,088,048	4,662,594	92%	8%			206,575	3,128	717	114	1,089	
2016	5,142,272	4,712,113	92%	8%			208,776	3,161	724	107	1,026	
2017	5,196,496	4,761,631	92%	8%			210,978	3,194	732	101	962	
2018	5,250,720	4,811,150	92%	8%			213,179	3,228	739	95	898	
2019	5,304,944	4,860,669	92%	8%			215,381	3,261	747	88	835	835
2020	5,359,168	4,910,187	92%	8%			217,582	3,294	755	81		836
2021	5,413,392	4,959,706	92%	8%			219,784	3,328	762	70		832
2022	5,467,616	5,009,224	92%	8%			221,985	3,361	770	70		840
2023	5,521,840	5,058,743	92%	8%			224,187	3,394	777	71		849
2024	5,576,064	5,108,261	92%	8%			226,388	3,428	785	72		857
2025	5,630,288	5,157,780	92%	8%			228,590	3,461	793	73		865

Caveats and Limitations

The projections are based on a **1 percent per year population** growth estimate.

All municipal ("city") populations are used to calculate municipal flow. All rural ("township") populations are assumed to be outside municipal service boundaries.

92 percent of the flow and load are assumed to be from cities with populations ≥ 2000.

Loads from municipalities with populations ≥ 2000 are estimated based on flow projections and a 1 mg/L concentration. Loads from municipalities with populations < 2000 are estimated based on flow projections and effluent concentrations that decline gradually based on the reductions shown in the 2000 to 2009 effluent data. They bottom out at 1 mg/L around 2020.

TMDLs and operational margins of safety push actual future loads below the projections.

Projected P Rule & TMDL Implementation Phase-In Period assumes a 10-year period to achieve full implementation.

The year 2000 discrepancy between "Actual Municipal Phosphorus Load" and "Projected Phosphorus Load Assuming Non Phosphorus Treatment" reflects pre-2000 implementation of phosphorus effluent limits.

Future Improvements

Increased frequency of phosphorus monitoring in industrial permits should allow for future estimates and projections to include industrial wastewater loads.

Financial Considerations

Contributing Agencies and Funding Sources

NA

Communication Strategy

Target Audience

The primary audience would be regulated municipalities and permitting authorities. However, this measure is of interest to anyone interested in the effectiveness of wastewater programs.

Associated Messages

This measure is important to communicate to a variety of audiences to help understand the long term trends in wastewater control measure effectiveness.

Other Measure Connections

This measure links to other outcome-related measures on environmental trends, as well as financial measures showing inputs and activities related to wastewater funding.

Measure Points of Contact

Agency Information

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Appendix G: Evaluation of ChesapeakeSTAT

Minnesota Pollution Control Agency

Analysis Report

ChesapeakeStat and Minnesota State Level Nutrient Reduction Project

Watershed Data Integration Program

Analysis on the Use of ChesapeakeStat for the Minnesota State Level Nutrient Reduction Project

Executive Summary

There is a business need to present the strategies and trends emerging from monitoring and data collection related to nutrient reduction implementation activities in order to showcase resulting milestones from 2012 through 2025. This project is funded by the EPA Gulf of Mexico Regional Partnerships "intended to increase regional and national coordination to reduce Hypoxia in Gulf of Mexico coastal waters and estuaries and will be part of a state level strategy to reduce nutrient loading to waters of the state". The MPCA Watershed Division requested that a tool be built for the tracking and communicating progress toward state-level nutrient loading reduction. If implemented, this tool may contribute to meeting EPA grant requirements for delivering enhanced water quality as part of the Minnesota State level Nutrient Reduction Strategies. This report summarizes the background, context, and discoveries made while assessing the feasibility of adapting the ChesapeakeStat website framework.

When this project was chartered, it had been thought that the ChesapeakeStat website could provide a framework to incorporate an effective method for tracking nutrient reduction progress along the Mississippi River Basin. The site was viewed as a potential model for a new tool to communicate with stakeholders and watershed managers in Minnesota as well as with member states along the Mississippi River Basin and the Gulf of Mexico Task Force. Analysis performed during the project revealed significant gaps between data required to support a Chesapeake-style website and the current abilities of MPCA to provide that data. Future planned work at MPCA will increase data availability, but significant work remains to be done for watershed modeling as well as program requirements.

Table of Contents

Minnesota State Level Nutrient Reduction Program (MSLNRP)

The Minnesota State Level Nutrient Reduction Strategy Project is funded by a Gulf of Mexico Regional Partnerships Grant from the Environmental Protection Agency Gulf of Mexico Program. The goal of the project is to develop nutrient reduction strategies designed to be protective and restorative for Minnesota waters as well as contribute progress toward the downstream collective responsibilities to meet the Goals of the Gulf of Mexico Action Plan. The national effort that Minnesota has committed to be a part of to protect the Mississippi is being coordinated by the "Mississippi River/Gulf of Mexico Watershed Nutrient Task Force". One task of the project is to develop a progress tracking and communication tool for use with the nutrient reduction strategies. Initial communications with EPA staff indicated that the Chesapeake Bay tracking database, Chesapeake Stat, could be modified and developed for use in reporting progress on Minnesota State Level Nutrient Reduction Strategies developed through the overall project. It was envisioned that water quality and BMP implementation data from the MPCA and other state agencies be gathered to generate and publish clean water outcomes in the Mississippi watershed related to the restoration and protection of the Upper Mississippi River basin's water quality. It was also envisioned that the development of such a tool could be incorporated into a multi-state effort to track state level strategy efforts in reducing the hypoxic zone in the Gulf of Mexico.

ChesapeakeStat

A goal of the Minnesota State Level Nutrient Reduction Project is to provide a progress tracking and communication tool for the state level nutrient reduction strategies being developed by the project. The concept was to publish relevant water quality and BMP implementation data on a website. To that end the MPCA team had preliminary conversations with the EPA/Chesapeake Bay administrators and initially believed the site could be adaptable for use in Minnesota and eventually with other Mississippi River Basin states.

A small amount of project funds were allocated to the task of developing such a tool. These funds were set up for use as a sub-project (7a) in the MPCA Water Data Integration Project (WDIP) to evaluate whether and how the Chesapeake Stat program could be adapted and utilized by the MPCA for tracking the state's nutrient reduction strategies when the project was completed. WDIP Project 7a was undertaken to gather business requirements at MPCA, evaluate the capabilities of the website, and define requirements for website implementation.

MSLNRP Business Requirements

- A web-based database that tracks and communicates progress on statewide nutrient level reductions.
- Statewide phosphorus and nitrogen pollution reduction strategies publically available via web sites and other formats
- An effective tool for making adaptive management decisions that will ensure that nutrient reduction activities will coincide with monitored water quality information
- Timely communication with the public about nutrient sources when goals and reductions are, or are not, achieved
- An effective method for tracking nutrient reduction progress and communicating with member states along the Mississippi River Basin and the Gulf of Mexico Task Force about Minnesota's contribution of nutrients
- Nutrient reduction activities in the watersheds are tracked over time to gain a better understanding of how nutrient reduction actions are linked to reduced nutrient conditions in streams

As part of the project to evaluate whether the ChesapeakeStat website would meet the needs of the Minnesota State Level Nutrient Reduction Program, business requirements were gathered from MPCA employees. These requirements are contained in the following spreadsheet as compiled by Greg Johnson.

Topic/Hyperlink	Information Needed	Use (P–Presentation, F–Functionality, PF–Both)	Data Source/ Availability	Priority (H, M, L)
About ChesapeakeStat http://stat.chesapeakebay.net/?q=node/5	Background text	P	To be written (TBW) – mainly static	H
Partner Coordination and Support - Overview http://stat.chesapeakebay.net/?q=node/127	Text – including Watershed Framework diagram	P	Written or TBW – mainly static	H
Partner Coordination & Support – Making Connections http://stat.chesapeakebay.net/?q=node/127&quicktabs_25=1	Text and diagram – describing processes and focus areas	P	TBW	L
Partner Coordination & Support – Funding http://stat.chesapeakebay.net/?q=node/127&quicktabs_25=2	Source of funds – federal, state, local Year of funds Goal(s) funds used for – initially just Water Quality Topic for funds – wastewater, agriculture and animals, stream restoration, stormwater	PF	CWF Annual program budgets TBW TBW	H H M L
Partner Coordination & Support – Monitoring http://stat.chesapeakebay.net/?q=node/127&quicktabs_25=3	Integrated report – impaired, non-impaired – state, major watershed Report cards – link to major watershed page information Water monitoring details – sites, data results (chemistry, biology), trends, yields; nitrogen, phosphorus, TSS	P	EDA, MPCA watershed web pages, TBW	M
Water Quality – Overview http://stat.chesapeakebay.net/?q=node/130	Total loads – nitrogen, phosphorus, sediment; years – observed and target; scale – statewide, 8-digit HUC watershed Total funds spent Current health of lakes and streams – individual lakes and streams, benthic IBI Detailed WQ Funding – same as Partner Coordination & Support – Funding above	PF	Watershed load monitoring and/or Modeling CWF TBW See above	H H L See above
Water Quality – Agriculture http://stat.chesapeakebay.net/?q=node/130&quicktabs_10=1 (There is overlap between this and the TMDL tracking.)	Goals – load per year, N. P, and sediment – the TMDL (ultimate goal), interim goals TMDL – allocations by sector – WLA and LA Baseline loads Factors Influencing Goals – Land cover, soils; estimated loads by source, location, etc. Current Efforts and Gaps – BMPs implemented and needed Strategies and Resources – BMP targets (#), resources available Monitoring – measured pollutant loads, trend analyses Performance Assessment – tracking progress to meet TMDL allocations and evaluation of BMPs for use in implementation; Case Studies Make Your Own Map (available on several pages)	PF	State level goals TMDLs Wtshd. loads &or modeling GIS, modeling eLink TBW TBW, EQuIS, Hydstra, Delta TBW 	H M H M L M M M L

Topic/Hyperlink	Information Needed	Use (P–Presentation, F–Functionality, PF–Both)	Data Source/ Availability	Priority (H, M, L)
	Agriculture Workgroup members – some list of an organizational team			L
Water Quality – TMDL Tracking http://stat.chesapeakebay.net/?q=node/130&quicktabs_15=8&quicktabs_10=2	Chesapeake Bay TMDL Tracking and Accounting System – allocations and progress towards meeting planning targets by State Basin Segment (8-digit HUC watershed and/or other scales) Permitted Facilities By Year, Scale (above), Source (below), Goal, Program (below), Practices Point sources TMDL Implementation Goals – WLA's Permit requirements – wastewater, stormwater, industrial Effluent reporting, SWPPP reporting Nonpoint sources Targets – LA's Program data – 319, CWP,CWF, BWSR cost-share, other BWSR $, MDA loan $; grant dollars, # and type of projects, individual project list, SWIFT Implementation data – e-Link Legacy funds Local planning USDA funds Other funds Sources: Ag., forestry, urban, etc. Practices – NRCS Standards, BWSR, other	PF	TBW	MN only – H M L M
Water Quality – 2009-2011 Milestones http://stat.chesapeakebay.net/?q=node/130&quicktabs_15=8&quicktabs_10=4	Commitments/Targets for BMP types/groups by sector – Ag., wastewater, stormwater, forestry; by scale – statewide, basin, major watershed	PF	TBW from Nutrient Reduction Strategies, WRAPS, and implementation plans	H (State reduction strategy)
Water Quality – 2012-2013 Milestones http://stat.chesapeakebay.net/?q=node/130&quicktabs_15=8&quicktabs_10=5	Progress in meeting milestone commitments by location and year	P	TBW	L
Watersheds - Overview http://stat.chesapeakebay.net/?q=node/131	Overall progress in protecting lands Overall amount of money being spent on watersheds Current health of smaller watersheds – benthic IBI scores for Chesapeake	P	TBW with eLink, CWF reporting, some sort of assessment of our WQ data	M H L
Fisheries – Overview http://stat.chesapeakebay.net/?q=node/128	Not applicable, in near term		Some future effort	Very L

Topic/Hyperlink	Information Needed	Use (P–Presentation, F–Functionality, PF–Both)	Data Source/ Availability	Priority (H, M, L)
Habitats – Overview http://stat.chesapeakebay.net/?q=node/128	Progress and funding in restoring habitats		Some possible future effort	Very L
Habitats – Submerged Aquatic Vegetation http://stat.chesapeakebay.net/?q=node/129&quicktabs_13=1	Not applicable, in near term		Some possible future effort	Very L

Description of the ChesapeakeStat

The ChesapeakeStat website [http://stat.chesapeakebay.net/] presents water quality implementation results for the Chesapeake Bay Estuary and the nine large contributing tributaries to the Chesapeake Bay (CB) watershed. The statistical model used by the ChesapeakeStat web site WRTDS[1] is referenced in the footnote. The CB statistical model is a weighted regression equation with time, discharge, and season as independent variables. It does not encompass Best Management Practices (BMPs) and has provided time and season variables with a goal of gleaning information from long term data sets comprised of varied sampling approaches. Data sampling at multiple sites in the Chesapeake Bay watershed has occurred over a period of the past 30 years. The website reports on multiple aspects of Chesapeake Bay water quality, watershed health, fisheries, habitat, and partner coordination and support; this Analysis Report focuses on the Water Quality aspects of the site (See *Overall Web Flow ChesapeakeStat site* in APPENDIX C*)*.

1. The ChesapeakeStat (CB-Stat) website presents the analysis of long-term surface water-quality strategy goals implemented to decrease pollutants existing in the Chesapeake Bay Estuary and the nine large tributaries of Chesapeake Bay from 1978 to 2008 across multiple states.
2. The milestones are showcased in the CB-Stat website and show a wide range of patterns of change in Total Phosphorus and in Dissolved Nitrate plus Nitrite. These results are presented with a variety of charts and interactive map features which lend themselves to the overall understanding of the actions taken and the funding provided by federal, state and local entities contributing to the predefined targets of restoration and protection using Best Management Practices and cooperation among multiple partners, states and federal agencies.
3. In 1996 the Chesapeake Bay *Strategy for Increasing Basin-wide Public Access to Chesapeake Bay Information* called for development of a shared resource of information, available through the internet, and based on standards and protocols that facilitate access to information and data across agency and jurisdictional boundaries.
4. As a result, the Chesapeake Information Management System (CIMS) was created as the framework to carry out the *Strategy*.
    a. Within CIMS, it is necessary to have consistent standards and uniformity for recording and reporting data and information to allow users in different locations to access the data and information they need.
    b. The foundation to this level of consistency and uniformity is metadata. Metadata provide basic documentation about the source, content, and quality of data and other information.
    c. The metadata has been evolving over the past 20 years and continues to evolve. See APPENDIX B for the metadata data schema used by the CB-Stat Program to collect data from multiple contributing state sources.
5. A representative sampling of CB-Stat website pages is included in APPENDIX D.
    a. These web page screen shots have been provided by Denise Leezer to show how a chart or map might be utilized to display water quality data gathered for a Mississippi Nutrient Reduction Project.

[1] Hirsch, Robert M., Douglas L. Moyer, and Stacey A. Archfield, 2010. Weighted Regressions on Time, Discharge, and Season (WRTDS), With an Application to Chesapeake Bay River Inputs. *Journal of the American Water Resources Association* (JAWRA) 46(5):857-880. DOI: 10.1111/j.1752-1688.2010.00482.x

6. The architecture of the CB-Stat website includes a complicated Watershed Basin statistical model in combination with use of HSPF modeling and the outcome drives the reporting accuracy and pertinence of the information presented on this site.
    a. A statistical model could be implemented to help the context of additional data monitoring and water quality collections based on the work undertaken for the Minnesota state level nutrient reduction project as it relates to the Mississippi Basin within the state of Minnesota.

7. The data on *point-source* and *non-point-source* depositions within the dense urban setting of the Chesapeake Bay relate to the water quality of the Chesapeake Bay estuary. TMDL data supporting the CB Milestone targets and resulting outcomes are presented on the site using the environmental models used throughout the CB-Stat website.

8. The Chesapeake Bay statistical models (see footnote 1 for reference) focuses on monitoring sites for point-sources and non-point sources. The Point-source & Non-Point Source Best Management Practices (monitoring sites and collection of sample data from each of these sites) of the Chesapeake Bay area of study is sent quarterly to the Chesapeake Bay Office repository for storage and aggregation of this data. Each of the six states participating in this program sends data based on a request from the Chesapeake Bay Program Office node (receiving hardware site for standard data formatted for water quality).

9. Data is exchanged automatically to the CBO (Chesapeake Bay Office) node and is refreshed with each new quarterly request; all historical data is kept in the Chesapeake Bay Data Warehouse repository.
    a. See Figure 2 below for flow of data example from MPCA node to EPA. See APPENDIX A-1 for flow of data via any state 'node' (CBO and MPCA, etc.) to the EPA NEIEN (National Environmental Information Exchange Network) data mart.
    b. See APPENDIX A-2 for additional technical details on the architecture employed for the CB site data flowing to the EPA and infrastructure involved for the Chesapeake Bay program office node.

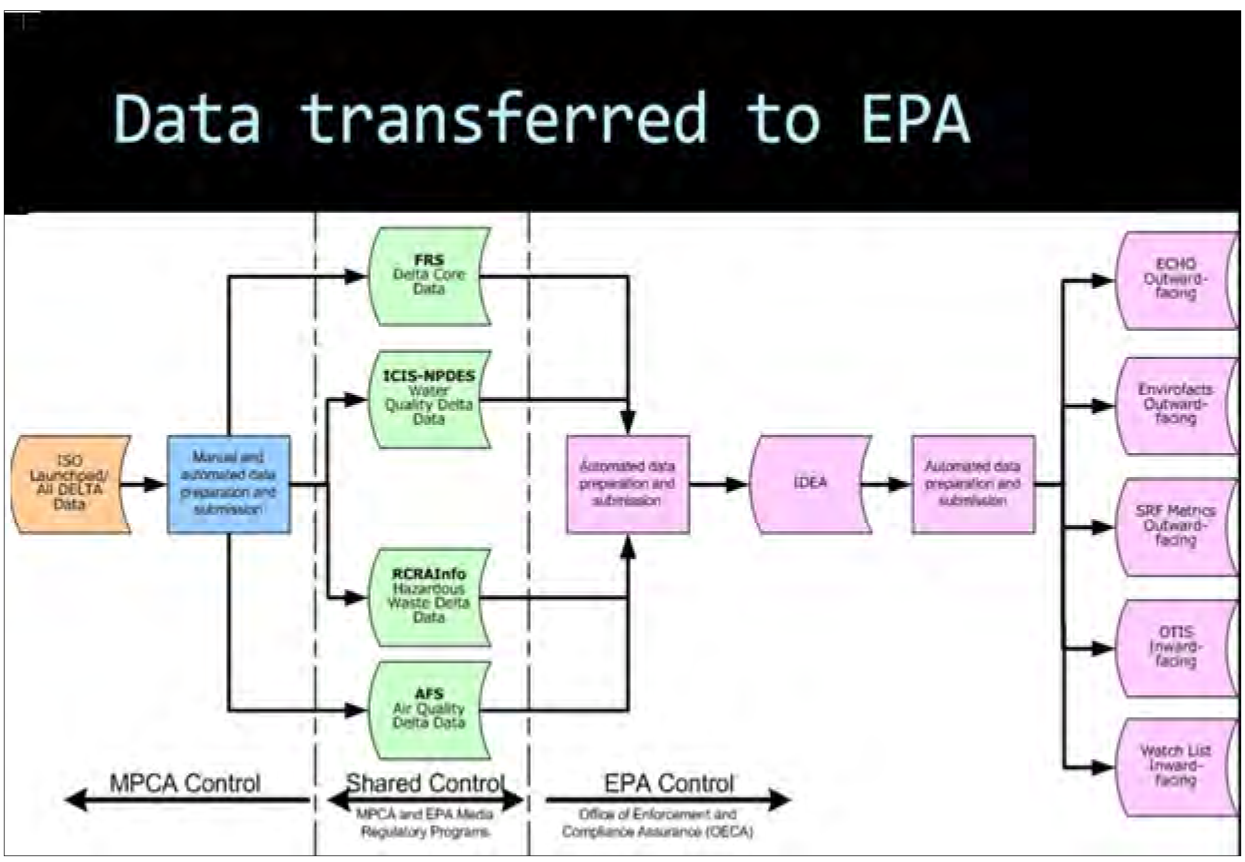


Figure 2: How Data flows to and from the EPA for point source & non-point source data.

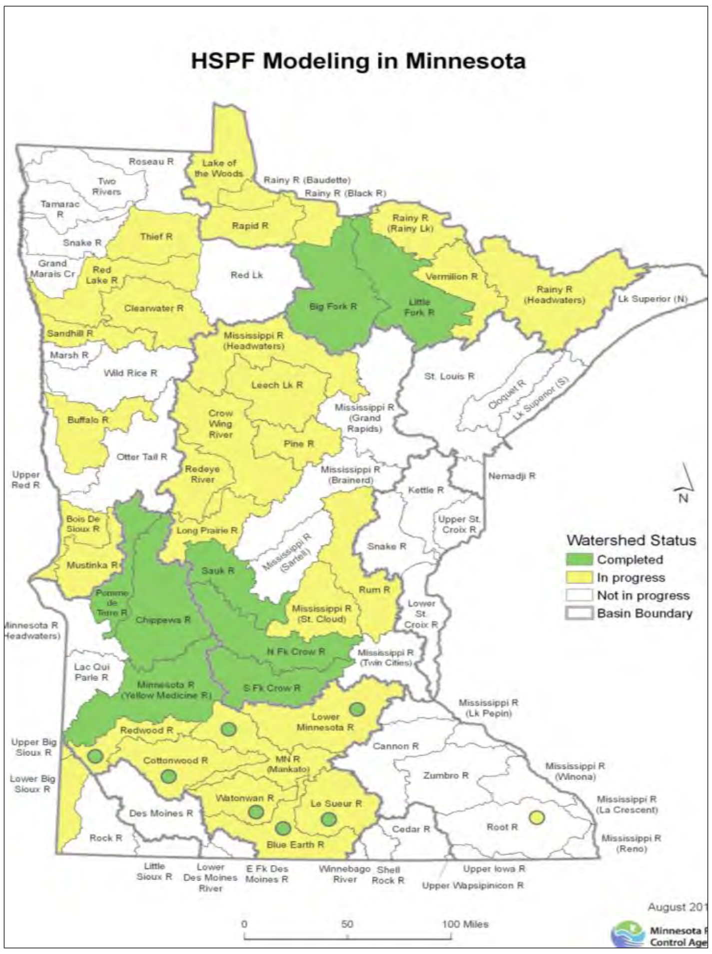
10. Hardware Nodes are required for states to automatically send data to the EPA data exchange network. All data must conform to the strict guidelines and correct data formatting for the type of data being submitted via a Node.
    a. A sample of the Chesapeake Bay Information Management System data schema used for EPA data submissions and also used to submit data to the Chesapeake Bay node is included in APPENDIX B. The full instructions needed to implement the data fields of this schema as well as the required heading and trailer information for each data file is contained in detail in the primary document, which is accessible via the link in the appendix.

Prerequisites for a ChesapeakeStat-Style Website

1. Uniform water quality data – chemistry and flow, with loads calculated from the data – plus statistical model/analyses to show changes
2. Uniform watershed modeling – Chesapeake Bay Program uses HSPF; need a means of tying the model outputs together
3. Nonpoint source BMPs and related information – number, cost, location, reduction estimates – need from all agencies in state; need database to house the data or portal to access other agencies data
4. Point source data – WQ Delta upgrades or a successor
5. Data reporting, storage and aggregation processes for the two items above
6. Mechanism for data exchange and update, and data access for the web software/portal
7. Hardware Nodes are required for all parties to automate data exchange to the EPA and are used in the CB-Stat currently. (See APPENDIX A-2 for further technical information.)

MPCA Watershed Modeling

The MPCA has selected the HSPF watershed model for use in its Watershed Restoration and Protection Strategy (WRAPS) approach. The HSPF model is being developed for all 8-digit HUC watersheds in the state. The map below shows the current status of the modeling. At this time, the modeling has not yet been completed on all watersheds that are part of the Mississippi River basin. The HSPF models, when complete, could be used in a CB-Stat-like web portal with supporting data system. Work would have to be undertaken to provide the linkage of models to data to provide a comparison between watersheds from the outlet of the Mississippi River in Minnesota.



MPCA staff indicated that an alternative to the use of the HSPF model for the development of a tracking system for the state level nutrient reduction strategy may be the use of the SPAtially Referenced Regressions On Watershed attributes (SPARROW) watershed model. SPARROW integrates water monitoring data with landscape information to predict long-term average nutrient loads that are delivered to downstream receiving waters.   Results of the modeling completed for the upper Midwest could be used in presenting a static picture of nutrient loads for the state level strategies in lieu of an active CB-Stat-like web portal.

MPCA Watershed Monitoring

The MPCA has begun a long-term watershed load monitoring program where flow and water quality data are collected for use in calculating pollutant loads. The outlet of each 8-digit HUC watershed is monitored in this program. The monitoring results will be available for presentation, but the reporting system is yet to be built. This may become a part of the WDIP development process.

A report, *Upper Mississippi River Nutrient Monitoring, Occurrence, and Local Impacts: A Clean Water Act Perspective,* published in September 2011 by the *UMRCC* (Upper Mississippi River Conservation Committee), provided recommendations for improving the consistency and comprehensiveness of water quality monitoring in the Upper Mississippi River basin. The needs and recommendations should be considered when/if a tracking system is explored with the Mississippi River states.

In order to create a web portal for featuring the strategies and reporting of trends and outcomes from the MSLNRP, the data collected at multiple sites within the basin and sub-watershed areas would need to be tracked and stored in a database that would be able to aggregate the data into various views of results based on funding, environmental restoration and protection actions implemented to create cleaner watershed quality standards for Minnesota and also for the partners and agencies involved in these efforts.

There is a long-term interest in including a hoped-for vision of data from the 9 downstream partner states to contribute to the restoration and protection of the Mississippi Basin. The Minnesota State Level Nutrient Reduction goals will contribute collection and monitoring data results to extend the water quality information within the Minnesota state boundaries and hope to coordinate these downstream partner states to apply their data to a watershed model developed for the restoration and protection goals for reducing nutrient loads from point source and non-point source outflows along the Mississippi Basin and Atchafalaya Basin to the northern Gulf of Mexico. The geographic scope of such an undertaking is considerable.

MPCA Existing Integrated Infrastructure

1. The MPCA uses the EPA node exchange network to send point source and non-point source data monitoring to the EPA.
   a. The point-source water quality data the MPCA sends to EPA through the node to the Central Data Exchange (CDX) is referred to by the business as DMR (daily monitoring results). (See APPENDIX A-1 for flow).
   b. MPCA is required to do monitoring and send the results to EPA based on the National Pollution Discharge Elimination System (NPDES) permit. MPCA data is stored in WQ Delta.
2. The Environmental Data Access (EDA) water quality section on the MPCA website features data from surface water monitoring sites located around Minnesota. Where available, you can also view the conditions of lakes, rivers or streams that have been assessed.
   a. EDA (on the MPCA website) accesses data from the EQuIS and WQ Delta databases.
   b. WQ monitoring data going to EPA's WDX [water data exchange] comes from both the WQ Delta database which holds compliance monitoring data; and from the EQuIS database which is the repository of ambient WQ monitoring data. There may be a few exceptions, but generally this is the concept of how the data is organized at MPCA. (Source: Joan de Meurisse, 9/2012).
3. The MPCA node is of the same type as that used by the Chesapeake Bay Program, node.
   a. This node is of the hardware 2C# (i.e., written in 2C sharp programming language).
   b. See APPENDIX A-1 and A-2 respectively, for the EPA NEIEN flow of data and technical information and see APPENDIX B for the spreadsheet of partial data fields which are mandated by the EPA for sending data to the Water Quality Data Exchange network of the Central Data Exchange.

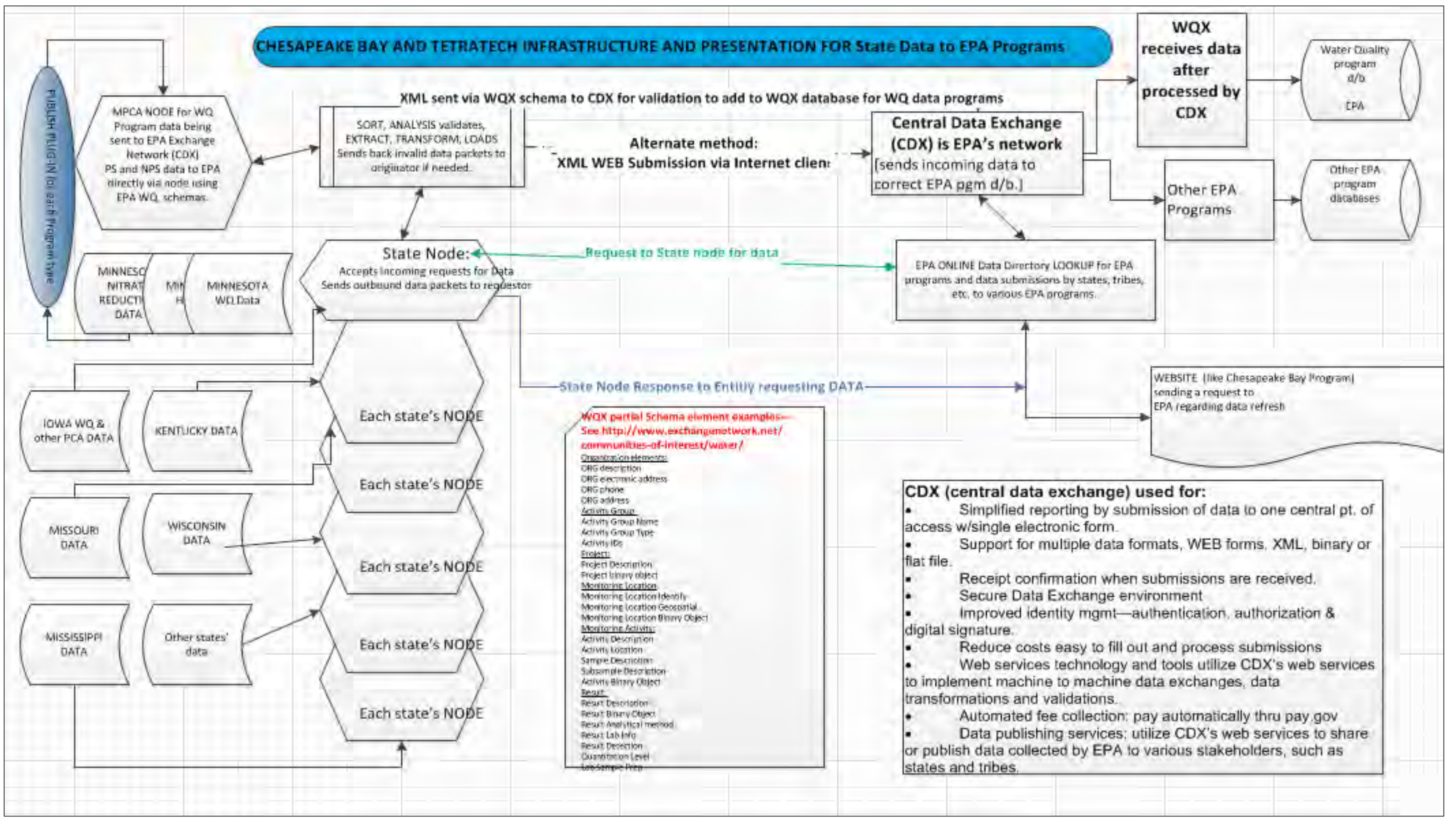
Elements Needed for Future Completion of a Mississippi River CB-Stat type of system

- A Watershed Statistical Model to provide context for Minnesota data.
- Data to support this model from the State of Minnesota, related to Mississippi river headwaters and all outflows beyond state borders.
- Minnesota inter-agency data collection project
- Interstate agreements and development of databases and system for the Mississippi River Nutrient Reduction efforts

Recommended Steps for Development of a Tracking Tool for MSLNRP

1. Coordinate data definition with other agencies in Minnesota to enable aggregation, standardization, and reporting of calibrated data. This would involve considerable effort to achieve.
2. Coordinate the vision of the MSLNRP with the MPCA Watershed Data Integration Program. Combine resources when appropriate funding becomes available. Track and store data at levels of detail and in formats: that enable aggregation; that make the data compatible with reporting guidelines, and; that meet requirements to support development of an inter-agency web portal.
3. Apply synergies between the MSLNRP visions with strategies of the WDIP program wherever feasible. Incorporate water quality WRAP information in communications to a wider audience by using viable outcomes from the WDIP program. Store data and share via the web when possible using options as they become available.
4. Promote creation of web services for data sharing at each partner organization.
5. Support creation of an interagency network of databases and portals needed to enable the tracking and presentation of BMP implementation progress to address the reduction strategies to be developed in the MSLNRP.
6. Coordinate with other state agencies both within Minnesota and outside of Minnesota to coordinate in the monitoring and collection of data at sites along the Mississippi Basin. Data exchange nodes are available at many of the downstream states on the Mississippi Basin and these partners, as well as in-state agency partners would enhance nutrient reduction efforts.
7. Define a Watershed Statistical Model which could be similar to the undertaking of the Chesapeake Bay.
8. Collect, store, and transmit data according to EPA requirements (i.e., NEIEN WQX schema). See flow in APPENDIX A-1.

APPENDIX A-1 Data Flow Diagram to US EPA via NEIEN Nodes from CB & Other States



APPENDIX A-2: CB Technical Information on EPA Node Setup & Management of Data

The National Environmental Information Exchange Network (NEIEN) is an innovative approach for the exchange of data between the EPA, states, and partner organizations. The Network provides the framework for the exchange of quality environmental information. The framework is built on Internet-based standards, technologies, and protocols. This is critically important for the long-term success of the Network.

To participate in the Network, each exchange partner requires a Network node (Node). The Node hosts a suite of standard web services that facilitate the authentication and exchange of data between partners. The messaging between partners is handled through standard extensible markup language (XML).

In federal fiscal year 2004, the Pennsylvania Department of Environmental Protection (PADEP) was awarded a Network Challenge Grant to facilitate the exchange of non-point source best management practice (BMP) data between the Chesapeake region states of Pennsylvania, Maryland and Virginia; and the Chesapeake Bay Program Office (CBPO).

The grant called for the establishment of a new Node at the Chesapeake Bay Program Office in Annapolis, Maryland (Chesapeake node). The Chesapeake node is required to support exchanges between the state nodes and Chesapeake node, and the EPA node (CDX) and the Chesapeake node.

The technology of choice for the Chesapeake node is the Microsoft .NET framework with Microsoft's SQL Server as the backend data store. Existing node configuration and requirements serve as the blueprint for the Chesapeake node. In particular, the development team follows the guidelines established in the *Network Node Functional Specification* (v.1.1, September 2003); the *Exchange Network Node Implementation Guide* (v.1.0, April 2003); and the *Developing and Implementing an Exchange Network Node, 30 Minute Guide* (v.1.1, March 2005).

Further, the CB development team plans on leveraging existing demonstrated node configuration documents. The *Washington State Department of Ecology, Demonstrated Node Configuration* (v.1.0, November 2003), the *Mississippi Demonstrated Node Configuration* (v.1.1, December 2003), and the demonstrated node configuration server side code for Microsoft C#.NET and Microsoft VB.NET were all considered prior to the development of the Chesapeake node.

Node Authentication Model

The Chesapeake node uses the Network's Network Authentication and Authorization Service (NAAS) to handle all authentication functions. The Chesapeake Bay Program manages privilege to the Chesapeake node within the NAAS using a web-based user interface provided by the Network.

As detailed in Figure 1, the Chesapeake node obtained a security token from the NAAS using the authentication service. The security token is passed to send or retrieve data from a partner node. The partner node validates the security token prior to responding to the request.

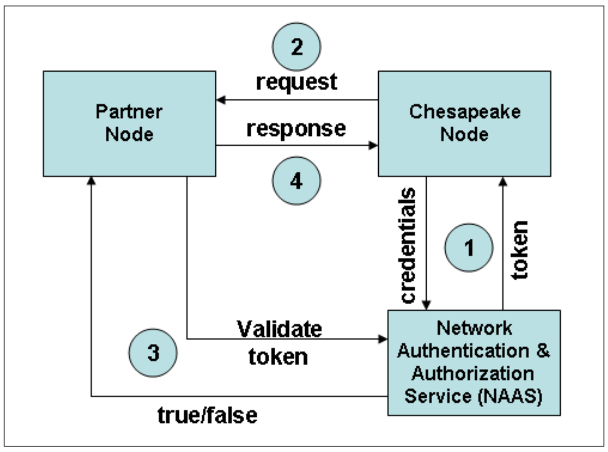


Figure 1: Authentication Model

Auditing

Pertinent node activity is logged to a Microsoft SQL Server database. This includes the date and time of outbound requests submitted to partner nodes, the date and time of inbound requests from partner nodes, and the status of those requests. Additional information about the requests may be captured in the future, which may include the request parameters and request response times.

Technical Specification

The following specifications will be used for the initial installation of the Chesapeake node:

- Microsoft Server 2003, Enterprise Edition
- Microsoft Internet Information Server (IIS) 6.0
- Microsoft SQL Server 2003
- Microsoft .NET Framework 1.1
- Web Services Enhancements 1.0 (WSE)

References

For further specifications about the Chesapeake Bay Node and Data consult the following links at MPCA node documentation and referenced documents below the links.

1. X:\Agency_Files\Administrative_Services\Information_Systems\Section_Stuff\Projects\WDIP Phase 3\Projects\7a ChesStat BayTAS\NEIEN\CIMS Metadata Report Guidelines.pdf
2. X:\Agency_Files\Administrative_Services\Information_Systems\Section_Stuff\Projects\WDIP Phase 3\Projects\7a ChesStat BayTAS\NEIEN\NodeFunctionalSpecification_v2.1.pdf
3. X:\Agency_Files\Administrative_Services\Information_Systems\Section_Stuff\Projects\WDIP Phase 3\Projects\7a ChesStat BayTAS\NEIEN\WQ Data Exchange Node tutorial.pdf
4. X:\Agency_Files\Administrative_Services\Information_Systems\Section_Stuff\Projects\WDIP Phase 3\Projects\7a ChesStat BayTAS\NEIEN\WQX_FCD_v2.1.pdf
5. X:\Agency_Files\Administrative_Services\Information_Systems\Section_Stuff\Projects\WDIP Phase 3\Projects\7a ChesStat BayTAS\NEIEN\NPS_Schema_Users_Guide.doc and in same folder: ..\NEIEN\NPS_NEIENetwork ExchangeTradingPartnerAgreement.doc
6. *Network Node Functional Specification*, v.1.1, September, 2003
7. *Network Exchange Protocol*, v.1.1, September, 2003
8. *Exchange Network Node Implementation Guide*, v1.0, April, 2003
9. *Washington State Department of Ecology, Demonstrated Network Node Configuration*, v1.0, November 2003
10. *Developing and Implementing an Exchange Network Node*, v1.1, March, 2005
11. *Mississippi Demonstrated Node Configuration*, v1.1, December 2003

APPENDIX B: Data Schema Used to Transmit Data to EPA

The EPA uses a data schema (partial schema fields below) for transmission of data that is defined by Categories, sub-categories, sorts within the sub-categories, and Data Element XML tags. The full spreadsheet of EPA schema is located at the following link within the MPCA server environment:

X:\Agency_Files\Administrative_Services\Information_Systems\Section_Stuff\Projects\WDIP Phase 3\Projects\7a ChesStat BayTAS\CHESAPEAKE BAY SITE DATA & CHARTS\Data Elements for EPA schema__WQX_DET_v2.1b.xls

Sample of schema:

WQX Exchange schema v. 2.1 (abbreviated form)			
Category	**Subcategory**	**Data Element XML Tag**	**WQX Definition**
ORGANIZATION	ORG Description	OrganizationDescription	Header The particular word(s) regularly connected with a unique framework of authority within which a person or persons act, or are designated to act, towards some purpose.
	ORG Electronic Address	ElectronicAddress	Header This section allows for the description of many electronic addresses per owning Organization.
	ORG Telephonic	Telephonic	Header This section allows for the description of many telephone numbers per owning Organization.
	ORG Organization Address	OrganizationAddress	Header This section allows for the description of up to three physical addresses for the owning Organization.
PROJECT	PROJ Description	Project	Header; This section allows for the description of Organization Projects.
	PROJ Binary Object	ProjectAttachedBinaryObject	Header; This section allows for the association of References and electronic attachments to the project, including formal Project Plan and any other documents, images, maps, photos, laboratory materials, geospatial coverages, and other objects associated with the Project..
PROJECT MONITORING LOCATION WEIGHTING	Project Monitoring Location Weighting	ProjectMonitoringLocationWeighting	Header This section describes the probability weighting information for a given Project / Monitoring Location Assignment.
	Project Monitoring Location Weighting	LocationWeightingFactorMeasure	Header; A measurement of the monitoring location selection weighting factor.
	Project Monitoring Location Weighting	ReferenceLocationCitation	Header; Identifies the source that created or defined the Reference Location.
MONITORING LOCATION	Monitoring Location Identity	MonitoringLocationIdentity	Header This section allows the owning Organization to describe monitoring locations.
	Monitoring Location Geospatial	MonitoringLocationGeospatial	Header; This section allows for the geospatial description of a monitoring station. This section records the location in 3 dimensions.
	Monitoring Location Geospatial	HorizontalAccuracyMeasure	Header; The horizontal measure of the relative accuracy of the latitude and longitude coordinates
	Monitoring Location Geospatial	VerticalMeasure	Header; The measure of elevation (i.e., the altitude), above or below a reference datum.
	Monitoring Location Well Information	WellInformation	Header; Description of the attributes of a well
	Monitoring Location Binary Object	AttachedBinaryObject	Header; This section allows for the association of References and electronic attachments to the Monitoring Location description including any other documents, images, maps, photos, laboratory materials, geospatial coverages, and other objects associated with the Project.

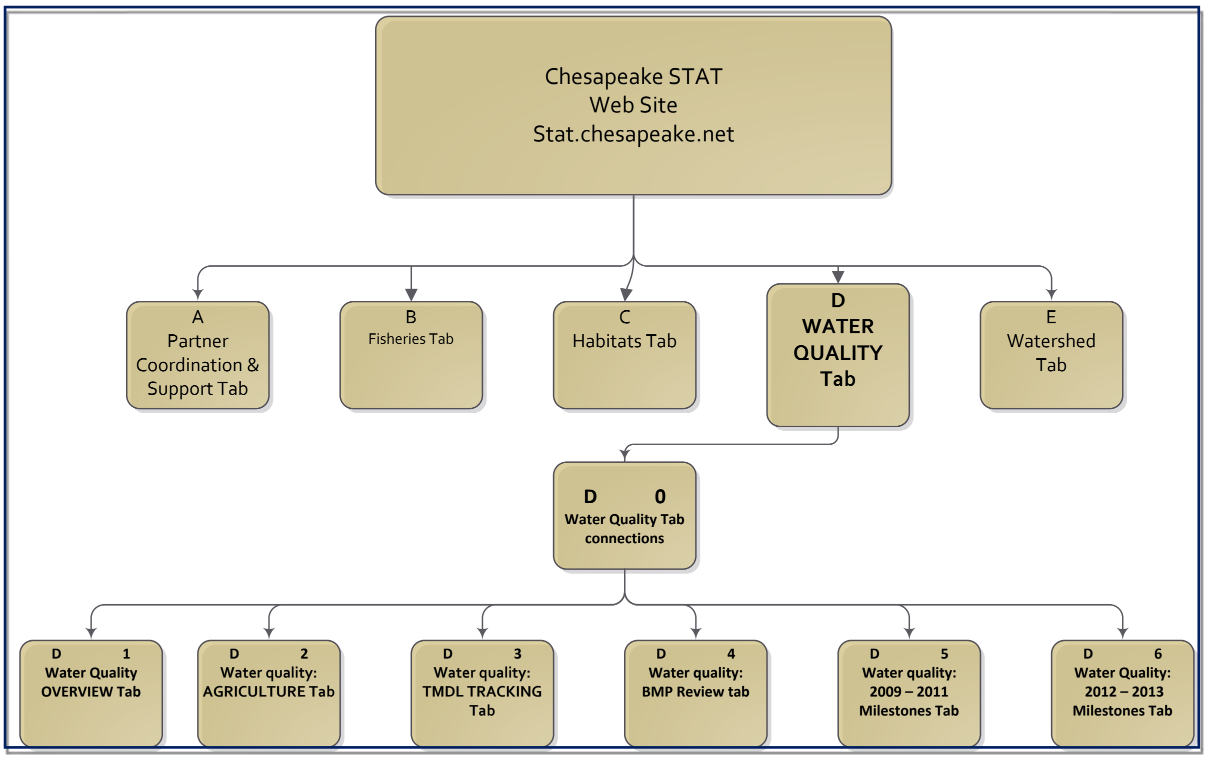
WQX Exchange schema v. 2.1 (abbreviated form)

Category	Subcategory	Data Element XML Tag	WQX Definition
	Biological Habitat Index	BiologicalHabitatIndex	Header; This section allows for the reporting of habitat and biotic integrity indices as a representation of water quality conditions.
	Biological Habitat Index	IndexType	Header; This section identifies the index type reported as part of a biological or habitat index.
	Biological Habitat Index	IndexTypeCitation	Header; Provides additional description of the source that created or defined the index.
MONITORING ACTIVITY	ACTIVITY Description	Activity	Header; This section allows for the reporting of monitoring activities conducted at a Monitoring Location
	ACTIVITY Description	ActivityStartTime	The measure of clock time when the field activity began.
	ACTIVITY Description	ActivityEndTime	The measure of clock time when the field activity ended.
	ACTIVITY Description	ActivityDepthHeightMeasure	Header; A measurement of the vertical location (measured from a reference point) at which an activity occurred.
	ACTIVITY Description	ActivityTopDepthHeightMeasure	Header; A measurement of the upper vertical location of a vertical location range (measured from a reference point) at which an activity occurred.
	ACTIVITY Description	ActivityBottomDepthHeightMeasure	Header; A measurement of the lower vertical location of a vertical location range (measured from a reference point) at which an activity occurred.
	BIOLOGICAL ACTIVITY Description	BiologicalActivityDescription	Header; This section allows for the reporting of biological monitoring activities conducted at a Monitoring Location
	BIOLOGICAL Habitat Collection Information	BiologicalHabitatCollectionInformation	Header; Allows for the reporting of biological habitat sample collection information
	BIOLOGICAL Habitat Collection Information	ReachLengthMeasure	Header; A measure of the water body length distance in which the procedure or protocol was performed.
	BIOLOGICAL Habitat Collection Information	ReachWidthMeasure	Header; A measurement of the reach width during collection procedures.
	BIOLOGICAL ACTIVITY Net Information	NetInformation	Header; Allows for the reporting of net sample collection information
	BIOLOGICAL ACTIVITY Net Information	NetSurfaceAreaMeasure	Header; A measurement of the effective surface area of the net used during biological monitoring sample collection.
	BIOLOGICAL ACTIVITY Net Information	NetMeshSizeMeasure	Header; A measurement of the mesh size of the net used during biological monitoring sample collection.
	BIOLOGICAL ACTIVITY Net Information	BoatSpeedMeasure	Header; A measurement of the boat speed during biological monitoring sample collection.
	BIOLOGICAL ACTIVITY Net Information	CurrentSpeedMeasure	Header; A measurement of the current during biological monitoring sample collection.
	SAMPLE Description	SAMPLE Description	Header; header in schema for Sample only
	SAMPLE Description	SampleCollectionMethod	Header: Identifies sample collection or measurement method procedures. Where a documented sample collection method has been employed, this enables the data provider to indicate the documented method that was employed during the field sample collection. Otherwise, the sample collection procedure will best be described in a freeform text.

WQX Exchange schema v. 2.1 (abbreviated form)			
Category	**Subcategory**	**Data Element XML Tag**	**WQX Definition**
	SAMPLE Prep	SamplePreparation	Header This section describes a sample preparation procedure which may be conducted on an initial Sample or on subsequent subsamples.
	SAMPLE Prep	SamplePreparationMethod	Header Identifying information about the method(s) followed to prepare a sample for analysis.
	ACTIVITY Metric	ActivityMetric	Header; This section allows for the reporting of metrics to support habitat or biotic integrity indices.
	ACTIVITY Metric	ActivityMetricType	Header; This section identifies the metric type reported as part of an activity metric.
	ACTIVITY Metric	MetricValueMeasure	Header; A non-scaled value calculated from raw results that may be scaled into a metric score.
	Activity Binary Object	ActivityAttachedBinaryObject	Header; This section allows for the association of References and electronic attachments to the Activity description including any other documents, images, maps, photos, laboratory materials, geospatial coverages, and other objects associated with the Project..
RESULT	Result Description	Result	Header; This section describes the results of a field measurement, observation, or laboratory analysis.
	Result Description	ResultMeasure	Header; The reportable measure of the result for chemical, microbiological, or other characteristics being analyzed.
	Result Description	DataQuality	Header; The quantitative statistics and qualitative descriptors that are used to interpret the degree of acceptability or utility of data to the user.
	Result Description	ResultDepthHeightMeasure	Header; A measurement of the vertical location (measured from a reference point) at which a result is obtained.
	BIOLOGICAL Result Description	BiologicalResultDescription	Header; This section allows for the reporting of biological result information.
	BIOLOGICAL Result Description	GroupSummaryCountWeight	Header: Captures the total count or total sample weight for a Group Summary
	Result Taxonomic Details	TaxonomicDetails	Header; This section allows for the further definition of user-defined details for taxa.
	Result Taxonomic Details	TaxonomicDetailsCitation	Header; Identifies the source that created or defined the Taxonomic Details.
	Result Frequency Class Information	FrequencyClassInformation	Header; This section allows for the definition of a subgroup of biological communities by life stage, physical attribute, or abnormality to support frequency class studies.
	Result LAB Info	ResultLabInformation	Header; Information that describes information obtained by a laboratory related to a specific laboratory analysis.
	Result LAB Info	AnalysisStartTime	The local time and relative time zone when the analysis began.
	Result LAB Info	AnalysisEndTime	The local time and relative time zone when the analysis was finished.
	Result Detection Quantitation Limit	ResultDetectionQuantitationLimit	Header; Information that describes one of a variety of detection or quantitation limits determined in a laboratory.

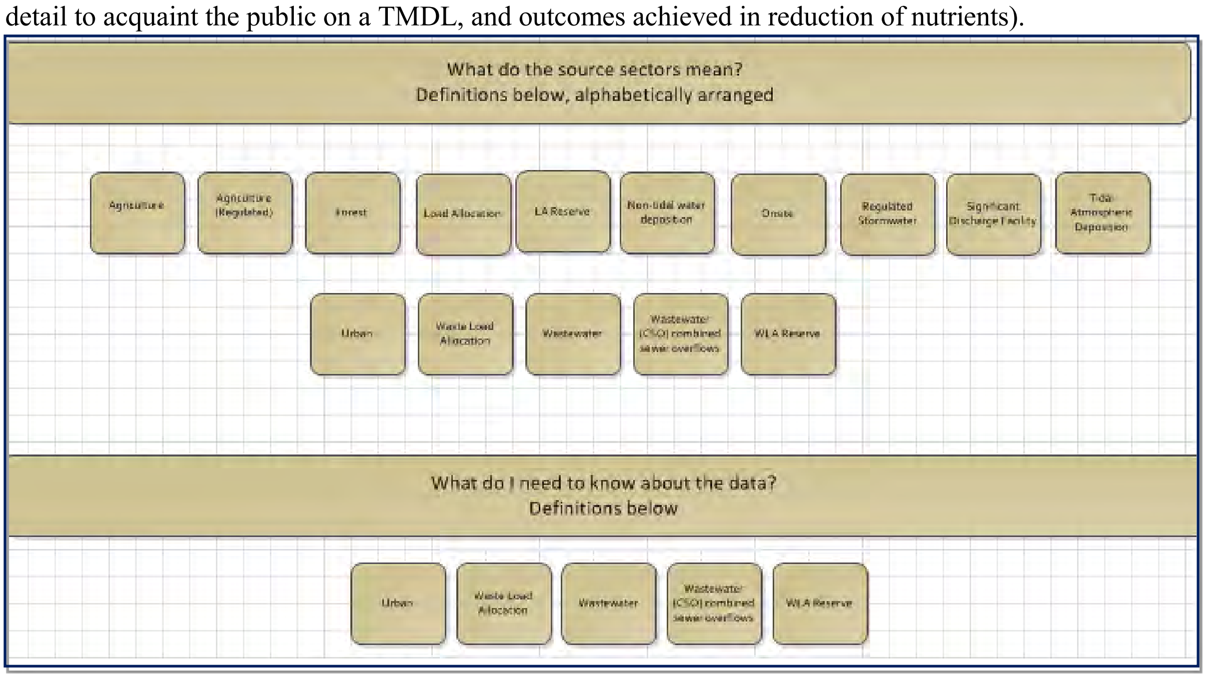
WQX Exchange schema v. 2.1 (abbreviated form)			
Category	**Subcategory**	**Data Element XML Tag**	**WQX Definition**
	Result Detection Quantitation Limit	DetectionQuantitationLimitMeasure	Constituent concentration that, when processed through the complete method, produces a signal that is statistically different from a blank.
	LAB Sample Prep	LabSamplePreparation	Header; Describes Lab Sample Preparation procedures which may alter the original state of the Sample and produce Lab subsamples. These Lab Subsamples are analyzed and reported by the Lab as Sample results.
	LAB Sample Prep	LabSamplePreparationMethod	Header; Identifying information about the method followed to prepare a sample for analysis
	LAB Sample Prep	PreparationStartTime	The local time when the preparation/extraction of the sample for analysis began.
	LAB Sample Prep	PreparationEndTime	The local time when the preparation/extraction of the sample for analysis was finished.
	ACTIVITY Group	ACTIVITY Group	Header; Allows for the grouping of activities

APPENDIX C: Overall Web Flow of ChesapeakeStat Site



Above are the primary tabs for navigation of the Water Quality section of the CB website. The Water Quality Tab is expanded into tabs D1 through D6 (above). These are the main tabs evaluated for the analysis project. Sample pages from the website which are representative of the types of presentation and formatting recommended for the Minnesota project are contained below in APPENDIX D.

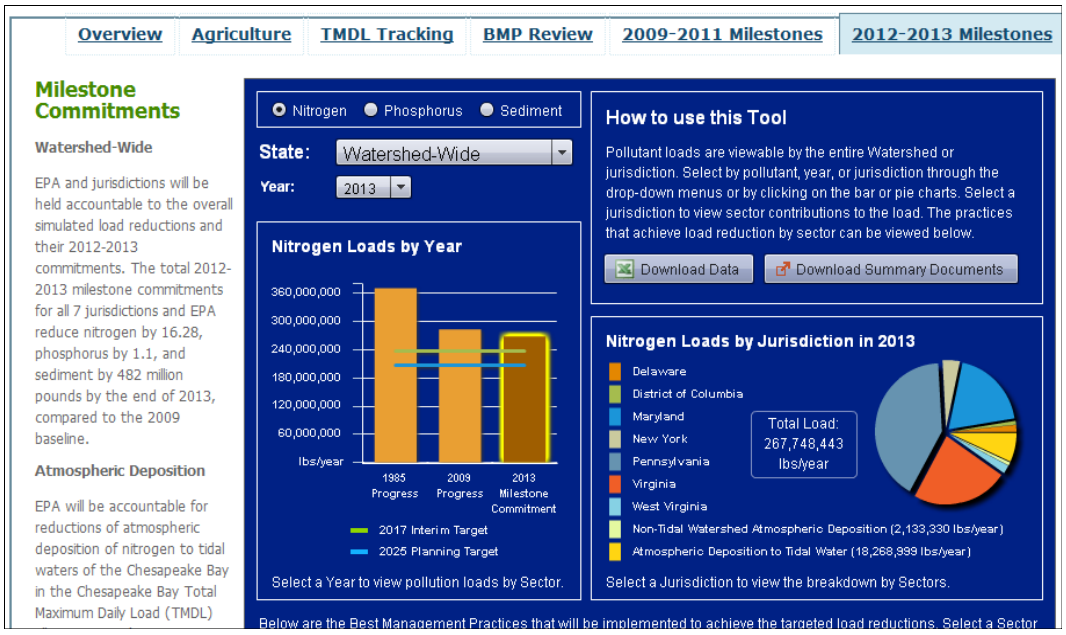
The following shows the D3 Tab TMDL detailed steps presenting the TMDL elements (specific definition, detail to acquaint the public on a TMDL, and outcomes achieved in reduction of nutrients).



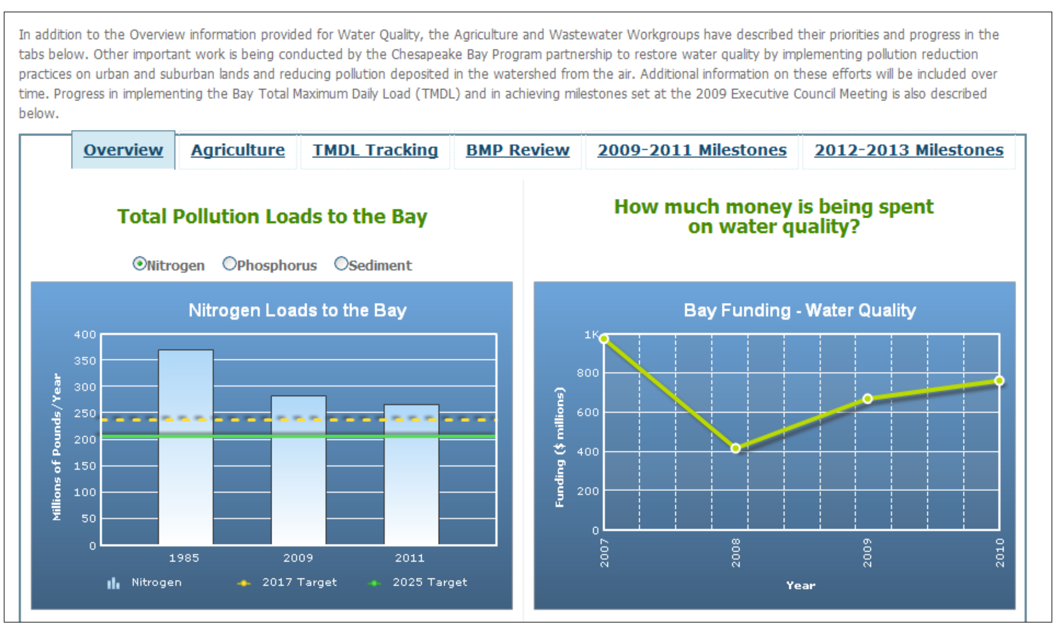
APPENDIX D: Examples of ChesapeakeStat Website Pages for Visual Reference

Partial Sampling of Interactive Charts and Maps from the ChesapeakeStat website which provide a visual presentation of water quality data and how it might be presented to convey nutrient reduction targets set and achieved over 25 years for the Bay estuary.

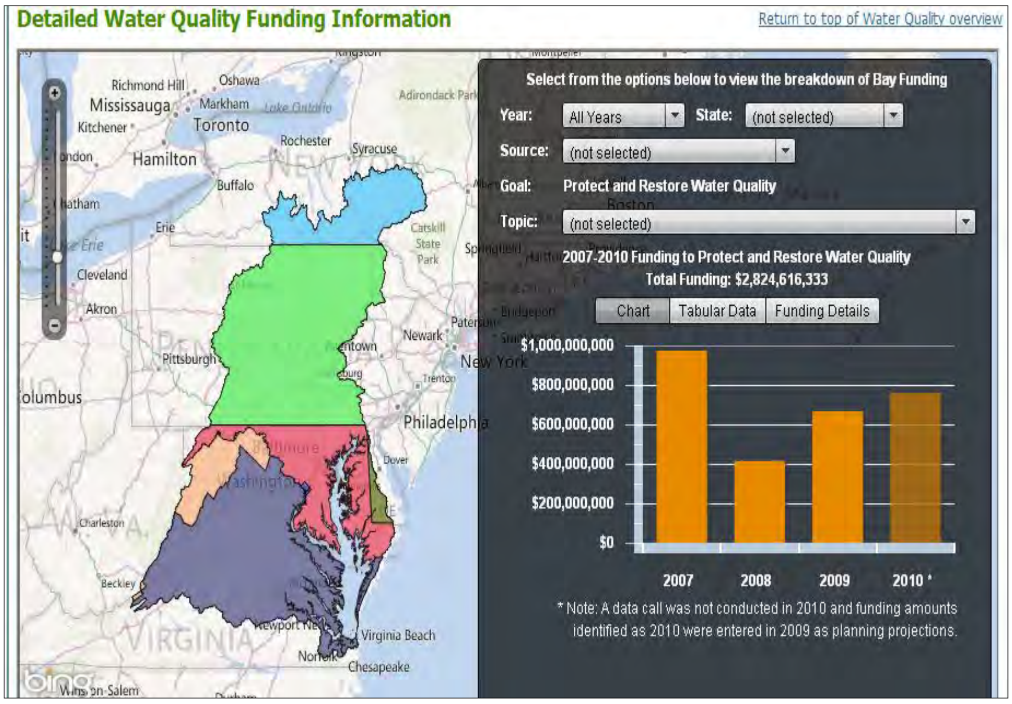
Milestones 2012-2013



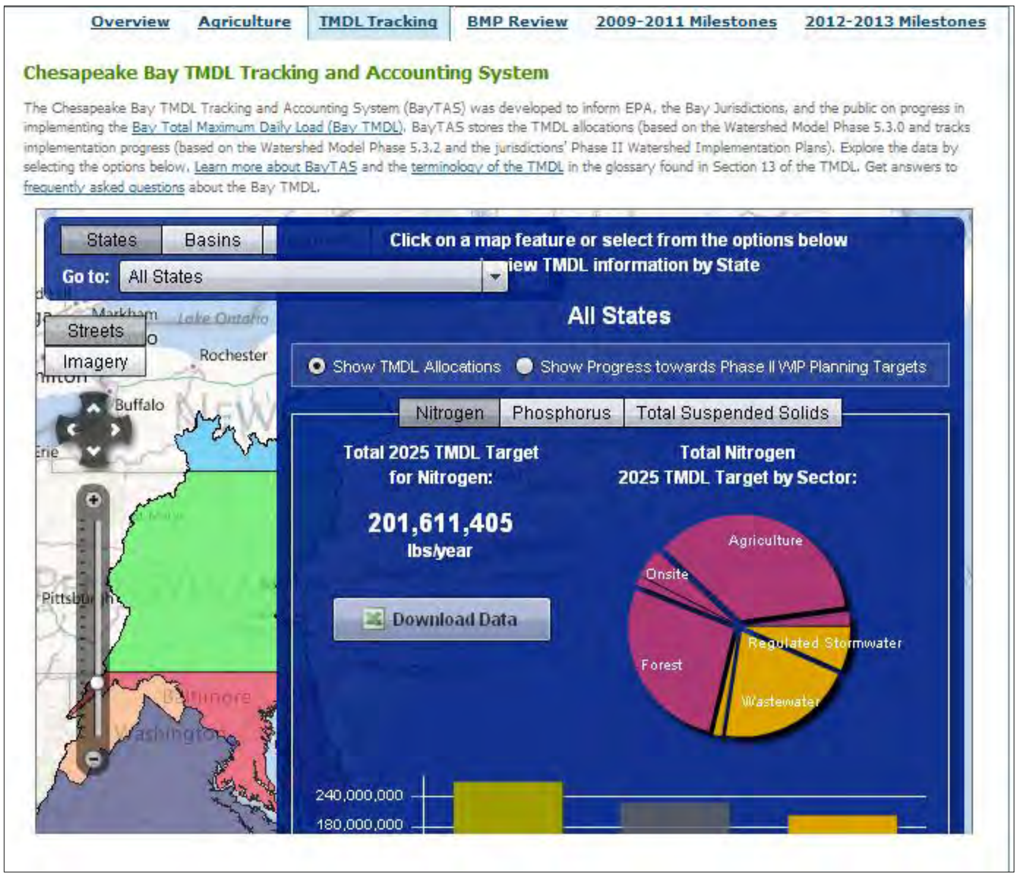
Overview: Pollution Loads and Funds Spent



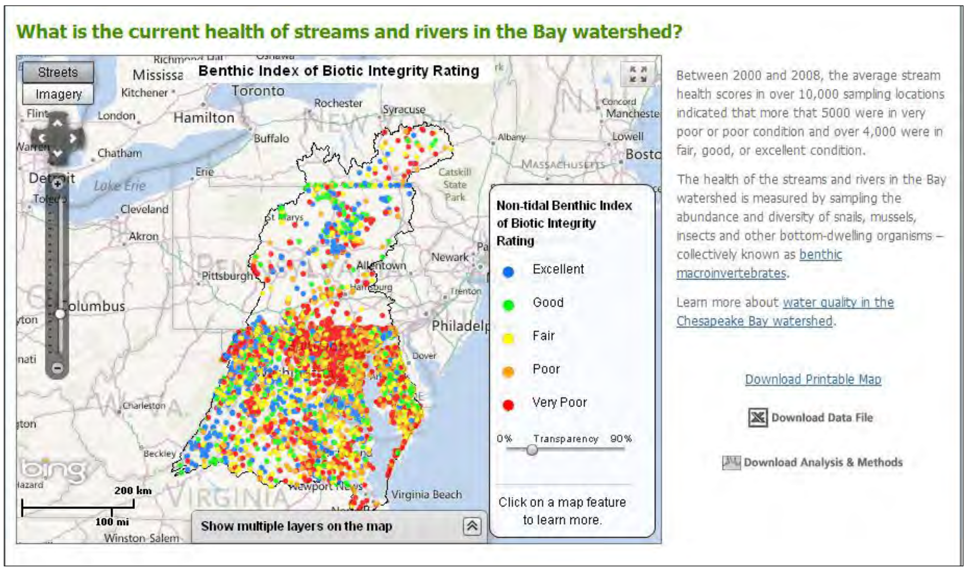
Detailed Water Quality Funding by State, Year, Source, Goal & Topic



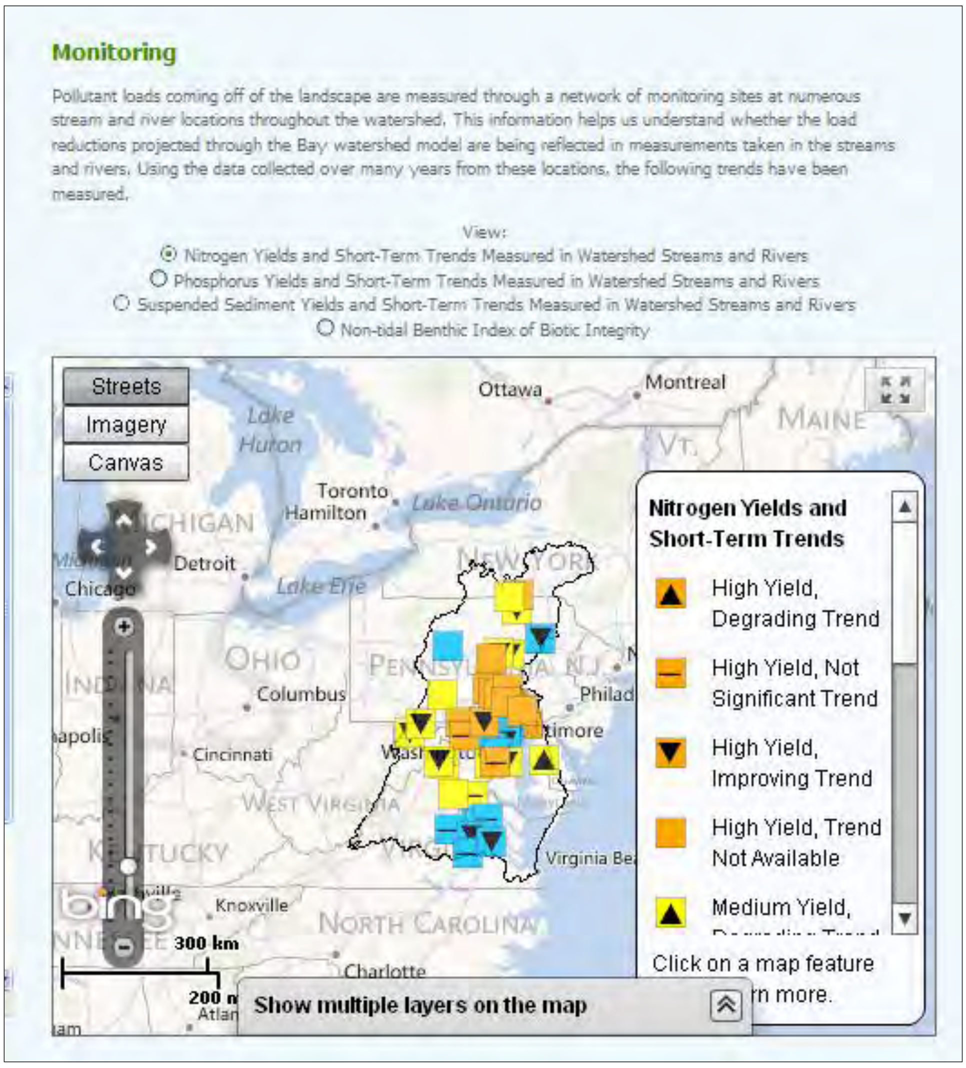
Interactive Map/Chart for TMDL tracking by State, Basin and Pollutant



Interactive Map tool showing Major Basin Health



Interactive Map/Chart for Monitoring Strategy by Pollutant



End of Report

Appendix H: Tracking Tool Recommendations

Purpose of this Document

Tracking progress toward the Minnesota Nutrient Reduction Strategy (NRS) goals and milestones requires a wide array of program output and water quality outcome data and information from federal, state, and local partners and stakeholders. While a variety of tracking tools exist within many federal, state, and local agencies, a coordinated system for tracking nutrient reductions associated with implementation activities to support the NRS is not available.

The development of the program and water quality measures highlighted the challenges associated with compiling the data necessary to quantify implementation activities and nutrient loads by major basin. The data compiled for the suite of programmatic and water quality measures vary in collection methodology and frequency, documented in the measure metadata worksheets provided in Appendix F of the NRS. Data from several nutrient reduction programs are tracked through grant or program-specific systems such as BWSR's eLink. Over time, an inter-agency, integrated tracking tool will provide a more systematic approach for compiling the data from the various programs to support regular assessments of the NRS's progress and reporting to key stakeholders within and outside of Minnesota.

This document provides an overview of the preliminary requirements for a NRS tracking tool, as well as information on existing data management systems related to program measures, and an overview of IT efforts taking place in Minnesota that could affect the development of a NRS tracking tool. It concludes with recommendations on the type of tracking tool Minnesota should be considered to support progress tracking and reporting for the NRS goals and milestones, with both short- and long-term proposed tasks and estimated costs for tool development.

Preliminary NRS Tracking Tool Requirements

In information management system development, the term *requirement* is used to describe a feature, behavior, or performance goal expected from an information management system. In this context, requirements are the features and performance goals needed from a tracking tool to support the NRS. There are three types of requirements involved in the system development process: 1) business requirements, 2) user requirements, and 3) non-functional requirements. A description of each type of requirement is provided below. The sections below discuss preliminary system requirements. These requirements are by no means comprehensive; they represent requirements gleaned from the information provided by MPCA staff through the NRS development process. A more rigorous requirements analysis would be required prior to system development, but the information here could serve as a starting point.

Business Requirements

Business requirements provide the high-level vision for the NRS tracking tool. They explain the compelling reasons for the NRS tracking tool, including the expected benefits. At the highest level, these requirements define what would be expected for the tracking tool to be successful. The business requirements will enable MPCA and other agencies involved in NRS implementation to measure the success of the tracking tool by tracing the requirements through the tracking tool design into tool use so that every element of the tool can be evaluated against these overarching requirements. Table 1 presents the high-level business requirements identified through discussions with MPCA staff and a working knowledge of the NRS's tracking needs.

Table 1. Preliminary High-level Business Requirements and Priority for the NRS Tracking Tool

BR ID	High-level business requirements	Priority
BR1	Track BMP implementation related to the NRS, including the key BMPs identified under selected program measures implemented by state agencies and federal agencies	High
BR2	Improve process and information management efficiency among many state and federal agencies, as well as local-level partners	High
BR3	Extract BMP information (type, location, date of implementation, treatment area, size of BMP) from existing data management tools and systems associated with key programs reflected in program measures	High
BR4	Calculate or estimate the phosphorus and nitrogen load reductions associated with BMPs	High
BR5	Track nutrient reductions associated with BMP implementation over time against Phase I Milestone s	High
BR6	Track implementation of BMPs by major basin and HUC8	High
BR7	Track BMP implementation implementation-related activities related to other state agency programs including Farm Bill programs	High
BR8	Track BMPs implemented voluntarily by landowners that are not affiliated with specific governmental programs	High
BR9	An effective tool for making adaptive management decisions that will ensure that nutrient reduction activities will coincide with monitored water quality information	High
BR10	Provide data to support communicating with member states along the Mississippi River Basin and the Gulf of Mexico Task Force about Minnesota's contribution of nutrients	High
BR11	Support timely communication with the public and nutrient sources when goals and reductions are or aren't achieved	High
BR12	Provide web-accessible implementation progress information for all stakeholders	High
BR13	Integrate with ongoing MPCA IT initiatives and other statewide IT data considerations	High
BR14	Track BMP costs where cost information is available	High

User Requirements

The user requirements describe the processes and tasks that system users need to perform their job. For the NRS tracking tool, user requirements include tracking specific BMPs in the program measures, using pre-determined effectiveness values for nitrogen and phosphorus for each type of BMP, extracting data from existing agency systems, and providing information in useable formats such as Excel spreadsheets, GIS mapping, and charts. Table 2 provides a preliminary list of the user requirements that a NRS tracking tool for Minnesota should address and links these user requirements to the high-level business requirements described in the previous section.

Table 2. Preliminary User Requirements and Related Business Requirements for the NRS Tracking Tool

UR ID	User Requirements	Related BR ID
UR1	The system should track the specific BMPs in the program measure metadata worksheets used to quantify implementation in the NRS	BR1, BR3
UR2	The system should use pre-determined effectiveness values for phosphorus and nitrogen removal assigned to each BMP	BR4, BR5
UR3	The system should extract data from eLink, the RIM database, NRCS database for EQIP, FSA database for CRP, AgBMP database, WQ Delta database.	BR2, BR3
UR4	The system should develop reports in tabular format using Excel spreadsheets.	BR2, BR9, BR10
UR5	The system should allow for GIS mapping of BMP locations at the HUC8 scale.	BR2, BR6, BR9, BR10
UR6	The system should generate online graphs and charts to illustrate trends over time.	BR2, BR9, BR10
UR7	The system should track nitrogen and phosphorus reductions from sector-specific BMPs against Phase I Milestone for each major basin as documented in the NRS.	BR1-11
UR8	The system should capture instream monitoring and modeling information generated by MPCA's watershed approach to show trends in instream nutrient loads at key locations.	BR5, BR9-11
UR9	The system should allow other implementation partners to manually enter voluntary BMP implementation data related to non-governmental activities through a web-based interface.	BR7, BR8, BR12
UR10	The system should track BMP and in-stream trend information at the HUC8 level	BR6
UR11	The system should allow for additional integration with future state program databases.	BR13
UR12	The system should allow for manual input of additional program information that is not stored via database.	BR8
UR13	The system should export BMP costs where cost information is available in existing systems and allow for manual input of cost information where it is not tracked in existing systems.	BR14

There are other user requirements for the NRS tracking tool that will need to be defined by potential tool users. These requirements can be defined through a requirements scoping session by answering a series of questions, including:

- How many different report structures will there be?
- What functions will be offered to the public versus backend users?
- How many users will there be?
- How many user roles and will there be and what will they be able to do?
- What are the technology and hosting requirements of the system (e.g., which agency will host the NRS tracking tool)?
- How many records will it need to manage?
- What advanced features, such as complex logic, computations and integrations with 3rd-party tools, are required to make the system successful?
- What is the final number of other systems that it must interact with, what is the complexity of each interaction, what is the maturity and stability of each peer system?
- What is the degree of GIS functionality required and what is the level of GIS data integration?

- How flexible must the system be accommodate changes in business processes? Will those changes be configured and entered by administrative users, or will they implemented by changes to programming code?

Nonfunctional Requirements

Limitations that affect one or more user or functional requirements are referred to as nonfunctional requirements. For example, "Maintain a schedule" is a functional requirement. The corresponding nonfunctional requirement might state "Do not let the schedule consume more than 10MB of disk space." Table 3 presents common types of nonfunctional requirements. Table 4 contains a preliminary list of nonfunctional requirements related to the NRS tracking tool.

Table 3. Type of Nonfunctional Requirements

Type	Description
Availability	The amount or percentage of time that the system is available for use by the users. Availability may be negatively affected by a variety of events including user error, hardware failure, external system events, unavailability of support personnel, and such.
Compatibility	The ability of the system under discussion to appropriately interact with others systems in its context
Completeness	For the domain of the system, the allowable maximum number or percentage of errors of omission
Correctness	The allowable maximum number or percentage of errors of commission
Cost of Ownership/ROI	The total costs (direct and indirect) of owning the system
Environmental	The environmental conditions in which the system must function
Extensibility	The use of the system in the same context with additional functionality
Installation Complexity	The combination of direct or indirect costs of installing the system
Parallel Processing	The ability of the system to fulfill requirements simultaneously using duplicated rather than shared resources
Performance	A measure of user expectations of system response times
Portability	The ability of the system to fulfill its requirements in more than one operating environment
Regulatory	The specific regulation(s) with which the system must be compliant
Reusability	The use of the system in a different context with the same functionality
Scalability	The ability of the system to fulfill its requirements for increasing numbers of users, transactions, and such.
Security	The requirements of the system with respect to access control and/or other context-specific security rules and/or regulations
Time to Market	The statement of the time at which the system must become available to and operable by its intended users
Training Complexity	The combination of direct or indirect costs for training the system's users
Usability	The measurement of how often, how efficiently, and/or correctly people use the system
Portability	The ability of the system to fulfill its requirements in more than one operating environment

Table 4. Preliminary List of Nonfunctional Requirements for the NRS Tracking Tool and Associated Category

NFR ID	Nonfunctional Requirement	Category
NFR1	The system should be consistent with the NRS goals, milestones and Minnesota's water quality standards	Compatibility
NFR2	The system should link to existing state agency and federal partners' tracking tools (i.e., databases, spreadsheets)	Compatibility
NFR3	The system should have the capacity to include additional information beyond the program measures over time	Extensibility
NFR4	Make it available to the public over time	Scalability
NFR5	Allow third-party volunteer information with screening	Security

Constraints

Constraints limit the system development process. They affect user and functional requirements at the management level. Table 5 contains a preliminary list of constraints based on knowledge of the NRS. More constraints would be identified in a comprehensive system requirements analysis.

Table 5. Preliminary List of Constraints for the NRS Tracking Tool

CON ID	Constraint	Priority
CON1	The system should be compatible with the new MPCA enterprise data model.	High
CON2	The system should be maintained and operated by MPCA, with accessibility by other state agencies.	High
CON4	Involve point person from each program captured through the existing program measures.	High

Ongoing Data Management Initiatives Affecting the NRS Tracking Tool Conceptualization

The timing of the NRS and the associated data tracking needs coincides with several other tracking and reporting efforts taking place within the state. This allows for the NRS's tracking needs to be incorporated into other ongoing system development and refinement projects. Examples of ongoing system development opportunities that could integrate NRS tracking needs include the following:

MPCA's Transformation Project. MPCA is currently changing their information systems to a tempo-based enterprise system. As a result of this change, all program data will be managed in a similar manner, allowing program data within the agency to be better integrated.

MPCA's Watershed Data Integration Project (WDIPs). A multi-year data integration project intended to improve MPCA's staff handling and sharing of data and information generated through the watershed management process. (http://www.pca.state.mn.us/index.php/view-document.html?gid=15386) Through the WDIP, MPCA staff are working with TMDL and WRAP program staff to develop a data capture tool to present implementation tables on MPCA's website by 2016, as required under the 2013 Clean Water Legacy Accountability Act.

Portal. Minnesota agencies are also engaging in a Portal project that would allow better inter-agency data sharing. This project is currently in the discovery stage. It would offer the opportunity to integrate MPCA's data systems with those at other key agencies, including BWSR, MDA, and MDNR.

FSA CRP System. FSA mentioned that their existing data management system is currently changing. Further information about the old system and the new system would be needed for integration into a NRS tracking tool.

There is also a need for improved data sharing among Minnesota agencies and key federal agencies working within the state, specifically FSA and NRCS. In addition there is a need for a tracking tool that would allow private-landowners or other government entities such as counties and SWCDs to provide information on voluntary conservation practices that are not related to state or federal programs and funding.

In addition to the programs and BMPs currently identified in the NRS, the NRS tracking tool will also need to capture non-governmental program information about voluntary BMP implementation from other entities, possibly soil and water conservation districts and extension programs. At this point in time, it is unclear how this voluntary BMP information is tracked at the local level and the type of systems that might be in place to manage this type of information. Tracking tool development will need to include a task to investigate data sources for voluntary BMP implementation and determine feasible mechanisms to either capture information from existing data systems with this information or allow for manual data entry from these entities via a Web-based interface.

NRS Tracking Tool Development Recommendations

Based on the review and understanding of the preliminary requirements of the NRS tracking tool and the current understanding of the technical environment, it is recommended that Minnesota consider developing a tracking tool that is conceptually similar to the Chesapeake Bay Tracking and Accounting system (BayTAS) as a starting point for development of the Minnesota NRS Tracking and Accounting System (System) using .NET, ESRI Flex or JS API and SQL Server. The concept of BayTAS is a hub and spoke tool, meaning that the tracking system pulls data from a variety of existing data sources and integrates the information according to a set of specified metrics to fulfill program tracking and reporting needs. Therefore, development of the tool requires an in-depth understanding of the existing data management systems used by information that will travel from the spokes to the hub or, in this context, the NRS tracking tool.

The functionality of the NRS tracking tool will ultimately depend on the high-level business and user requirements for the tool, coupled with information about the existing data management systems. Developing this type of tool will require additional scoping to refine the business and user requirements to further define functionality. Once a final comprehensive system analysis is complete, Minnesota can begin to develop the NRS tracking tool's Web page interface and defined functionality, using 3-5 program measures as a tracking pilot for the tool. The recommended tasks for comprehensive scoping, initial development, and long-term maintenance of the NRS tracking tool are described below.

TASK 1: IDENTIFY TRACKING TOOL TEAM

The initial task for development of the NRS tracking tool is to assemble a Tracking Tool Team that can draw from the existing ICT members, as well as include program data analysts who understand the functionality of the existing data systems that will feed the NRS tracking tool. The Team will provide input on the preliminary system requirements and aid in refining those requirements.

TASK 2: REVIEW EXISTING PROGRAM MEASURES, REFINE METRICS, SELECT MEASURES FOR TRACKING PILOT

Under this task, the NRS tracking tool team will review the existing program measures in Appendix F of the NRS and identify those that require updating or refinement.

To focus efforts and demonstrate utility from development to web reporting, the number of program measures used in the initial NRS tracking tool should be limited to 3-5. This will allow for piloting the NRS tracking tool to assess the functionality before incorporating the other measures. Once the Team identifies the 3-5 pilot program measures, work can begin to refine these program measures, using the existing measure metadata worksheets.

TASK 3: ANALYZE EXISTING DATA MANAGEMENT SYSTEMS TO SUPPORT DATA EXTRACTION AND INTEGRATION

There are several data sources that are not clearly understood at this point in time or are in transition. This task focuses on collecting detailed information on the functionality of each data management system that will contribute nutrient data to the NRS tracking tool, including the type of system, planned or existing changes, users, maintenance procedures, and other factors that could influence export of data from the contributing systems into the NRS tracking tool. This task will likely require the Team to work with data management analysts and specialists from the agencies that support the program measures.

TASK 4: IDENTIFY DATA SOURCES OR APPROACHES FOR OBTAINING VOLUNTARY OR INDUSTRY-LED BMP INFORMATION

Understanding data systems used to track voluntary and industry-led BMPs that aren't affiliated with a specific governmental program is a less straightforward task, but is necessary to ensure the NRS tracking tool provides as thorough a picture of statewide BMP adoption as possible. At this point in time, voluntary BMP implementation is a significant data gap that the NRS tracking tool should attempt to fill. Under this task, the Team would work with county soil and water conservation district staff, watershed districts, crop advisors, extension staff, and other entities working with agricultural producers to improve adoption of conservation practices and BMPs on agricultural lands. This could occur through focus group sessions or a survey to better understand 1) if these voluntary BMPs are tracked, 2) the type of systems used, and 3) potential challenges to having these entities use the NRS tracking tool to voluntarily provide this information via the Web-based interface. This information will help the Team understand the requirements necessary for reaching non-governmental BMP adoption information and how to develop NRS tracking tool in a way to capture this information.

TASK 5: CONDUCT COMPREHENSIVE SYSTEM REQUIREMENTS ANALYSIS

Using the information collected under Tasks 2-4 coupled with the preliminary system requirements documented in Tables 1, 2, 4, and 5, the Team should conduct a comprehensive system requirements analysis. Under this task, the Team would verify the preliminary requirements are accurate and identify additional user requirements based on the list of questions identified under Table 2. This analysis might benefit from facilitation by a neutral third-party with IT experience to ensure the Team answers all necessary system questions and that the analysis is comprehensive.

TASK 6: DEVELOP NUTRIENT STRATEGY TRACKING AND ACCOUNTING SYSTEM WEBPAGE

The final comprehensive system requirements analysis developed under Task 5 will then allow the Team to proceed with initial development of the NRS tracking tool using the 3-5 pilot program measures identified under Task 2.

The features described below serve as a preliminary starting point, based on Minnesota's interest in the approach used for the Chesapeake Bay tracking and accounting system (BayTAS). These features are subject to evolve based on the findings under Task 5.

1. **System Database.** Like the BayTAS, the NRS tracking tool would include an enterprise database. The NRS tracking tool database should be modeled to support short and long-term goals and allow Minnesota to add future program measures and tracking against those measures. These will also include quantitative Phase I Milestone tracking for both program outputs and environmental outcomes.
2. **Public Module:** The NRS tracking tool Public Module would display NRS metrics (e.g., program outputs and environmental outcomes) in a way that is easily understandable and meaningful to the public using a GIS interface integrated with an existing Minnesota agency website, such as MPCA or BWSR, using either ESRI Flex or Javascript viewer (not Flex viewer which was used for BayTAS). The Public Module will provide a public facing web page that will inform the state, local, and federal stakeholders of the progress being made toward the NRS goals and milestones. The agency hosting the NRS tracking tool would have full control over the data that is shared through the Public Module so that the data available is relevant, timely, and accurate. In addition to distribution of data, the Public Module will also serve as a communication and outreach tool to communicate success, improve awareness and encourage action by specific sectors key to NRS success. For example, the Planning and Management module in BayTAS provides services to the public facing portion of the application maintained by the Bay program. The same initial design could be developed for the NRS tracking tool, which will provide key features and benefits in meeting the requirements identified for NRS tracking tool and will be a starting point for further refinement using an iterative tool development process.

- ✓ Provides a flexible GIS framework and driven webpage, dedicated to NRS tracking and accounting that contains HUC8 and major basin information on progress towards implementing goals and milestones.
- ✓ As data is populated and managed in the Planning and Management Module it could be automatically visible in the Public Module using web services.
- ✓ Includes general information related to the NRS and opportunities to be engaged and provides information relevant to those responsible for implementing various aspects of the NRS and what resource may be available to assist them (e.g., funding, technical assistance).
- ✓ Displays implementation actions spatially to allow the public to see the activities going on
- ✓ Allows user to view progress across the NRS's key metrics (e.g., program output measures and environmental outcomes by basin and HUC8) to spatially communicate progress toward meeting goals and milestones
- ✓ Can be fully integrated into an existing web presence, such as BWSR's eLink, to leverage existing stakeholder awareness and to ensure consistency and recognition for the user community

3. **Planning and Management Module:** The NRS tracking tool Planning and Management Module would be designed for users who are responsible for the planning, management, and oversight of the NRS implementation activities. This would include Minnesota agency staff, partner agency staff, and other people that are recording information related to specific NRS metrics (e.g., program measure outputs and environmental outcomes). The Module would provide users with tools that allow them to enter, manage, track, account, and report all of the data related to the NRS, or future NRS metrics added to the System. This include screens for data entry and editing of basic data elements, data upload tools for streamlining loading of larger more complex data sets, a map interface for spatial tagging and viewing NRS progress and actions across the key parameters/metrics, and a reporting dashboard to provide real time metric tracking and enable enhanced decision making. The Planning and Management Module would provide a single login secure access point for all of the data being collected, analyzed, and tracked as part of the NRS.

4. **Home Page and Data Viewer**

- ✓ Password protected to allow only certain users to add/edit information.
- ✓ Home Page provides a snap shot of progress at the State, Basin, and HUC8 levels for nitrogen and phosphorus.
- ✓ Toggling capability provides the ability to view data across a variety of filters such as Delivered and Edge of Stream loadings as well as multiple data source dates or versions
- ✓ A series of action icons serve as communication and outreach tools, allowing users to generate standardized reports in various formats, providing ease access to supplemental resources, and highlighting current system functions and future enhancements.
- ✓ The site would provide access to online information identified or developed as part of this NRS tracking tool so that implementing parties can prioritize their activities and report on progress toward meeting goals and milestones, as well as program optimization goals, if desired.
- ✓ Data viewer would provide a GIS map interface with supporting tabular data dynamically updated based on map selection and filtering
- ✓ Provides spatial view of progress and implementation activities

5. **Data Admin, Milestones and Facilities**

- ✓ Data Admin screens provide straight forward data entry screens for the adding, editing, and review of relevant NRS data. Allows specified users to manage and work with their own data including adding new metrics at a later date.
- ✓ The Facility data entry module provides screens for capturing Facility location, permitting, DMR, and allocation data to allow for integrated tracking of Facilities within HUC8 watersheds.
- ✓ The Facility data entry screens are integrated with the GIS capabilities so as Facilities are added or progress data is updated they become accessible from the map interface
- ✓ Data Admin screens provide straight forward data entry screens for the adding, editing, and review of implementation Milestones for the tracking and accounting of planned activities and future progress.
- ✓ The System accommodates both quantitative and qualitative goals and milestones providing users full flexibility in capturing the planned implementation actions.
- ✓ Each goal or milestone can be linked spatially to HUC8 watersheds and basins, displayed through the map interface

- ✓ Goal and milestone tracking can be integrated with existing program databases to show a consolidated view of actual versus planned actions

6. Management Reporting

- ✓ The fully integrated and automated Management Report can be generated at any time and will reflect the most current data.
- ✓ The Management Report presents a status of the progress towards meeting the NRS goals and milestones, including WWTP nitrogen and phosphorus loads, agricultural nitrogen and phosphorus loads, aggregated loads by parameter, facility permitting action status, and overall load vs milestone target comparison.
- ✓ The Management Report can be generated in a variety of formats (PDF, Word, Excel) and can be used as both a formal communication tool as well as an internal working reporting for data analysis and decision support.

TASK 7: LONG-TERM O&M NRS TRACKING TOOL PLAN

In support of the production deployment of the NRS tracking tool, the Team should develop an Operation and Maintenance (O&M) Plan, which will address staffing, tasks, processes, and tools necessary to ensure consistent, reliable, and comprehensive production support of the NRS tracking tool. The plan should recommend O&M and hosting service level agreements to be documented in the plan to establish clear and standardized performance benchmarks to be maintained throughout the O&M period by the hosting provider.

The O&M Plan shall lay out a strategy along with the roles and responsibilities for the continued use and enhancement of the NRS tracking tool. The O&M Plan should recommend a Change Control Board that would serve as the primary decision makers regarding system priorities and enhancements and should also document the processes that will be followed for the submission of enhancement request for the Board to consider. The O&M Plan should also include technical considerations such as implementation of web services, technology enhancements, and integration with other County, State or Federal tools over time.

COST ESTIMATE

Developing the proposed NRS tracking tool is estimated between $200-$900K, depending on the full suite of comprehensive system requirements developed under Task 5. A variety of variables affect the potential cost of developing the recommended NRS tracking tool. Factors that impact costs include the following:

- Level of involvement and availability of client staff to assist with system design, data integration, and other tasks relating to designing and building the system
- Amount and types data analysis and migration that would be required to start using the system, as well who is responsible for the migration (contractor or client IT staff)
- Level of data cleanliness and corrections and/or transformations that must be applied before loading them, as well who is responsible for the data changes (contractor or client IT staff)
- How many stakeholders will provide input on the design and implementation of system, how involved will they be
- Amount and type of training and system documentation is required. How many people will be trained over how many sessions.
- Who will be responsible for system deployment and final system integration
- Who will be responsible for which types of testing

Groundwater Pollution Prevention in Southeast Minnesota's Karst Region

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Groundwater Pollution Prevention in Southeast Minnesota's Karst Region

Jeffrey St. Ores, E. Calvin Alexander, Jr., and Clifton F. Halsey*

Introduction

Approximately three-fourths of Minnesota's groundwater is contained in aquifers (water-bearing rock formations) underlying southeast Minnesota. Some of these aquifers underlie terrain classified as karst. Other aquifers, because of their cracked and jointed nature, can be considered karst aquifers.

Karst aquifers and aquifers underlying karst features are extremely susceptible to contamination. Reported cases of typhoid fever in Illinois, infectious hepatitis in Michigan, phenol poisoning in Wisconsin, and gastrointestinal illness in Missouri have all been tied to the rapid transmission of the particular disease agents through karst aquifers to the suspected water supplies.

S.P. Kingston, a former Minnesota health official, noted in 1943 that the regional groundwater system in southeast Minnesota is particularly vulnerable to contamination from many sources including surface runoff, domestic sewage, and industrial waste. Kingston, investigating an outbreak of typhoid fever in Fillmore County, concluded that infectious organisms were transmitted from the source of contamination to the wells of the infected individuals via cavernous and fissured underground limestone deposits (karst aquifers).

Many shallow wells in southeast Minnesota contain coliform bacteria and high nitrate levels—both indicators of possible contamination. Some southeast springs also contain these substances as well as traces of pesticides. Even aquifers hundreds of feet deep are considered in danger of contamination.

This publication describes the nature of karst areas and groundwaters, the extreme sensitivity of these groundwaters to many human everyday activities, and procedures which can reduce groundwater pollution potentials.

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Glossary

Agronomic rate: Amount of added nutrients (generally N, P, and K) necessary to sustain a "reasonable" anticipated crop yield. The supplemental source could be manure or inorganic fertilizer.

Aquifer: A geologic formation which yields useful amounts of groundwater. An aquifer must have an appreciable porosity and permeability and must contain drinkable water. In southeast Minnesota the bedrock aquifers are the sandstones and the karst limestones and dolomites. The alluvial sands and gravels may also yield useful amounts of groundwater —particularly in the valleys.

Aquitard: A geologic formation which does not yield useful amounts of groundwater and which retards the movement of groundwater between aquifers above and below it.

Blind valley: A valley which has no surface outlet. Blind valleys terminate in bedrock walls and are formed by disappearing streams.

Blowing well: A well which alternately blows air in and out. The movement of air indicates that the well has intersected a significant air-filled void in the subsurface.

Closed surface depression: A depression in the surface of the land surrounded by a closed contour. In a karst region such depressions often indicate the presence of a buried sinkhole.

Coarse (sandy) soils: Coarse-textured soils have a large proportion of sand-sized mineral particles. The soil is generally characterized by large pore (air) spaces and less total pore space area (relative to loams and clays). Large pores decrease the soil's ability to hold water. Reduced pore area decreases the quantity of water that can be stored at one time. Both characteristics result in rapid downward or lateral movement of water and some contaminants toward fractured limestone bedrock.

1) Coarse sands and gravels are extremely coarse.
2) Medium to fine sands and loamy sands are coarse.
3) Sandy loams and fine sandy loams are medium coarse.

Disappearing streams: A stream which sinks completely underground. The flow may sink at one or more discrete points, stream sinks, and/or it may disappear gradually over a length of the stream bed, a stream sieve. A disappearing stream is a direct connection between the surface and groundwaters.

Karst region: In this publication refers to the area underlain by carbonate bedrock. Includes, but is not limited to, that portion of southeast Minnesota exhibiting terrain classified as karst.

Losing stream: A stream which loses part of its flow into the subsurface. The loss can occur through stream sinks, or stream sieves, or both.

Normal household amounts: Refers to the amount of liquid wastes that can legally be placed in certified sanitary landfills. No absolute values have been established. But, for example, a partially full or full 5-gallon pesticide container is not a normal amount. An empty container of bleach would be a normal amount. Spent motor oil, antifreeze, and similar substances should be recycled rather than placed in landfills.

Permeability: In soil, refers to the ease with which gasses, liquid, or plant roots pass through a bulk mass of soil or a layer of soil (after Brady 1974. *The Nature and Property of Soils*).

Shallow or thin soils: Shallowness is a relative term depending on soil use. Twenty inches or less is generally considered shallow for taxonomic or soil naming purposes. However, the following definitions should be considered for use in karst aquifer protection relative to depth to limestone or water tables.

1) 50 feet or less is shallow if cesspools are being used and impermeable clay or hard bedrock layers do not separate limestone from the bottom of the cesspools.
2) 20 feet or less of coarse- to medium-textured soils is shallow if waste lagoons or holding ponds are used (measured from bottom of structures).
3) 5-10 feet of most soils is shallow if lagoons or holding ponds are used. 5-10 feet of extremely coarse- to coarse-textured soils is shallow when considering manure application, particularly waste irrigation, and manure storage methods other than lagoons or ponds.
4) 3-5 feet of coarse- to medium-coarse-textured soils are shallow when considering any activity.
5) Less than 3 feet of any soil texture is shallow for any potentially polluting activity.

Shallow well: A well which receives water from the near-surface aquifer. The aquifer tapped by each well is determined by the local geology, the depth of the well, and the construction of the well. A properly cased and grouted well only 100 feet deep may act as a deep well and avoid the surface aquifer. Conversely, an improperly constructed well 400 feet deep may be acting as a shallow well if it receives most of its water from the near surface aquifer.

Sinkhole: A closed, usually circular, depression which forms in karst areas. Sinkholes are formed by the removal of material from beneath by underground water flow. Sinkholes are *dug from the bottom* by groundwater. Sinkholes provide a direct conduit connecting surface waters with underground waters.

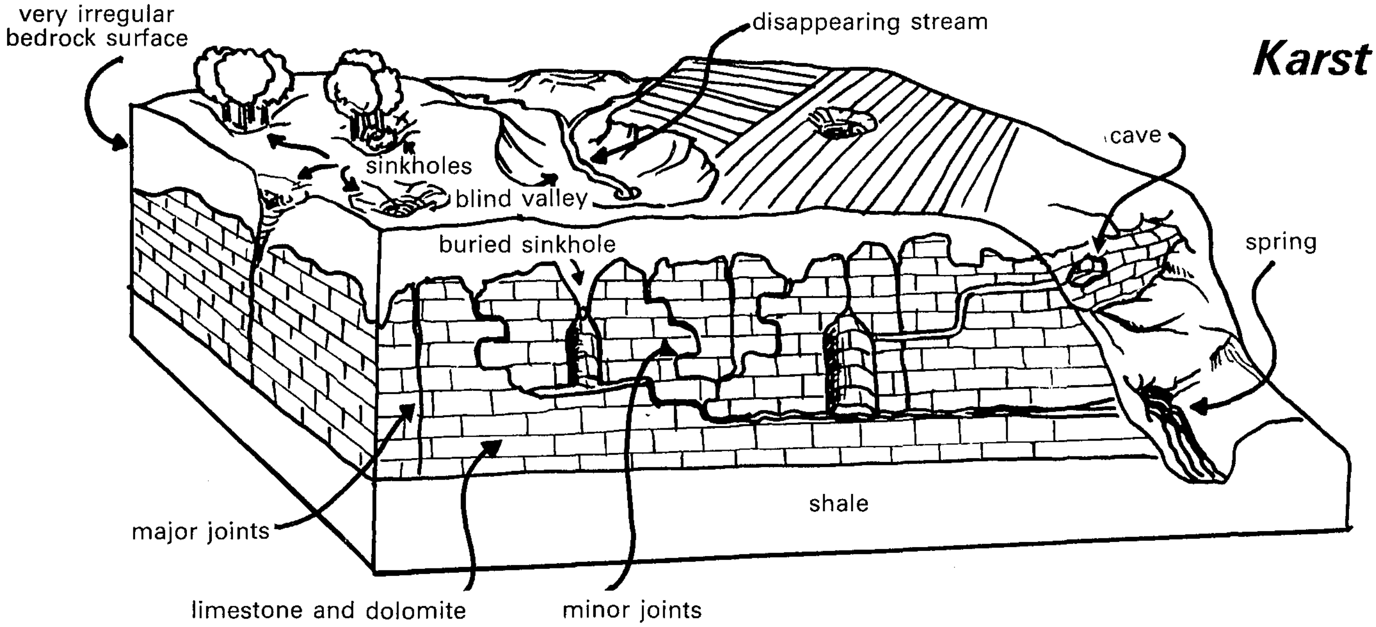


Figure 1. Block diagram showing terrain and subsurface features of karst.

Karst is a geologic term for a land area characterized by streams which disappear underground (disappearing streams) or which lose most of their flow into the ground (losing streams); valleys which have no surface outlet (blind valleys); caves, springs, and circular depressions in the earth referred to as sinkholes (figure 1). Karsts develop in areas where bedrock near the earth's surface is soluble in groundwater. The bedrock, generally limestone (calcium carbonate) or dolomite (calcium and magnesium carbonate), is normally fractured and contains numerous cracks, crevices, channels, and caves.

Karsts typically have very little flowing surface water. Most of the precipitation that starts running across the soil surface quickly disappears into underground drainage. After flowing underground for varying distances, the water will usually return to the surface in the form of springs. Runoff entering the ground via sinkholes, disappearing, and losing streams can become groundwater in hours or just minutes. Contaminants in this runoff, including soil and chemicals attached to soil, will also become part of the groundwater as evidenced by the number of shallow

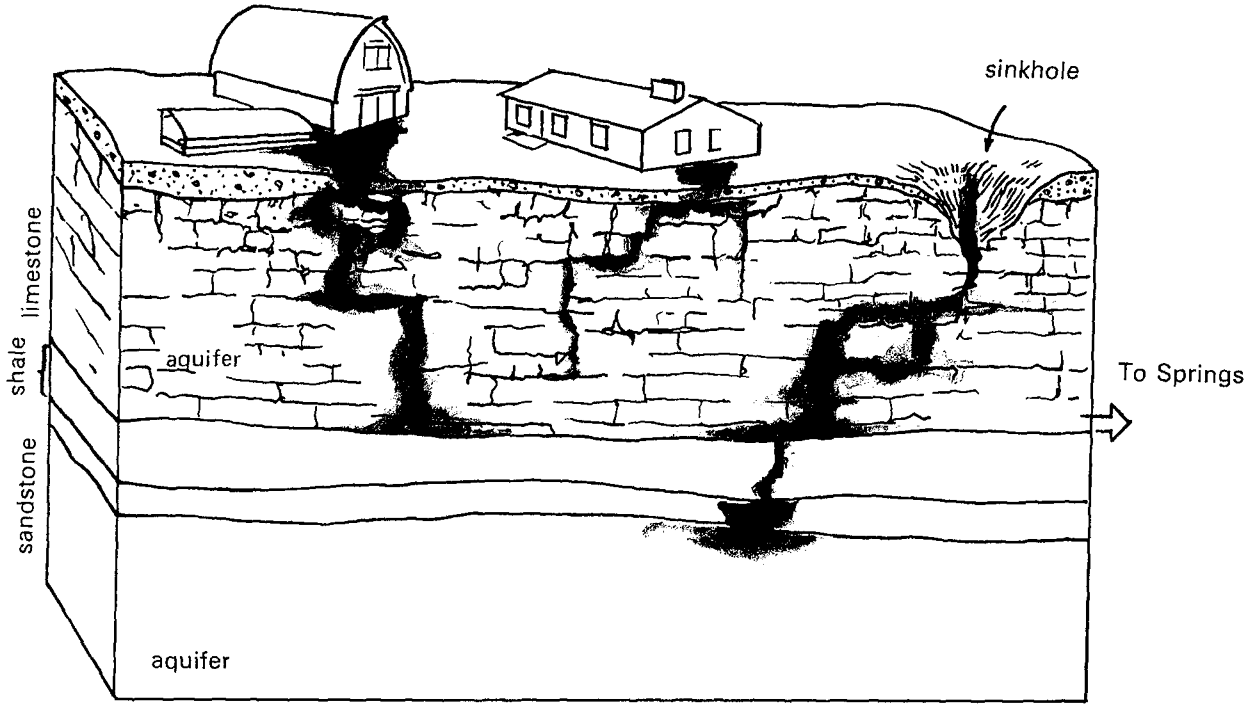


Figure 2. Contaminant movement through shallow soils, limestone bedrock and sinkholes.

southeast Minnesota wells which yield soil-rich water after heavy rainfalls.

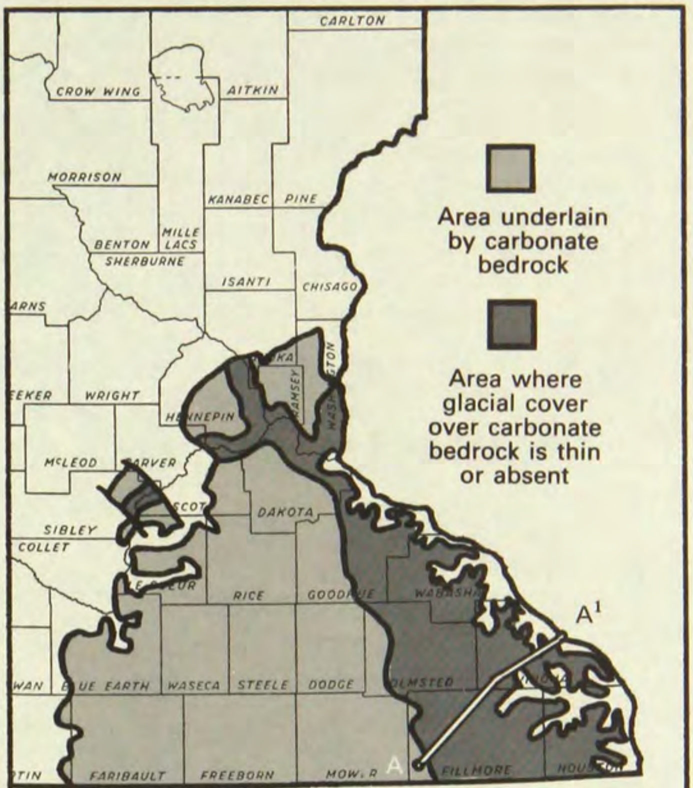
Karst aquifers are fractured and partially dissolved limestone or dolomite bedrock containing quantities of groundwater. Groundwater flowing through the cracks and channels of karst aquifers does not come in contact with as many mineral particles as does groundwater flowing through nonkarst aquifers such as sandstone. So, not only does karst aquifer groundwater flow rapidly (flows have been measured in miles per day versus the inches or feet per year common to sandstones), but contaminants in the groundwater are not readily filtered out. As a result, contaminants can reach domestic wells located miles from the source of contamination.

Karst aquifers can underlie both karst and areas not displaying karst features. Varying thicknesses of soil separate these aquifers from the ground surface. The overlying soil and soil organisms are natural filters of water and contaminants moving down toward the aquifers. But the thinner and coarser the soil, the less the amount of purification. Additionally, sinkholes and disappearing streams can bypass this natural purification process by creating direct links between the ground surface and aquifers. Consequently, karst aquifers underlying only a few feet of soil or aquifers underlying karst are easily contaminated (figure 2).

Figure 3 shows the areas in Minnesota underlain by limestones and dolomites (karst aquifers). A series of these aquifers as well as sands and muds were deposited on top of one another millions of years ago as a sequence of oceans advanced and retreated across southeast Minnesota. The sands became sandstone aquifers and the muds became shales, which now function as aquitards or confining bedrock layers which restrict water movement and partially protect underlying aquifers from contamination. The karst and sandstone aquifers and shale aquitards are not level but rise gently in several directions, including toward the Mississippi River. Figure 4 illustrates the series of aquifers and aquitards present in an area extending from Mower County northeast toward the Mississippi River. Note the rise of the formations and the division of the aquifers into upper, middle, and lower aquifers.

A few million years ago, giant ice sheets began to advance and retreat across part of southeast Minnesota. These glaciers left thick deposits of clay, sand and gravels covering the sandstones, shales, limestones, and dolomites. But the latest group of glaciers did not cover extreme southeast Minnesota (the figure 3 area indicated as glacial cover thin or absent). The absence of the glacial deposits in this area and centuries of erosion have resulted in a thin protective cover overlying aquifers. Additionally, the rising upper aquifers and aquitard have been completely worn away in many portions of the Mississippi River border counties (note the right side of figure 4). Karst has developed in areas (for example, Fillmore and Olmsted Counties) having deep river valleys and a relatively thin, but still present, soil layer covering *upper* aquifers.

Figure 3. Karst region.



A-A1 is the line of cross section shown in figure 4

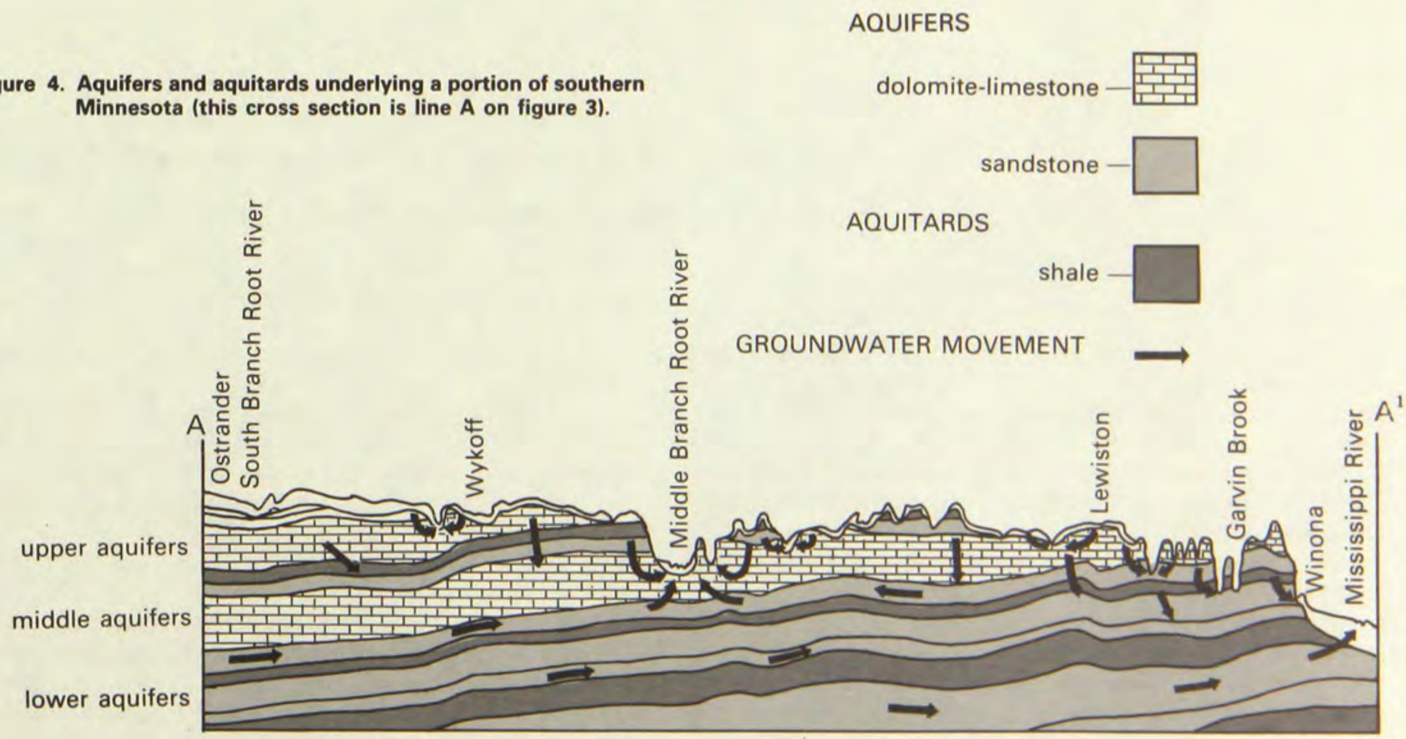
All of the area indicated in figure 3 as underlain by carbonate bedrock is sensitive to groundwater contamination. Sensitivity is lowest where both the protective glacial deposits and upper aquitard are present (the light shaded area in figure 3). Yet, scattered spots of high sensitivity occur in this western half. Pockets of shallow soils exist, and activities such as home site development and quarrying can strip away soil and decrease the distance between aquifers and the soil surface.

The eastern and northern portions of southeast Minnesota (dark shading, figure 3) are very susceptible to groundwater contamination. This high susceptibility is due in part to the occasional occurrence of karst terrain but is primarily due to the more frequent occurrence of shallow soils overlying karst aquifers. Shallow soils in parts of the Mississippi River border counties are particularly critical because they overlie *middle* karst aquifers (as noted, the upper aquifers and more important, the protective upper aquitard have disappeared).

In summary, the entire area underlain by carbonate bedrock is sensitive to groundwater pollution. But this sensitivity varies. Each piece of land (for example 40 acre segment) and underlying soil and rock formations should be examined, both to detect the presence of groundwater contamination and to determine the potential to contaminate groundwater at that particular spot. This publication cannot provide information based on such an intensive evaluation program.

However, table 1 summarizes southeast Minnesota features which indicate susceptibility to groundwater contamination. Table 2 lists human activities which

Figure 4. Aquifers and aquitards underlying a portion of southern Minnesota (this cross section is line A on figure 3).



(Source: Adapted from Hydrologic Investigations Atlas HA-548, 1975) can contribute to contamination. Use of the two tables can help in the initial evaluation of a rural area. The presence of any listed feature or activity indicates potential for pollution to take place at that particular spot and implies need for a closer look. However, only periodic well water sampling will determine the actual presence of groundwater contamination because activities occurring miles away can affect the quality of water in many wells.

Table 1. Karst features indicating high groundwater pollution potential

Indicators of direct connections from the soil surface to groundwaters.
- Sinkholes.
- Disappearing or losing streams.
- Blind valleys (see glossary).
- Closed surface depressions (see glossary).
- "Blowing" wells and wells that turn murky after storms.

Indicators of minimal separation between limestone or dolomite bedrock and the soil surface.
- Outcrops of bedrock.
- Shallow soils above bedrock (see glossary).
- Lack of surface drainage.

Table 2. Activities or structures that can contribute to groundwater pollution

1. Disposing of *any material* in sinkholes, streams, or drainageways leading to these features.
2. Cesspools.
3. Drywells (seepage pits) less than 50 feet above limestone bedrock or groundwater.
4. Drainfields with bottoms less than three feet above limestone bedrock.
5. Malfunctioning and poorly maintained septic tanks and drainfields.
6. Bypassing malfunctioning septic systems by pumping wastes into the nearest ravine, sinkhole, stream, or field.
7. Disposing of materials accumulating in septic tanks (septage) other than as called for by MPCA guidelines.
8. Improperly constructed and grouted active water wells.
9. Uncapped and unsealed abandoned water wells.
10. Pasturing animals in or near disappearing streams and sinkholes.
11. Manure storage areas and outdoor animal confinement areas not having a good soil surface seal or situated such that runoff carries pollutants from these areas to wells, sinkholes, streams or drainageways leading to wells, sinkholes, or streams.
12. Applying more manure and fertilizer than soils and crops can retain or use.
13. Applying manure and fertilizers at high runoff times to areas draining to sinkholes and disappearing streams.
14. Disposing of normal household amounts of flammable, toxic, and explosive "household" wastes in other than a certified sanitary landfill, recycling facility or waste recovery plant.
15. Runoff and erosion on crop and pastureland.
16. Disposal of full or partially full pesticide containers or contents of the containers in any area including landfills which has not been designed to contain or treat such chemicals.
17. Formulating pesticides and/or washing application equipment within 200 feet of wells, sinkholes and streams or drainageways leading to these features.
18. Failure to triple rinse "empty" pesticide containers followed by disposal of containers other than at certified sanitary landfills, drum reconditioners or recycling facilities.
19. Lack of anti-siphoning devices on pesticide applicator filling equipment.
20. Leaking above or below ground fuel, manure, silage or other storage facilities.
21. Others (see text).

Polluting Activities and Practices Which Reduce Groundwater Pollution Potential

Almost any human activity can result in groundwater contamination if the nature of karst and karst aquifers is not realized. Activities include those conducted by urbanites, suburbanites, units of government, and commerce and industry. However, this publication addresses activities associated primarily with rural residences and farms (table 2).

There are many well-known practices which can be used to minimize groundwater pollution potential in rural areas. These practices are discussed in the following pages. However, all the practices do not apply to every southeast Minnesota acre. Consultations with experts (see listing at the end of this publication) will help determine if and what practices are necessary in a particular area.

SINKHOLES

Sinkholes must not be used as disposal sites because sinkholes are direct conduits to groundwater. Placing anything in sinkholes or runoff entering sinkholes is almost like putting that material into wells. Unfortunately, garbage, herbicide cans, old railroad ties, debris from burned buildings, and other materials have been observed in sinkholes in southeast Minnesota. Feedlots draining to sinkholes have also been noted.

Attempts to eliminate sinkholes by plugging with sand and other fill materials can prove ineffective. Subsurface water and soil processes responsible for sinkhole formation may be accelerated by improper filling procedures. Contact university geologists trained in karst phenomenon and United States Department of Agriculture-Soil Conservation Service (USDA-SCS) staff for help in determining if sinkhole plugging will work.

Diverting potentially polluted runoff. Keeping runoff away from sinkholes is a pollution control practice, provided the diverted water does not trigger new sinkhole formation. Again, it is important for geologists and SCS or local Soil and Water Conservation District (SWCD) staff to help determine the feasibility of diversion.

Fencing around sinkholes. This practice protects animals from possible injury; discourages dumping of materials into holes; and may result in natural vegetation growing up around sinkholes.

Growing natural vegetation around a sinkhole. Natural vegetation creates a buffer zone which filters pollutants out of runoff. Guidelines for buffer zones have not been developed, but new guidelines applicable to feedlots may prove worthwhile. Alternatively, research indicates that forest or grass buffer strips from 50-100 feet wide greatly reduce nitrogen concentrations in runoff. Widths down to 13 feet have also proved effective. Perhaps 25 feet should be a minimum width around sinkholes.

HOME SEWAGE TREATMENT

Based on rural population, there could be at least 15,000 home sewage treatment systems just in Fillmore, Houston, Wabasha, and Winona Counties. A number of these systems were likely installed without knowledge of karst, and do not use sufficient soil for adequate treatment. Such systems may be a major source of groundwater contamination.

Agricultural Extension Service publications (see page 18) discuss in detail, system evaluation, design, and maintenance. The publications and local extension agents, SCS staff, zoning administrators, and regional Minnesota Pollution Agency (MPCA) staff should be consulted for specific information.

Systems. Common sewage systems are septic tanks and drywells, septic tanks and drainfield trenches or beds, and cesspools.

- *Cesspools* can no longer be legally installed. Raw sewage is discharged into a leaky tank. The soil around the cesspool eventually seals and the sewage surfaces, constituting a health hazard. Or the cesspool is in contact with fractured bedrock and the sewage discharges without treatment.

- *Drywells* (alternately called leaching pits or seepage pits and incorrectly called cesspools) are small confined areas receiving wastes from septic tanks. Dry wells can be a poor choice in karst areas because sewage from drywells encountering fractured bedrock can move directly into channels leading to groundwater. Individual Sewage Treatment System Standards (WPC-40) of the MPCA states that seepage pits shall not be installed "in areas where limestone or any geological formation characterized by similar fault patterns is covered by less than 50 feet of earth."

Additionally, drywells should not be installed in the following instances: where domestic water wells shallower than 50 feet are used; in soils having a percolation rate slower than 30 minutes per inch or where the percolation rate of any soil layer contacting the drywell side or bottom is faster than 0.1 minutes per inch; or when barrier rock such as clay and nonfractured bedrock or the known level of the groundwater table would be less than 3 feet below the drywell bottom.

- *Soil absorption fields* such as drainfield trenches or beds are subsurface systems which receive effluent from septic tanks. Drainfield trenches are 18-36-inch-wide excavations on the contour into which trench rock (¾-2½ inches) and a 4-inch distribution pipe are placed. The trench rock is backfilled with the removed topsoil. A slime layer of organisms, called an organic mat, forms at the contact point between the trench rock and the underlying soil. Both the organic mat and the soil treat the effluent. But at least 3 feet of aerated soil below the trench bottom is necessary for adequate treatment. Less than 3 feet of suitable soil between the trench and underlying fractured bedrock or sandstone can result in inadequate removal of pathogens (disease causing agents) from sewage and subsequent movement of those pathogens into the groundwater. Soils having percolation rates between 0.1 and 60 minutes per inch are generally considered suitable for efficient operation of a soil absorption field.

- *Mound systems* are options for use in shallow soil areas. Effluent from a septic tank is directed to a seepage bed elevated above the original ground surface by carefully selected fill materials which maintain acceptable separation distances between the bed and shallow fractured bedrock. NCR Bulletin 130 discusses mound systems, as well as other alternative systems to use in problem soil areas.

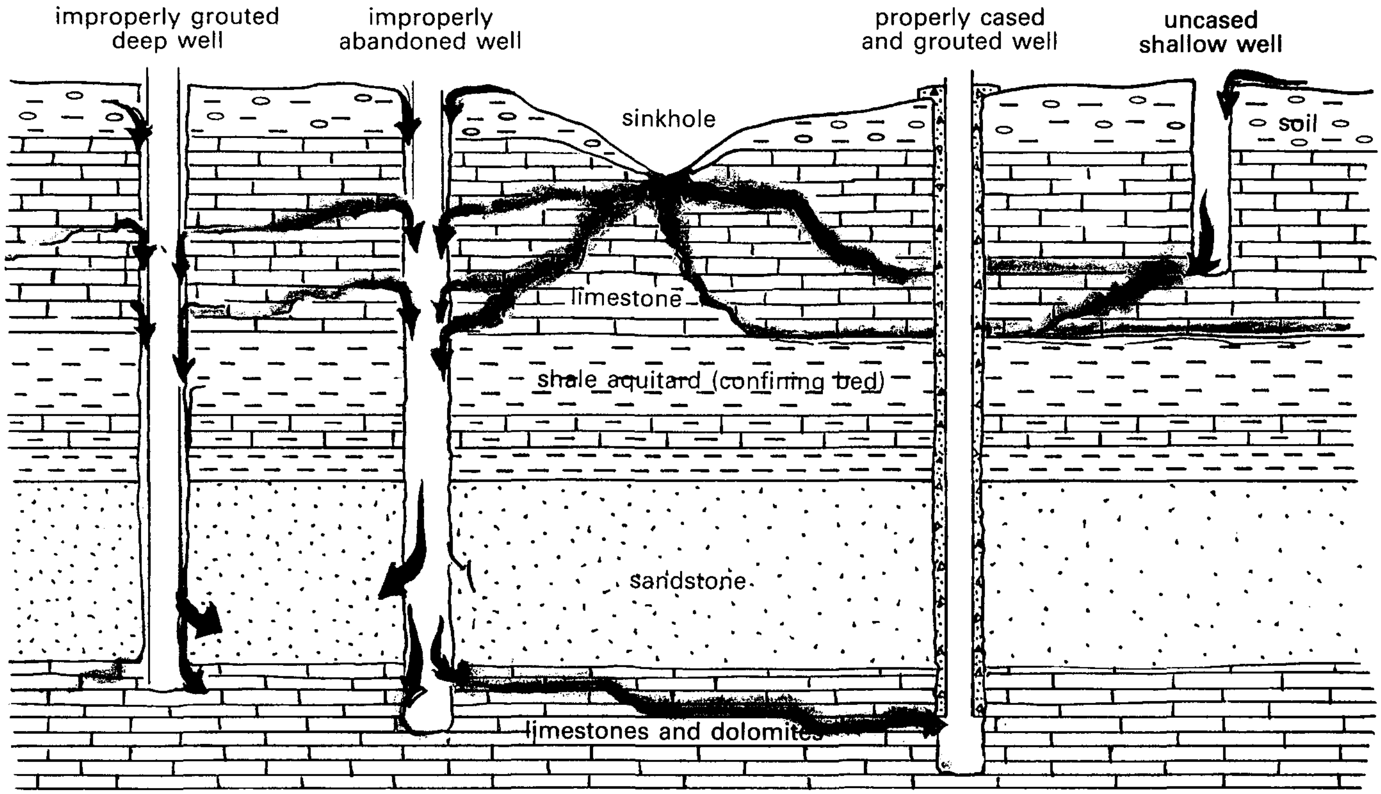
System use and maintenance. Garbage such as coffee grounds, cooking fats, disposable diapers, wet-strength paper towels, rags, and other materials which disintegrate slowly should not be put in sewage systems. These materials will rapidly fill septic tanks and if not removed periodically will flow to and clog drywells or soil absorption fields. Materials from sink garbage disposals can also clog a treatment system.

Septic tanks must be maintained and periodically cleaned out (preferably by professionals). Failure to remove accumulated materials (septage) from septic tanks can clog the system's soil absorption area. Waste may then be discharged to the ground surface and run into a stream or sinkhole if the system fails because of clogging.

Disposal of septic tank septage. Septage removed from septic tanks should be treated as a fertilizer and disposed of according to MPCA guidelines for septage disposal. Never discharge septage into quarries, ravines, sinkholes, and other karst features.

Malfunctioning systems. Have a malfunctioning treatment system immediately repaired. Running a pipe to the nearest field, ditch, or other area is not a solution to a plugged system.

Figure 5. Contamination of wells through improperly constructed or abandoned wells.



(Adapted from: Problems relating to safe water supply in southeastern Minnesota. Report to the Legislative Commission on Minnesota Resources from the Minnesota Department of Health)

WELLS

Proper well construction and abandonment procedures are essential in southeast Minnesota. Minnesota's Water Well Construction Code (7MCAR), instituted in the mid 1970s, addresses all aspects of proper well construction, maintenance, and abandonment. It further requires that wells be constructed only by drillers licensed by the Minnesota Department of Health.

Construction. Improperly constructed wells are a major pathway of pollutant movement to groundwater. Well boreholes are generally larger than well casings. A conduit is created linking the soil surface or upper soil formations to lower aquifers if the space between the wellhole walls and casings is not sealed or grouted properly (figure 5). Additionally, deteriorating and leaking casings allow materials to enter and move down the well itself. Contaminated runoff or contaminants in the upper soil layers can and will move toward wells and down the outside or inside of the well casing under the conditions just discussed.

There are, based on Minnesota Department of Health estimates, at least 14,000 active water wells in that portion of southeast Minnesota indicated on figure 3 dark shading. Estimates of the number of active wells, which need improvement or redrilling, range as high as 10,000 in the four county area of Fillmore, Houston, Wabasha, and Winona. These wells may have been drilled into shallow polluted aquifers, improperly grouted or sealed, or constructed with poor quality casing. Wells constructed prior to passage of the Water Well Construction Code are most suspect. Many existing wells should be evaluated for adequacy and, if necessary, repaired or replaced.

New well construction must comply with code requirements. Among other things, wells drilled through a number of aquifers must be sealed off from any contaminated aquifers encountered. Any spacing between boreholes and casing or between various casings must be adequately grouted and sealed. No openings should exist linking the ground surface to aquifers other than that through which water is produced. Only approved casing material should be used. Well tops should generally extend above ground and the site should be graded to divert runoff away from the well top.

Well location. Runoff, depending on site conditions, can drain toward well tops. Shallow subsurface water can also move toward wells. For these reasons, wells should be located away from potential contamination sources. At a minimum, insure that wells are located at least:

- 150 feet from a chemical preparation or storage area
- 100 feet or greater (depending on conditions) from below grade manure storage areas if these areas are in compliance with MPCA regulations
- 75 feet from cesspools, leaching pits, and drywells
- 50 feet from septic tanks, subsurface sewage disposal fields, graves, livestock yards and buildings, and manure storage piles

Wells with casings less than 50 feet deep and not encountering at least 10 feet of impervious soil should be located at least 150 feet from cesspools, leaching pits, or dry wells and at least 100 feet from a subsurface disposal field or manure storage pile.

Abandoned wells. Abandoned wells are another major source of concern. Any abandoned well which has not been filled, sealed, and covered properly is a potential pathway for pollutant movement to groundwater. Contaminants can move directly down the well itself.

Estimates of the number of abandoned wells in southeast Minnesota range as high as 9,000. Many of these have not been filled and sealed properly. The seriousness of the problem cannot be overstated. Persons knowing locations of abandoned wells should contact district or state health officials. An accurate count of abandoned wells will help officials assess the magnitude of the problem and develop programs to correct it.

Wells to be abandoned. Wells when being abandoned must be abandoned in accordance with the state code. This means doing the following:

- notifying health officials of abandonment procedures
- disconnecting the well from the system
- plugging the well hole according to the code procedures
- permanently sealing the top of the well according to code procedures

Well water testing. Have well water periodically tested for contaminants and record the results. Groundwater pollution trends may be detected before the water becomes undrinkable. Contact county community health service for well sampling instructions.

LIVESTOCK PRODUCTION

Local SWCDs and SCS technicians, and geologists, extension agents, and MPCA staff should be contacted for help in evaluating pollution potential of livestock production activities and selecting pollution control practices (including manure disposal plans).

Unconfined livestock. Animals are allowed free access to or may be pastured near disappearing and losing streams and sinkholes (figure 6). Wastes from these animals can move into the groundwater system. Practices to keep livestock away from streams and sinkholes should be used and include: well-located livestock watering facilities, vegetated buffer strips, and fencing.

Confined livestock. This section pertains to areas where animals are concentrated, including housed or partially housed animals and outdoor confinement areas such as beef feedlots, outdoor dairy feeding operations, and sow feeding pens.

Southeast Minnesota has a high density of animals (number of animals per square mile), a relatively large number of feedlots, and relatively great potential for runoff. Runoff can carry contaminants from feedlots and manure storage areas to sinkholes, disappearing and losing streams, and wells. High pollution potential exists when livestock are confined near these karst features and wells, and precautions have not been taken to prevent contaminants from entering the features. It is estimated that there are 480 total feedlots discharging wastes to streams and lakes in just Goodhue, Wabasha, Winona, Olmsted, and Houston Counties.

Feedlots and manure storage areas located on shallow sandy soils overlying fractured limestone can also pollute if the lot or storage area floors have not been sealed. Contaminants can move downward in the soil profile toward groundwater.

There are a number of practices which can reduce pollution potentials associated with confined animals.

- Runoff originating outside the lot can be diverted away from the lot or manure storage area.
- Down spouts and gutters on farm buildings can reduce the amount of runoff flowing across the lot.

Figure 6. Livestock pastured near a stream.

- Lot or manure storage area floors can be sealed. Paving may be necessary when limestone is only a few feet deep. Animal traffic can compact unpaved lot floors. This compaction reduces movement of water and contaminants into the soil and downward toward groundwater. Remove manure carefully from compacted unpaved lot floors. Avoid disturbing the lower 3-4 inch mixture of compacted soil and manure during manure scraping operations.
- Manure can be stored in storage tanks or above ground silos. These facilities when made of concrete or steel provide good assurance against leaching or runoff.
- Locate lots away from sinkholes, streams, and shallow sandy soils.
- Wastes from lots or animal housing can be collected, stored, and sometimes treated with holding ponds, settling basins, lagoons, and oxidation ditches. These structures should have sealed bottoms (either naturally or artificially sealed) particularly in areas where limestone is only a few feet deep. One group of scientists, however, (see Extension Handbook MWPS-18) suggests avoiding the use of lagoons when the lagoon bottom would be less than 20 feet above limestone (depending on soil type).

Proper land application of manure. This practice is as important as proper storage. Nitrates from manure can move downward (leach) toward fractured limestone if plants haven't used the nitrates and water is moving down in the soil. Disease bearing (pathogenic) organisms, if present in manure, can leach toward fractured limestone if the organisms are alive, soils are relatively sandy, and water is moving downward.

Additionally, nitrates and pathogens can move to sinkholes, wells, and disappearing streams by runoff and soil loss. Nitrate movement occurs primarily when manure is applied on actively melting snow or thawing ground or irrigated at a rate which causes runoff. Pathogen movement occurs when soil loss and runoff occur, provided the organisms are present and alive.

The potential for groundwater contamination from land-applied manure is real in karst areas. But this potential can be minimized by developing and following a sound manure disposal plan. Such a plan should recommend methods, timing, and amount of manure applications for individual fields based on characteristics of those fields.

The following recommendations should be considered when developing a manure disposal plan. The first three apply to all areas in southeast Minnesota and if followed, will greatly reduce pollution potential. The last six apply to especially critical areas which occur in some fields or portions of fields.

1. Apply at rates no greater than necessary to satisfy plant phosphorus (P) or potassium (K) or nitrogen (N) needs in a single year (agronomic rates). But do not exceed the agronomic rate for N. First, the N, P, and K nutrient need for the crop to be grown should be determined by the use of soil tests, with credit given for contributions from preceding legumes and past manure application. Then the amount of manure, and perhaps supplementary fertilizer, to meet this nutrient need, can be calculated based on the available nutrient content of manure after it has undergone collection, storage, and any treatment operations occurring on the farm. Periodic manure testing will help determine manure nutrient content. Publication MWPS-18 can also be consulted to obtain average nutrient values of manure.

Sometimes, areas may exist on the farm where manure can be applied at greater than agronomic N rates without the potential for excessive leaching or runoff to occur. But on-farm investigation will be necessary to locate such areas.

2. Incorporate manure soon after application (when soil depth, crop life stage, and tillage technique permit).

3. When irrigating animal wastes, apply light applications which do not exceed the soil's capabilities to retain the liquid (depth to limestone bedrock or local water tables and soil water holding capacities, percolation rates, and moisture content must be considered).

4. Limit or avoid applications including irrigated applications within 200 feet of wells, disappearing streams, and sinkholes (100 feet from sinkholes for non-irrigated wastes). Increase this distance to 300 feet (200 feet from sinkholes for non-irrigated wastes) on slopes greater than 6 percent.

5. Avoid applications on saturated soils, actively melting snow, or thawing ground on fields upslope from sinkholes, streams, and drainageways.

6. Limit or avoid applications on alfalfa fields or pastureland draining to sinkholes and disappearing streams.

7. Avoid applications on coarse sands and gravels which do not have fine clays or impermeable rocks underlying and separating the sands from limestone or local water tables.

8. Avoid applications on coarse to fine sands and loamy sands when depth to bedrock is less than 10 feet and on sandy loams when less than 5 feet. If applications are necessary, space them out throughout the year (when workload and crop life stage permit) and reduce rates below estimated crop nitrogen needs (supplement with fertilizer).

9. Limit or avoid applications on fields or portions of fields where limestone is less than 2 feet deep (refers to limestone bedrock rather than to soil containing scattered pieces of limestone). Delay incorporation as long as possible if applications are necessary. Avoid injecting manure directly into limestone.

Special recommendations may be necessary when an entire farm is a critical area (for example, all fields contain numerous sinkholes). Such recommendations can only be made with on-farm inspections, but for example could include suggestions to apply manure on fields sloping to sinkholes if the applications occurred when chances of runoff were low; or to store and treat manure prior to application.

Milkhouse and milking parlor wastes. A considerable quantity of wastes can be generated from milkhouses or milking parlors. The quantity depends on the operation, but for example, a 100-unit cow operation with automatic washing equipment can use over 800 gallons of water per day for washing operations. Wastes can include feed, bedding, hoof dirt, medicines, residual cleaning chemicals, milk, and milk solids such as fat, albumin, and lactose.

Proper disposal of these wastes is essential and is discussed in Agricultural Engineering M-sheet 159. Portions of the following text are adapted from that sheet.

Milkhouse or milking parlor wastes should be discharged to a settling tank and from there be land-applied or stored in a lagoon and land-applied later (however the cautions discussed earlier regarding lagoon use should be noted). The settling tank must be frequently cleaned out to remove manure, feed, bedding, soil, and other solids.

Subsurface treatment of milkhouse or parlor wastes has generally proved unsuccessful. Milk solids do not settle out or decompose in a septic tank but rather flow to the drainfield trench or drywell and plug the system.

Large barns have rest rooms for human waste. These human wastes must be treated separately from parlor or milkhouse wastes by using the home sewage treatment systems discussed earlier in this publication.

Figure 7. Refuse-filled sinkhole in southeast Minnesota.
(Photo courtesy of the *Journal of Freshwater*, Navarre, Minnesota)

Land spreading of milkhouse or milking parlor wastes should be done in accordance with MPCA guidelines on septage disposal or the wastes should be treated as manure and disposed of as discussed previously.

Dead Animals. Leaving dead animals on the soil surface or disposing of them in the nearest ravine, gully, sinkhole, or quarry can be hazardous. The Minnesota Board of Animal Health requires that carcasses be burned, buried, or rendered. Rendering is preferable in karst areas.

HOUSEHOLD WASTES

The average household generates considerable quantities of waste in a year. Wastes include relatively harmless and solid materials, such as paper, wood, metal cans, and food debris; and more hazardous, generally liquid materials, such as solvents, adhesives, cleansers, lighter fluids, spent oil, paint thinners, and antifreeze.

Improper disposal of household wastes will pollute groundwater and is occurring in southeast Minnesota. Sinkholes, quarries, ravines, and dumps which cannot adequately contain wastes are being used as disposal sites (figure 7). This improper disposal need not occur because a number of good waste management practices exist.

Resource recovery. This is of major importance at the household level. Pollution is eliminated; landfills do not rapidly fill and nutrients, minerals, and other resources are conserved.

- *Composting,* discussed in Agricultural Extension Service Soils Fact Sheet 12, decomposes vegetable and other organic portions of garbage. Construction and use of compost heaps recovers nutrients, requires limited effort, and should be practiced.
- *Recycling* solvents, waste oils, glass, aluminum, and newspaper is equally important. A list of recycling facilities in southeast Minnesota is presented in this publication.

Waste reduction. Avoid disposable items when reusable ones are available. Prolong the life expectancy of materials.

Waste recovery and treatment plants. These plants replace or supplement landfills. Resources are recovered or treated rather than disposed of untreated. These facilities require commitment by local government and residents.

Certified sanitary landfills. Refuse which has not been recovered can be disposed of in these containment areas. Landfills are designed to hold solid and nonhazardous wastes. But normal household amounts (see glossary) of hazardous wastes are generally allowed in landfills. Only *certified* landfills have been found suitable for waste containment. The amount of wastes placed in them should be minimized by exercising options previously discussed.

Home disposal sites. Such sites are a final but least preferable waste management technique. Nonhazardous materials, which for some reason have not been recycled or recovered, can be disposed of on the homestead. The site must be kept sanitary, and filled, and covered. At least 5 feet of slowly permeable soil should separate the bottom of the site from water tables or limestone. Ravines, gullies, quarries, sinkholes, and similar features are *not* suitable. Hazardous materials such as empty pesticide containers should not be placed in homestead sites.

TILLAGE, EROSION, AND RUNOFF

Cropland and pastureland erosion rates are usually higher in the southeast than elsewhere in Minnesota. Runoff values are among the highest and the ability of runoff and soil particles to move off the field, is as great, if not greater than, anywhere else in the state.

High runoff and erosion rates are a problem in areas of sinkholes, disappearing, and losing streams. Contaminants contained in runoff move rapidly to these features and from there to groundwater. Erosion in areas where limestone bedrock is shallow is also critical because the protective soil covering the bedrock is lost.

The primary reason for excessive cropland soil loss is fall turnplow (moldboard) tillage followed by repeated secondary tillage. Approximately 70 percent of southeast Minnesota cropland is farmed this way. Erosion on sloping pastureland is caused primarily by overgrazing, poor maintenance of vegetation, and occasionally by failing to exclude livestock from critical areas.

SWCD, USDA-SCS, and local Agricultural Extension Service personnel should be contacted for help in determining the need for and installing of erosion and runoff control practices.

Tillage. Conservation tillage is of prime importance in southeast Minnesota. Any tillage system which limits the amount of soil turned over (inverted) and leaves enough crop residues remaining after planting to cover 25 percent of the soil surface is defined as conservation tillage. The term "system" is stressed because the type of tillage can vary over time depending on past, current, and projected future crops. Specifically, different types of conservation tillage can be used or rotated, depending on the crop rotation.

Agricultural Extension Bulletin 479 deals with soil conditions and crop rotations best suited to the various types of conservation tillage. Till-planting on ridges is one conservation tillage system adaptable to a number of crops and soil conditions. No-till is adaptable to only select conditions. Additionally, no-till's effects on runoff and deep leaching of nitrates have not been clearly defined. The use of no-till must, therefore, be carefully evaluated.

Use of Bulletin 479 and consultation with local experts will aid in the selection of a conservation tillage system resulting in crop yields or net incomes comparable to those from moldboard plowing.

Other cropland erosion and runoff controls. These include contouring, strip-cropping, diversions, terraces, grassed waterways and rotations (row crop, small grain, and meadow). *Diversion and terrace construction and use should not leave limestone bedrock exposed and the amount of runoff trapped or diverted should not trigger sinkhole formation or allow direct entry of nitrate rich water into limestone.*

Waterways, diversions, and terraces should not drain into disappearing or losing streams or sinkholes.

Pastures. These should be kept properly stocked and well vegetated. Local USDA-SCS and SWCD staff should be contacted to determine if livestock exclusion from critical, erodible slopes will also be necessary.

PESTICIDES

Field applications and handling of these chemicals can contaminate karst aquifers. Extension Bulletin 428 discusses all aspects of pesticide use. Agricultural Chemicals Fact Sheet 17 discusses in detail pesticide container disposal.

Field applications. Practices which encourage runoff and erosion are primarily responsible for movement of applied chemicals toward sinkholes and disappearing streams. But sprayed liquids and applied dusts can drift under favorable conditions (for example, when temperatures are high or air is gusty and turbulent, such as between 2 and 4 p.m.). Applying in close proximity to karst features increases the likelihood of spray drift or chemical enriched soil and water entering these features.

A number of practices can reduce chances of pesticides entering groundwater.

- *Estimating chemical needs.* Proper identification of pests and an understanding of crop and pest life stages are important. Misnaming a pest and applying the wrong chemical or applying the right chemical before it is needed can result in poor control and a need for additional applications. The Agricultural Extension Service has several publications on pest identification. Pest scouting programs are also being developed which help in pest identification and selection of control practices.

- *Even applications.* Sprayer equipment should be well-maintained and cleaned to prevent leakage as well as uneven applications. Sprayers should be properly calibrated to insure application of the right amount of pesticide in the right area. Extension Bulletin 428 or Agricultural Chemicals Fact Sheet 5 describes calibration procedures. Procedures or tables may also have

Table 3. Relative mobility of pesticides in soils (adapted from Helling et al. 1971. Advan. in Agon. 23: 147-240)

Mobility Class*				
5	4	3	2	1
Dalapon** (Dowpon, Basfapon)	Picloram (Tordon 22K)	Propachlor (Bexton, Ramrod)	Bensulide (Betasan)	Chloroxuron (Norex, Tenoran)
Dicamba (Banex, Banvel)	MCPA	Prometone (Pramitol)	Prometryne (Prefas)	DCPA (Dacthal, Fatal)
Chloramben (Amiben, Vegeben)	Amitrole (Weedazol)	Naptalam (Alanap)	Diuron (Karmex, Dynex)	*Lindane*
	2,4-D	2,4,5-T	Linuron (Lorox, Afalon)	*Phorate* (Thimet, Rampart)
		Propham (Chem-Hoe, IFC)	EPTC (Eptam, Ordram)	*Parathion*
		Diphenamid (Dynid, Enide)	Vernolate (Vernam)	*Disulfoton* (Dimaz)
		Atrazine (AAtrex)	Chlorpropham (Furloe, CIPC)	Diquat (Ortho-Diquat)
		Simazine (Princep, Aquazine)	*Azinphosmethyl* (Carfene)	*Zineb*
		Alachlor (Lasso)	*Diazinon* (Basudin, Diazitol)	*Chloroneb* (Demosan, Tersan-SP)
		Ametryne (Evic)		Trifluralin (Treflan)
				Benefin (Balan, Balfin)
				Toxaphene (Motox, Toxakil)

*Class 5 compounds (very mobile) to Class 1 compounds (immobile) are in the scheme of Helling and Turner (1968). Within each class, pesticides are ranked in estimated decreasing order of mobility.
**Names of herbicides are set in roman type; insecticides, fungicides, and acaricides are in *italics*.

been included with the equipment or may be available from a pesticide dealer.

- *Use of mobile pesticides.* This should be minimized in areas of shallow soils over bedrock. Table 3 gives the relative downward mobility of some pesticides.
- *Rotate pesticides.* This reduces pests' ability to develop resistance to pesticides and reduces chances of chemical accumulation in the environment.
- *Minimize spray drift.* Extension Bulletin 428 and Folder 548 discuss procedures for minimizing spray drift.
- *Buffer strips.* Avoid applying chemicals in close proximity to sensitive areas (for example, sinkholes). A 50 foot no application area or a width consistent with vegetated buffer zones discussed earlier can serve as guidelines until research indicates differently.

Handling. The greatest misuse of pesticides occurs in the handling processes.

- *"Empty" pesticide* containers are seldom empty. Some undiluted chemical remains, Disposing of unrinsed "empty" containers or partially full or full containers in sinkholes, ravines, disappearing streams, and quarries, places chemicals in close proximity to pathways leading to groundwater. Disposal of empty containers in sinkholes and other karst features does occur in southeast Minnesota. Emptying the contents of full or partially full containers into these features or into roadside ditches is even more hazardous.

"Empty" containers should not be used to store food, feed, or water. Glass, metal, or plastic containers should be triple rinsed and this rinse water added to the makeup water of the applicator (when water is the carrier). The triple-rinsed containers as well as paper bag containers should then be disposed of in certified sanitary landfills. Metal containers can also be sent to drum reconditioners for recycling. Crush or puncture triple-rinsed metal containers before sending to a landfill.

Some landfill operators have been unwilling to accept containers fearing that the containers have not been triple rinsed. But the Minnesota Department of Agriculture is currently developing a container disposal certification program. Farmers will be encouraged to certify that they have triple-rinsed containers; reconditioners and landfill operators may then more willingly accept containers. Southeast farmers should join this program when it gets started.

Partially full or full containers which for some reason cannot be used, should if possible, be returned to the seller or manufacturer. Alternatively, a materials exchange site could be established. Consequently, farmers needing a chemical that others have in surplus can contact one another. If this is not possible, store the chemicals in a safe area and contact local officials, MPCA personnel, or the Minnesota Department of Agriculture for instructions. The stored containers should be periodically checked for leaks. Caches of arsenic based and other highly toxic pesticides should be called to MPCA officials' attention.

- *Formulation, tankfilling, and equipment washing activities,* if performed near disappearing streams, sinkholes and open-topped or improperly grouted wells can be hazardous because spilled chemicals, tank overflow, or wash water have only a short distance to travel to groundwater. These activities should be located at least 200 feet from wells, sinkholes, drainageways, ponds, and streams, and should not be sited on coarse soils overlying shallow bedrock. Never leave a sprayer unattended while the tank is being filled.
- *Lack of anti-siphoning devices* on tank filling equipment can result in dilute pesticide formulation moving down yard hydrant pipes into the soil and fractured limestone bedrock and then to groundwater (if the hydrant is shut off and the filling hose remains in the tank). Backflow in filler hoses can also occur when water pumps are used which have no devices preventing backflow (for example, pumping from a stream). Tank fillers should be equipped with anti-siphoning devices.
- *Pesticide storage* should be in original containers with labels intact. Never store pesticides with livestock feed, minerals, or other feed supplements. Pesticide storage areas should be separate and isolated from other facilities, as well as lockable. The area should be high and dry.
- *Disposal of excess chemicals in the sprayer* can be hazardous if the chemicals are indiscriminately dumped in one location—particularly in drainageways leading to sinkholes or disappearing streams or on shallow coarse soils. Carefully computing the amount of chemical formulation necessary to treat the target area and preparing no excess eliminates this problem. Excess chemicals, if remaining, should not be released in one spot. Waste pesticide solutions should preferably be land-applied at the same rate as for the target area and away from karst features.

Additionally, pesticide users may wish to consult university soil scientists to see if a portion of the farm could be used for excess applicator chemicals disposal. The area should not drain to sinkholes, well tops, or surface waters. Soil depth over limestone should be great and percolation rates should be moderately low. Cultivated fallow of the dedicated area may be necessary.

FERTILIZER USE

Excessive nitrogen fertilizer application. Applying more nitrogen fertilizer than crops can use during a year can result in excess nitrogen moving downward in the soil. Groundwater contamination can occur if the soils are sandy and the water table or limestone bedrock is near the soil surface (for example, 3-5 feet). Extension Bulletin 416 recommends fertilizer rates for various crops and yield goals. The nitrogen supplying power of soil organic matter and preceding leguminous crops is considered in the recommendations. Applying at recommended rates reduces chances of groundwater contamination—unless the expected crop yield is greatly overestimated.

Timing and manner of application. Nitrogen applied to soils at low crop demand periods (for example, late fall, winter, and spring) has the potential to leach downward if nitrogen is in the soluble nitrate form and water is moving downward in the soil profile (ammonium nitrate contains half nitrate and most other forms of fertilizer nitrogen eventually are converted to nitrate).

Applying nitrogen fertilizer to frozen ground, and at times of high runoff can result in nitrogen moving to sinkholes and streams when the site of application is near these features.

Usually, nitrogen fertilizer should not be applied on frozen ground or during the fall on coarse-textured soils (sands to loamy sands). Fall nitrogen fertilization should also be minimized on other soil types if possible. If not possible, select a nitrogen form that is not highly mobile. Incorporate nitrogen fertilizer, when possible, on high runoff fields draining to sinkholes and disappearing streams.

STORAGE FACILITIES

Leaking or ruptured storage tanks containing fuel oil, animal or human wastes, silage or chemicals result in contaminants moving toward groundwater. Underground tanks in areas of shallow soil over limestone bedrock result in only a few feet of soil separating potential leaks from channels leading to groundwater. Lack of periodic tank inspection unnecessarily increases risks.

Above ground storage facilities should be used in shallow soil areas. Periodic maintenance and inspection of both above and below ground tanks, including silos, is important. Leaks should be identified and controlled.

Summary

Figure 8. Sinkhole-dotted field in southeast Minnesota.
(Reprinted with permission from the *Minneapolis Tribune)*

Groundwater in southeast Minnesota's karst area is extremely susceptible to pollution. Shallow groundwater contamination is occurring. Contamination of deep, high-quality waters can also occur. Shallow aquifers will continue to be contaminated and deep aquifers will likely become contaminated if measures are not taken to reduce pollution.

The nature of karst areas permits many activities to contribute to groundwater pollution as well as allowing one individual to affect the quality of many individuals' well water. Consequently, all southeast Minnesota residents must consider the sensitive nature of karst areas when performing everyday activities and take measures when necessary to avoid groundwater contamination.

Practices listed in this publication can reduce pollution potential. Some require little effort to perform; others require commitment of time and money. Local experts should be consulted, however, to determine the need for and selection of the appropriate practice(s) for specific circumstances.

Finally, southeast Minnesota residents may wish to consider the development of local groundwater protection programs. Such programs might help offset the cost to individual landowners for some of the more expensive practices and insure that all individuals take measures to protect groundwater. Options for local government involvement include participation in feedlot pollution control programs; regulations governing home sewage treatment systems; development and implementation of waste recovery, recycling, or disposal plans; expanded well water testing and abandoned well identification programs; and sinkhole protection guidelines.

Helpful Agencies

Sinkholes	Home sewage treatment	Wells	Livestock and feedlots	Erosion and runoff control	Pesticides	Fertilizers	Geology	Agency
								LOCAL
■			■	■				Soil and Water Conservation Districts
■	■	■	■	■	■	■	■	Agricultural Extension Service
	■	■	■					County Health and/or Zoning
■	■	■	■	■			■	USDA-Soil Conservation Service (SCS)
			■	■			■	USDA-Agricultural Stabilization and Conservation Service (ASCS)
								REGIONAL
	■	■						Minnesota Department of Health Southeast District 1220 4th Ave. Southwest Rochester, MN 55901 (507) 285-7289
	■		■		■			Minnesota Pollution Control Agency 1200 S. Broadway Rochester, MN 55901 (507) 285-7343
								STATE
			■		■	■		Minnesota Department of Agriculture Agronomy Services Division 90 West Plato Blvd. St. Paul, MN 55155 (612) 296-6121
		■						Minnesota Department of Health Division of Environmental Health 717 Delaware St. Southeast Minneapolis, MN 55440 (612) 296-5338
■		■					■	Minnesota Geological Survey 1633 Eustis St. St. Paul, MN 55108 (612) 373-3372
	■		■		■			Minnesota Pollution Control Agency 1935 West County Road B2 Roseville, MN 55113 (612) 296-7373

Other Educational Materials

PUBLICATIONS

University of Minnesota Agricultural Extension Service publications can be obtained from local county extension offices or the Bulletin Room, 3 Coffey Hall, 1420 Eckles Ave., University of Minnesota, St. Paul, MN 55108.

Composting

University of Minnesota Agricultural Extension Service

Building a Compost Heap. Soils Fact Sheet 12

Minnesota Pollution Control Agency

Composting for a Better Garden and a Better Environment

Erosion Control

University of Minnesota Agricultural Extension Service

Tillage—Its Role in Controlling Soil Erosion by Water. Folder 479

Estimating the Effects of Crop Residue Mulches on Soil Erosion by Water. Folder 477

Grassed Waterways—Construction and Maintenance. Folder 480

Modern Terraces for Soil Conservation. Folder 499

Feedlots and Manure

University of Minnesota Agricultural Extension Service

Livestock Waste Facilities Handbook. Midwest Plan Service-18

Using Manure as a Fertilizer. Folder 168

Tax Benefits for Animal Pollution Control. Agricultural Engineering Fact Sheet 20

Minnesota Environmental Quality Board (101 Capitol Square Building, St. Paul, MN 55101)

Environmental Issues Relating to Animal Feedlots

Fertilizer

University of Minnesota Agricultural Extension Service

Fertilizer Recommendation Tables for Guide to Computer Programmed Soil Test Recommendations in Minnesota. Bulletin 416

Home Sewage Treatment

University of Minnesota Agricultural Extension Service

Town and Country Sewage Treatment. NCR Bulletin 130

Shoreland Sewage Treatment. Bulletin 394

How to Run a Percolation Test. Folder 261

Treatment and Disposal of Milkhouse and Milking Parlor Wastes. M-159

Minnesota Pollution Control Agency (1935 West County Road B2, Roseville, MN 55113)

Land Application and Utilization of Septage—Recommended Guidelines

Landfills and Recycling

Minnesota Pollution Control Agency

Recycling Information

Some Things Don't Belong in Your Trash Can

Operating a Recycling Program: A Citizen's Guide

Pesticides

University of Minnesota Agricultural Extension Service

Pesticide Applicator's Manual. Bulletin 428

How to Calculate Herbicide Rates and Calibrate Herbicide Applicators. Agricultural Chemicals Fact Sheet 5

Herbicide Spray Drift. Folder 548

Pesticide Storage and Formulation Shed. Agricultural Chemicals Fact Sheet 4

Fire Hazards of Stored Pesticides on Farms. Agricultural Chemicals Fact Sheet 1

Pesticides and Pesticide Container Disposal. Agricultural Chemicals Fact Sheet 17

Wells

University of Minnesota Agricultural Extension Service

Private Water Systems Handbook. MWPS-14

Chlorination of Private Water Supplies. M-156

Iowa State University Cooperative Extension Service (Ames, Iowa 50011)

Good Wells for Safe Water

Office of the State Register, Department of Administration, Documents Section (117 University Ave., St. Paul, MN 55155)

Minnesota Code of Agency Rules. Department of Health Water Well Construction Code (7MCAR: 1.210-1.224)

FILMS

Secrets of Limestone Groundwater. 13 minutes. Indiana University (available from Minnesota Agricultural Extension Service, Communication Resources)

TAPE-SLIDE SETS

Inquire at Minnesota Agricultural Extension Service, Communication Resources, about *Groundwater Pollution in Southeast Minnesota's Karst Region*, a companion to this publication.

Recycling Facilities in Southeast Minnesota

(check business hours with each)

DAKOTA COUNTY

Metals

Coca-Cola
Town's Edge Shopping Center
Farmington 55024
(507) 388-2951
aluminum

Coca-Cola
Mun. Liquor-Holyoke Ave
Lakeville
(507) 388-2951
aluminum

Glass

Hampton B&B 4-H Club
c/o Vernon Hupf-260th St
Randolph 55065
(507) 263-2705

Alcorn Beverage Co.
7879 218th St W
Lakeville 55044
(612) 469-5555

Faith Lutheran Church
7095 Upper 163rd St
Rosemount 55068
(612) 432-4658

Donal Tutewoht
23142 Denmark Ave
Farmington 55024
(612) 463-7489

Tim Turek
14809 Chili Ave W
Rosemount 55068
(612) 423-2888

Full service

Stoffel Beverage Co.
1272 W 8th St
Hastings 55033
(612) 437-6466
glass, aluminum

John Ginther
1226 Eddy
Hastings 55033
(612) 437-3570
glass, aluminum

Trinity Lutheran Church
413 Main St
Farmington 55024
(612) 463-8922
paper, glass

DODGE COUNTY

Metals

Coca-Cola
American Legion
Dodge Center
(507) 388-2951
aluminum

Coca-Cola
Municipal Parking Lot
Kasson-Mantorville
(507) 388-2951
aluminum

Darrel Quesnel
RR 1, Box 264A
Dodge Center 55927
(507) 374-6660
paper, corrugated, cans scrap metal, glass

Lin's Used Iron
502 3rd St. SE
Dodge Center 55427
(507) 374-2439
scrap metals, aluminum cans (not steel cans)

GOODHUE COUNTY

Metals

Coca-Cola
Hub Red Owl
Zumbrota 55066
(507) 388-2951
aluminum

Reynolds Aluminum
Pamida Store-Hwy 61 & Tylan Rd
Red Wing 55066
(800) 288-2525
aluminum

Coca-Cola
Pamida-Hwy 61 & Tylan Rd
Red Wing
(507) 388-2951
aluminum

Coca-Cola
Cannon Mall
Cannon Falls 55009
(507) 388-2951
aluminum

Buf's Truck Parts
Hwy. 56
Cannon Falls 55009
(507) 263-2226
scrap metal, aluminum cans

Glass

George Lucius
1005 W Hauffman St
Cannon Falls 55009
(507) 263-2594

Erwin Buck
610 Lincoln Ave
Zumbrota 55992
(507) 732-5836

MOWER COUNTY

Paper

First Methodist Church
204 1st Ave N
Austin 55912
(507) 433-8839

Pacelli School
311 4th St NW
Austin 55912
(507) 437-3278

Metals

Coca-Cola
Oak Park Mall
Austin 55912
(507) 388-2951
aluminum

Reynolds Aluminum
K-Mart Parking Lot
Austin 55912
(800) 228-2525
aluminum

Chas. Dubinsky & Co.
10th Dr. & 8th Ave. SE
P.O. Box 29
Austin 55912
(507) 433-3496
all metals

Gopher Distributing Co
Hwy 218 N
Austin 55912
(507) 437-3278
aluminum

Crowley Beverage Co.
617 NE 11th St
Austin 55912
(507) 433-8295
aluminum

Full Service

Delmar Ellis
Rt. 5
Austin 55912
(507) 437-1893
cans, glass, paper

OLMSTED COUNTY

Metal

Gopher Distributing Co
1640 SE 3rd Ave
Rochester 55901
(507) 288-4211
aluminum

Reynolds Aluminum
Apache Mall-Hwy 52 & 14
Rochester 55901
(800) 228-2525
aluminum

Rochester Iron & Metal
1950 3rd Ave. SE
Rochester 55901
(507) 288-3228
sheet iron, beverage cans, scrap metals (not steel cans or wire)

Coca-Cola
Apache Mall-Hwy 52 & 14
Rochester 55901
(507) 388-2951
aluminum

Coca-Cola
Boyum Foods
Stewartville 55976
(507) 388-2951
aluminum

Chaddock Truck Parts
832 14th St. NW
Rochester 55901
(507) 288-3346
scrap tin

Sexton Auto Parts & Salvage
Route 2 Box 139
Rochester 55901
(507) 282-3777
scrap metal, aluminum and steel cans

Paper

S.E. Minnesota Recycling
4802 8th St. SW
Rochester 55901
(507) 289-7510
newspaper

Glass

Rodney Watson
809 1st St SE
Rochester 55901
(507) 282-7710

Full Service

Hemker Recycling
1214 1st St NE
Rochester 55901
(507) 282-4729
glass, paper, aluminum

RICE COUNTY

Metal

Reynolds Aluminum
Faribault Plaza-Hwy 65 & Division
Faribault 55021
(800) 228-2525
aluminum

Coca-Cola
Faribault 55021
(507) 388-2951
aluminum

Harley's Auto
510 NW 20th St
Faribault 55021
(507) 334-8290
metals: all kinds

Kelley's Auto Parts
Faribault 55021
(507) 334-7035
scrap metals, batteries, aluminum cans

Viking Auto Salvage
N. Hwy. 3
Northfield 55057
(507) 645-5819
(612) 332-0660
scrap metals, aluminum and steel cans

Glass

Sunrisers 4-H Club
Rt 2
Northfield 55057
(507) 645-8185

Full Service

Consolidated Catholic Schools
Home and Schools Assoc.
Faribault 55057
glass, aluminum, newspaper, flattened cardboard

STEELE COUNTY

Metal

Coca-Cola
Prairie House Parking Lot
Blooming Prairie 55917
(507) 388-2951
aluminum

Coca-Cola
Cedar Mall
Owatonna 55060
(507) 388-2951
aluminum

Reynolds Aluminum
Pamida Store
Owatonna 55060
(800) 228-2525
aluminum

Glass

H & S Distributing Co
670 24th Ave NW
Owatonna 55060
(507) 451-4169

Owatonna Redemption Center
1031 S Oak
Owatonna 55060
(507) 451-1320

Full Service

Owatonna Reclamation Center
453 Clearview Place
Owatonna 55060
(507) 451-8846
glass, newspaper, aluminum, tin

Cumberland Hide & Fur, Wool & Metal Co.
Box 408 Route 3
Owatonna 55060
(507) 451-7607
all nonferrous metals, aluminum cans

Owatonna Scrap Iron & Metal
P.O. Box 72
Owatonna 55060
(507) 451-1470
all metals

Poly Plastic
18th St.
Owatonna 55060
(507) 451-8650
plastics, cars, newspaper, cardboard, office paper

WABASHA COUNTY

Metal

Coca-Cola
Super Valu
Lake City 55041
(507) 388-2951
aluminum

Coca-Cola
Lannings Red Owl
Plainview 55964
(507) 388-2951
aluminum

Lake City Auto Parts
Lake City 55041
(612) 345-4224
scrap metals (no cans)

WINONA COUNTY

Metal

William Miller Scrap Iron & Metal
222 W. 2nd St.
Winona 55987
(507) 452-2067
metals

S. Weisman & Sons, Inc.
450 W. 3rd St.
Winona 55987
(507) 452-5847
aluminum

Glass

Winona Distributing Co.
4450 6th St
Goodview 55987
(507) 454-1355

Township Testing Program Update-May 2022

In a seven-year statewide effort, the Minnesota Department of Agriculture (MDA) offered nitrate-nitrogen (Nitrate-N) tests to private well owners. This extensive sampling effort was conducted as a result of a major revision of the Nitrogen Fertilizer Management Plan (NFMP). The NFMP called for an assessment of nitrate conditions at the township scale. In response, a statewide Township Testing Program (TTP) was established to assess the nitrate-nitrogen (Nitrate-N) concentrations in private wells.

Townships that are vulnerable to groundwater contamination and have significant row crop production were selected for nitrate testing. Some factors that make groundwater vulnerable are soil type and geology, which control how quickly nitrate can travel from the root zone to groundwater.

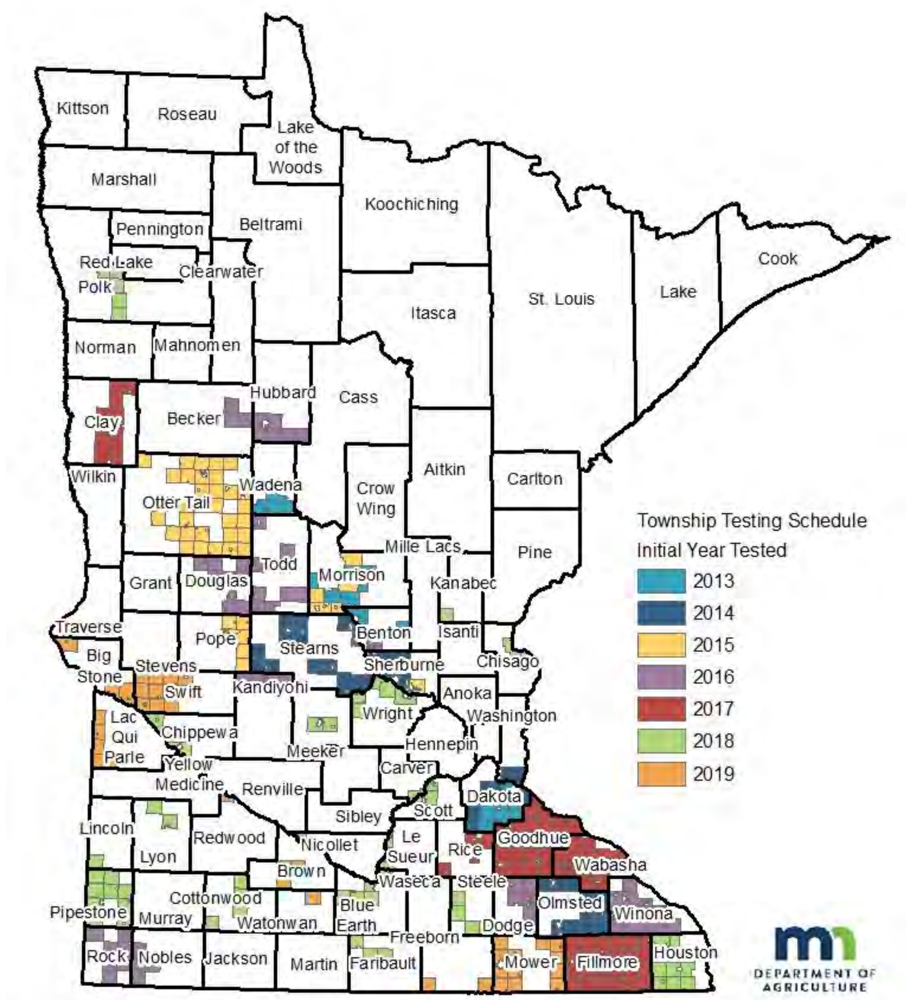


Figure 1. Township Testing Schedule

More than 90,000 private well owners were offered nitrate testing in 344 townships in years 2013 to 2019 for initial testing (Figure 1). Additional testing follow up continued through 2020.

The TTP was a substantial multi-year sampling effort to evaluate water quality in drinking water wells in areas vulnerable to ground water contamination from agricultural sources across the entire state and was a significant step towards addressing nitrate in groundwater in Minnesota. The data gathered is used to inform well owners about the water they are drinking and can be used to prioritize future work to address nitrate concerns, as described in the NFMP. Find more information about the NFMP at www.mda.state.mn.us/nfmp.

Initial Results

The MDA works with local partners such as counties and soil and water conservation districts (SWCDs) to coordinate private well nitrate testing using Clean Water Funds. In the initial sampling, all township homeowners using private wells were sent a nitrate test kit and the homeowner collected the sample.

From 2013-2019, 344 vulnerable townships from 50 counties participated in the initial TTP sampling. In the 344 townships tested, 143 (41%) had 10% or more of the wells over the Health Risk Limit (HRL) of 10 mg/L for Nitrate-N (Figure 2 & 3).

Through the TTP 32,217 private wells were tested for nitrate. Of the wells tested, 2,925 (9.1%) exceeded the HRL for Nitrate-N (Table 2). The minimum nitrate result was less than the detection limit and the maximum result was 159 mg/L Nitrate-N (Table 2). These initial results reflect nitrate concentrations in private well drinking water regardless of nitrogen sources, or well construction.

Final Results

If nitrate was detected in the initial sample, the homeowner was offered a follow-up nitrate test, pesticide test, and well site assessment. Trained MDA staff visited willing homeowners to collect the follow-up nitrate and pesticide water samples and conduct well site assessments, between 2014 and 2020. Once completed, the MDA analyzed the results and prepared a final report for each county. Final results were determined using two rounds of sampling and a process to remove wells with construction concerns, insufficient construction information, and those near potential non-fertilizer sources of nitrate. Final results represent wells that are potentially impacted by a fertilizer source.

For the final dataset, it was determined that 44 (13%) townships had 10% or more of the wells over the HRL for Nitrate-N, with the majority of these townships occurring in southeast Minnesota. For the final results, townships with less than 20 well were categorized separately because MDA considers less than 20 wells inadequate to characterize a township for the purposes of the NFMP (Figure 2 & Figure 4).

In the final dataset of 28,932 wells, 1,359 (4.7%) exceeded the HRL for Nitrate-N (Table 2). The minimum nitrate result was less than the detection limit and the maximum result was 69.8 mg/L Nitrate-N (Table 2). Detailed sampling results for each county are available at: https://www.mda.state.mn.us/township-testing-program. A detailed final report on statewide and regional data comparisons will be available in 2023.

Pesticide results were analyzed separately through the Private Well Pesticide Sampling Project, more information is available at: www.mda.state.mn.us/pwps

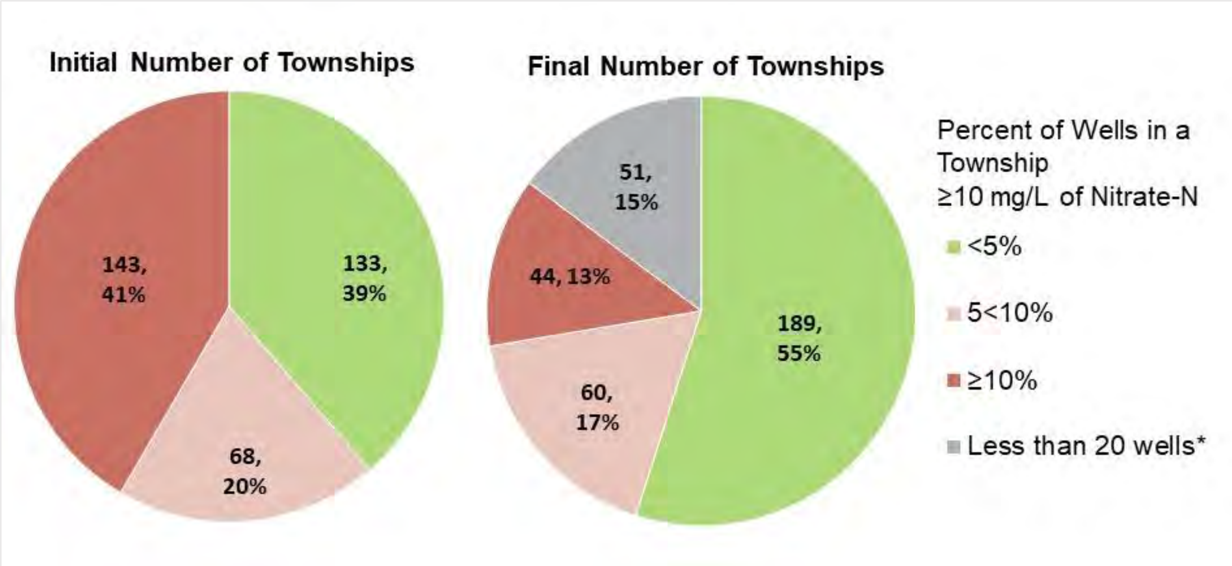


Figure 2. Initial and final number of townships and percent of townships in each nitrate category.
* Townships with less than 20 well were categorized separately because MDA considers less than 20 wells inadequate to characterize a township for the purposes of the NFMP

Table 1. Initial and final number of wells and percent of wells in each nitrate concentration range.

Township	Total Wells	Number of Wells <3*	Number of Wells 3<10*	Number of Wells ≥10*	Percent of Wells <3*	Percent of Wells 3<10*	Percent of Wells ≥10*
Initial	32,217	24,791	4,501	2,925	77.0%	14.0%	9.1%
Final	28,932	24,512	3,061	1,359	84.7%	10.6%	4.7%

* Nitrate-N mg/L or parts per million (ppm)

Table 2. Township testing program summary statistics for initial and final well dataset

Township	Total Wells	Min Value*	Max Value*	Mean Value*	50th Percentile[2]* (Median)	75th Percentile[2]*	90th Percentile[2]*	95th Percentile[2]*	99th Percentile[2]*
Initial	32,217	<DL[1]	159	3.5	1.7	4.5	9.4	13.9	22.2
Final	28,932	<DL[1]	69.8	1.8	0.6	2.1	5.1	8.1	14.6

[1]<DL means that this value is less than detection limit of the lab, which is typically between 0.03 and 0.25 mg/L nitrate-N.

[2]The 50th percentile (75th, 90th, 95th, and 99th, respectively) is the value below which 50 percent (75%, 90%, 95% and 99%) of the observed values fall

* Nitrate-N mg/L or parts per million (ppm)

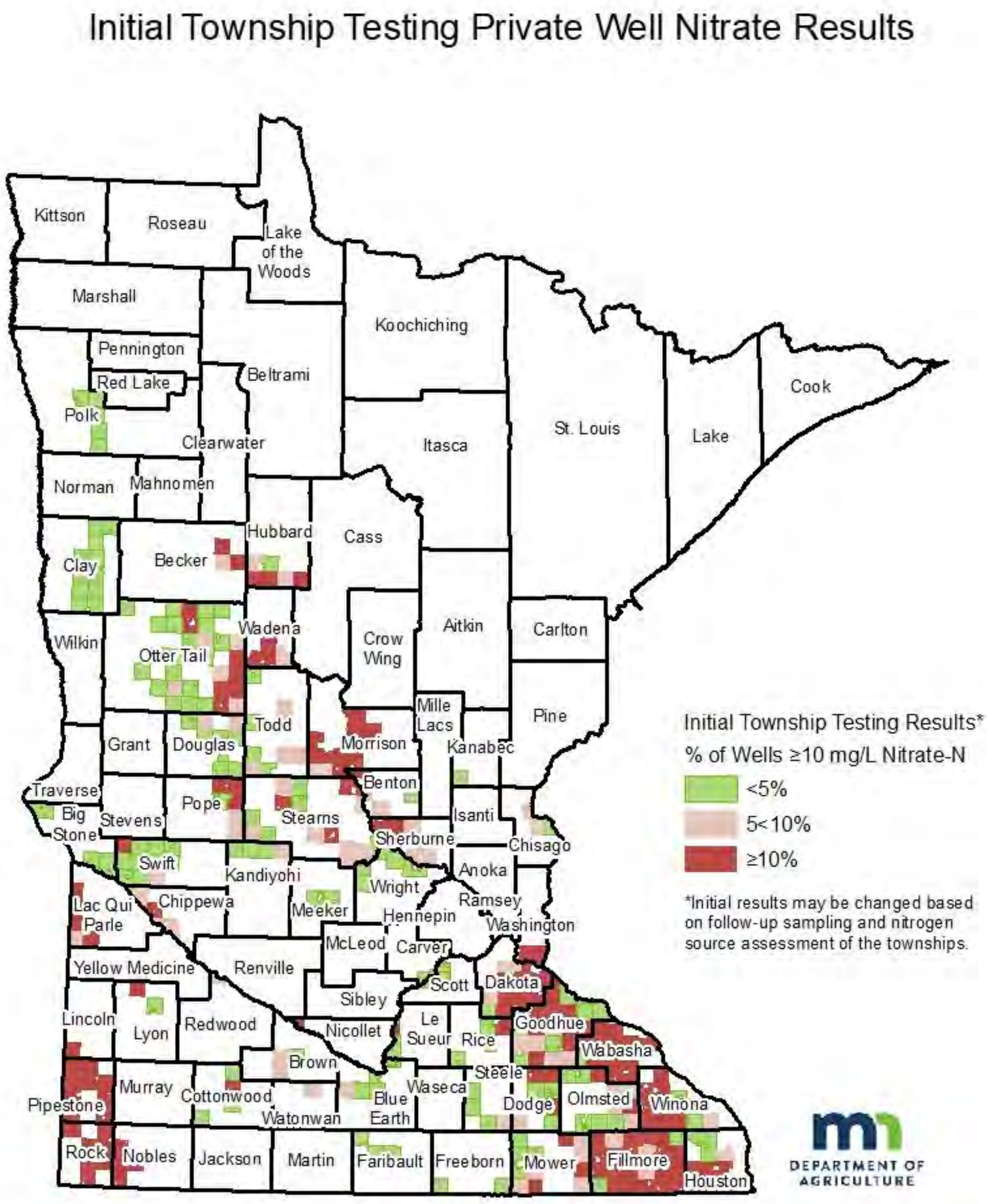


Figure 3. Initial Township Results Updated May 2022

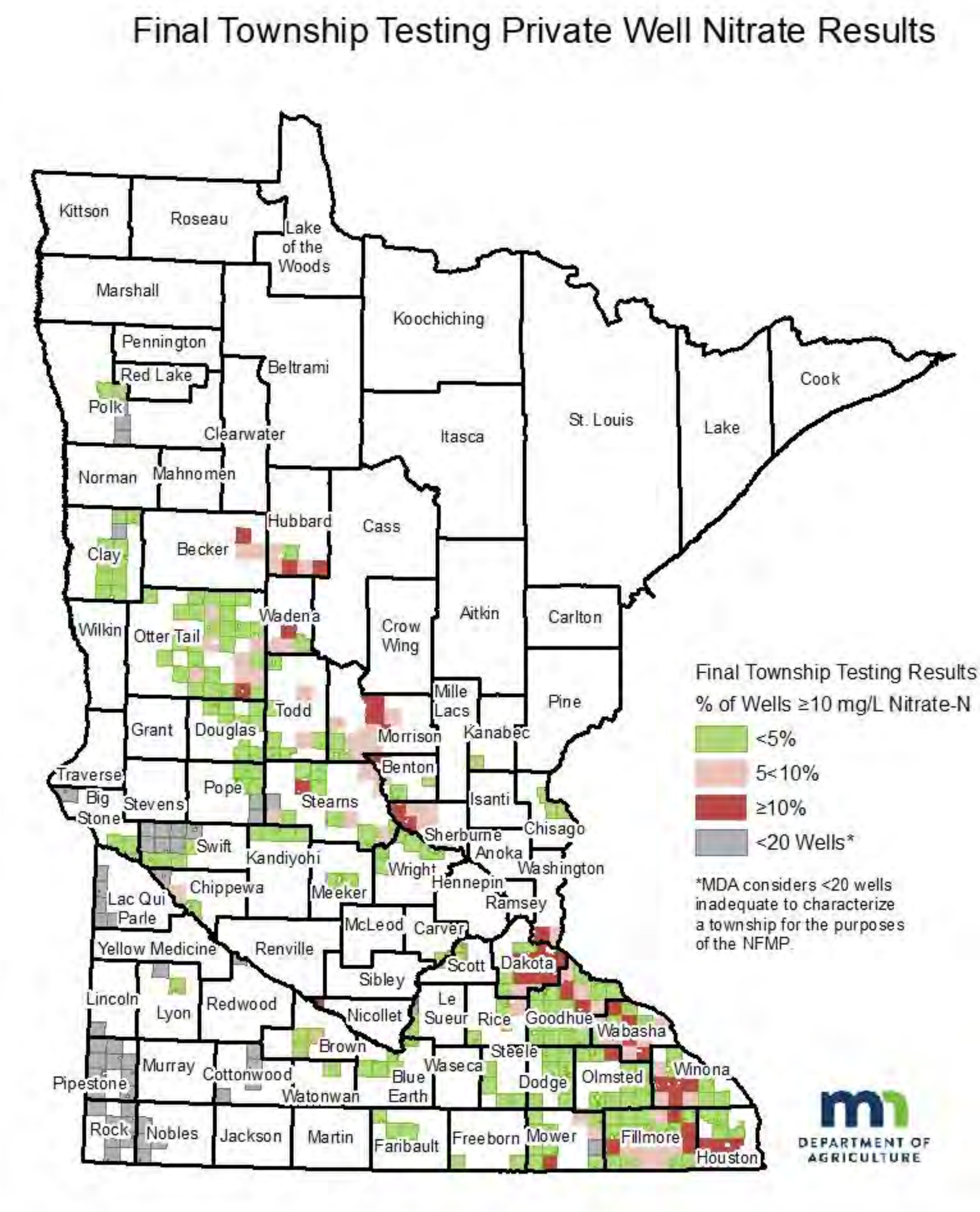


Figure 4. Final Township Results Updated May 2022

REGION 5 ADMINISTRATOR
CHICAGO, IL 60604

Brooke Cunningham M.D.
Commissioner
Minnesota Department of Health
Post Office Box 64975
Saint Paul, MN 55164-0975

Thom Peterson
Commissioner
Minnesota Department of Agriculture
625 Robert Street North
Saint Paul, MN 55155-2474

Katrina Kessler
Commissioner
Minnesota Pollution Control Agency
520 Lafayette Road N
Saint Paul, MN 55155-4194

Dear Dr. Cunningham, Mr. Peterson, and Ms. Kessler:

On April 24th, 2023, Petitioners[1] requested that the U. S. Environmental Protection Agency exercise its emergency powers under Section 1431 of the Safe Drinking Water Act (SDWA) to address groundwater nitrate contamination that presents a risk to the health of the residents in eight counties of the Southeast Karst Region[2] (Karst Region) of Minnesota. Section 1431 authorizes EPA to act upon receipt of information that a contaminant is present in or is likely to enter a public water system (PWS) or an underground source of drinking water (USDW), which may present an imminent and substantial endangerment to the health of persons, and that appropriate state and local authorities have not

[1] Petitioners: Minnesota Center for Environmental Advocacy, Environmental Working Group, Minnesota Well Owners Organization, Center for Food Safety, Clean Up the River Environment, Food & Water Watch, Friends of the Mississippi River, Izaak Walton League Minnesota Division, Land Stewardship Project, Minnesota Trout Unlimited, and Mitchell Hamline Public Health Law Center.

[2] Minnesota's Karst Region referenced in the petition consists of eight counties: Dodge, Fillmore, Goodhue, Houston, Mower, Olmsted, Wabasha, and Winona county.

acted to protect the health of such persons. Approximately 390,682[3] people reside in the Karst Region; about 300,000 people are served by 93 PWSs and approximately 93,805[4] people rely on private wells as their primary source of drinking water. Based on the information currently available from past nitrate monitoring, it had been estimated that 9,218[5] residents in the Karst Region were or still are at risk of consuming water at or above the maximum contaminant level (MCL) for nitrate, with Minnesota Department of Agriculture reporting that 12.1% of the private wells tested (equating to 1,058 wells) exceeded the MCL of 10mg/L[6]. Several of the PWSs in the Karst Region have also been impacted by MCL exceedances resulting in additional treatment and/or having to drill deeper wells.

We appreciate the time that you and your staff have taken to meet with my staff on numerous occasions to share each agency's efforts to protect Minnesota's drinking water, including the information you shared in and after our meeting on August 28, 2023 (See Enclosure). While we appreciate the collective commitment to address nitrate contamination through state-administered programs, based on our discussions and current available drinking water data, there is an evident need for further actions to safeguard public health.

EPA's immediate priority is to protect human health by ensuring that residents impacted by nitrate contamination are: (1) identified; (2) provided notice in all applicable languages regarding their potential exposure to elevated nitrate concentrations and information regarding the associated health risks; and (3) provided the opportunity to obtain alternate drinking water until nitrate contamination in groundwater falls below the MCL for nitrate of 10 mg/L.

EPA expects state agencies to take timely actions to address the nitrate contamination, especially with respect to providing public notice and alternate water. To address these priorities, EPA requests that the Minnesota agencies develop a coordinated and comprehensive work plan to identify, contact, conduct drinking water testing and offer alternate water to all impacted persons in the Karst Region, as soon as possible, and to sustain these efforts for as long as nitrate concentrations in the groundwater of the Karst Region remain at or above the MCL. An adequate work plan to address immediate health concerns should include the following:

1. **Coordination** – The state should create a communication plan that identifies how information and responsibilities will be shared among the state agencies, local governments

[3] Calculated using the 2022 data, for each county, reported on the Minnesota State Demographic Center "PopFinder For Minnesota, Counties, & Regions". https://mn.gov/admin/demography/data-by-topic/population-data/our-estimates/pop-finder1.jsp

[4] Calculated using Minnesota Department of Health "Community Water Systems: MNPH Data Access" to determine population serviced by CWS's, then subtracted by the population in the region. https://mndatamaps.web.health.state.mn.us/interactive/cwss.html last updated 03/07/2023.

[5] Calculated using the Township Testing Program "Final Report" by adding up the estimated population at risk, reported in the "Estimates of Population at Risk" section of each report, for each county. Data used ranges from 2014 – 2019. https://www.mda.state.mn.us/township-testing-schedule-reports

[6] From the Township Testing Program county reports for this region.

(county, city, township), and any private businesses or local utilities that have volunteered or been required to act, so that each entity's efforts serve a singular and coordinated response.

2. **Identification of Impacted Residences** – The state should identify each residence that obtains drinking water from a private well within the Karst Region. This includes wells that were constructed prior to the adoption of Minnesota's Well Code.

3. **Education and Outreach** – The state should provide notice to newly and previously impacted residents and continue to provide notice as long as contamination persists at or above the MCL for nitrate. If notice has not been provided to those that were previously identified as having private drinking water wells at or above the MCL for nitrate, we expect the state to provide notice *immediately* to such residents.

Similarly, if notice has not been provided to customers served by regulated PWSs that had nitrate levels at or above the MCL, we expect the state or owner/operators to provide notice *immediately*. Public education and outreach should be conducted in a form and manner reasonably calculated to reach all impacted residents in all applicable languages.

The state should prioritize its education and outreach toward the most vulnerable populations for associated health risks (e.g., homes with infants, pregnant women), including efforts to work with health care facilities and daycares serving such populations.

In addition to public health information, clear instruction for private drinking water well users to request drinking water testing should be included in appropriate languages. Minnesota should measure its progress in contacting all private well users identified as part of outreach efforts. For those private well users that do not respond to public notices, Minnesota should attempt personal communications, such as visits to individual residences (e.g., Minnesota Water Stewards).

4. **Drinking Water Testing** – Responsible agencies should create and implement a plan to provide analysis of drinking water samples obtained from any private well users in the Karst Region that request testing. For any residents identified as having private drinking water wells at or above the MCL for nitrate, we expect the state to provide timely notice to such impacted residents.

5. **Provision of Alternate Water** – Alternate drinking water should be offered as soon as practicable to each residence where water tests show an exceedance of the MCL for nitrate in the private well. The state should prioritize provision of alternate water to particularly vulnerable populations (e.g., homes with infants, pregnant women). As part of your response to EPA, please provide a detailed plan for distribution (e.g., water made available to residents at centralized locations) and a timeline for provision of such water.

Alternate water should be provided as needed for drinking, cooking, and maintaining oral hygiene. This shall be at no cost to the resident and in a manner that minimizes the burden on the impacted resident to obtain safe drinking water, such as water distribution locations and/or delivery services, reverse osmosis treatment units, or connection to a public water system.

6. **Public Records** – Maintain and regularly publish records such that Minnesota residents and the general public can better understand the scope and severity of nitrate contamination in the Karst Region and measure Minnesota's progress in implementing its response plan including provision of alternate water, and to establish an effective way to communicate updates to the general public.

7. **Communication with EPA** – EPA requests that the Minnesota agencies provide progress reports quarterly to EPA that (a) describe actions taken during the previous quarter to address the immediate health impacts of nitrate contamination; (b) identify major accomplishments and issues that arose; (c) describe actions and timelines planned for the next quarter; and (d) describe any problems or delays encountered and the solutions implemented to address them.

While this letter is largely focused on addressing immediate health concerns regarding nitrate contamination in drinking water in the Karst Region, Minnesota must also develop and implement a long-term solution to achieve reductions in nitrate concentrations in drinking water supplies.

Developing a complete understanding of potential sources of nitrate contamination is an important immediate step for the state. A risk analysis of current and future nitrate contamination of the impacted groundwater will be critical for determining long-term solutions, and such analysis should incorporate the latest science and technologies.

Minnesota has tools to effect reductions in nitrate concentrations through the National Pollutant Discharge Elimination System (NPDES) and State Disposal System permit programs, including development and implementation of more protective NPDES/SDS CAFO permits.

In addition, Minnesota should consider adopting monitoring requirements in NPDES/SDS permits related to (1) subsurface discharges from manure, litter, and process wastewater storage, as well as (2) discharges from land application, similar to those proposed by EPA as modifications to the EPA-issued CAFO general permit for Idaho: https://www.epa.gov/npdes-permits/npdes-general-permit-concentrated-animal-feeding-operations-cafos-idaho. We also encourage Minnesota to consider modifications to the state's Technical Standards for Nutrient Management with regard to land application of manure, litter or process wastewater, and any Minnesota guidelines for land application of commercial fertilizer, specific to Karst areas.

EPA expects Minnesota to hold sources of nitrate accountable using all available tools to reduce the amount of nitrate they release to ground water. While the Agency appreciates the state agencies' engagement and past efforts in addressing groundwater contamination in the Karst Region, EPA will continue to closely monitor this situation and consider exercising our independent emergency and enforcement authorities.

Given the urgency inherent in any situation involving drinking water contamination with known potential health risks, we respectfully request confirmation of your agencies' plan to provide "Education and Outreach" and "Provision of Alternate Water" as soon as possible. EPA expects a reply with respect to the elements noted above within 30 days, which must include the anticipated timeframe for submission of the agencies' work plan.

Sincerely,

DEBRA SHORE

Digitally signed by DEBRA SHORE
Date: 2023.11.03 08:31:31 -05'00'

Debra Shore
Regional Administrator
& Great Lakes National Program Manager

Enclosure: Summary of Minnesota Efforts to Address Nitrate Contamination

EPA recognizes the Minnesota's past and current efforts to address nitrate contamination:
The Clean Water council (consisting of MDA, MPCA, and MDH representatives) was able to advise the Legislature to appropriate $100,000 of the state's Clean Water Fund to the "Tap In" initiative, which was carried out at the county level, including counties in the Karst Region. This initiative in 2021 assisted low-income private well owners with nitrate contamination that exceeds the MCL. The initial grant covered 186 tests, 7 reverse osmosis filters, 6 new wells, and one well repair.

MDA and MDH created a private well network for residents in which to participate in the Central Sands and Southeast Karst Region. The purpose of the Southeast Minnesota Volunteer Nitrate Monitoring Network was to monitor long term trends of nitrate concentrations in private drinking water wells throughout Southeastern Minnesota. Samples were collected from 2008 – 2012.

MDA and MDH provide technical assistance to CWSs when the nitrate level is detected above 3 mg/L. MDA had established Nitrate Testing Clinics, which has provided 50,000 well owners with testing services and educational outreach since 1993, and local partners with equipment to carry out nitrate analysis.

MDA provided free nitrate sampling to private well owners in vulnerable Townships throughout the state from 2013 to 2019 via the Township Testing Program. Of the 344 townships determined to be vulnerable statewide, 133 are in the Karst Region.

MDA was the initial partner in the *We are Water MN*, providing technical assistance, staff time, and financial investments.

MDA continues to develop and publish videos, infographics, and additional resources targeted for residents of the Karst Region.

MDA developed the Groundwater Protection Rule to support the 2015 Nitrogen Fertilizer Management Plan, which went into effect on June 28, 2019.

MDH established and enforces laws and rules for proper construction and sealing of wells and borings and provides guidance to private well owners. MDH assists and regulates public water systems by approving system construction and treatment plans in response to nitrate issues, as well as requiring PWSs to protect water sources from contamination and providing technical assistance and grants to do so. Since 1993, MDH has successfully returned 8 CWSs and 38 NCWSs back to compliance with SDWA's regulatory limits for nitrates.

MPCA created the state's Nutrient Reduction Strategy in 2014 to guide the state in reducing excess nutrients in water to meet state and downstream water quality goals.

MPCA had released the Groundwater Protection Recommendation Report in 2016 which states recommendations for preventing nitrate contamination in groundwater.

MPCA uses NPDES permits to (1) prevent manure, litter, and process wastewater discharge to surface water from Large CAFO production areas and (2) minimize nutrient movement to surface water from manure, litter, and process wastewater application to land under the control of Large CAFOs. State Disposal System-based conditions in these permits, and in SDS-only permits for Large CAFOs, are for the purpose of protecting ground water. In a July 22, 2021 letter from MPCA to EPA, MPCA underscored that it set conditions in its 2021 statewide NPDES/SDS general permit for Large CAFOs for the specific purpose of addressing existing elevated levels of nitrates in ground water (Peter Tester letter to Cheryl Newton, page one). For decades, Minnesota has operated a supplementary state law regulatory program for feedlots as small as 50 animal units (10 in shoreland).

In addition, we thank Minnesota staff for taking time to participate in recent calls and sharing information on your work to address nitrate contamination including calls with MDH on May 8, May 18, and June 20; MDA on May 18, MPCA on August 22, and a joint call with all three agencies on August 28.

Winona County: Final Overview of Nitrate Levels in Private Wells (2016-2017)

The Minnesota Department of Agriculture (MDA) determines current nitrate-nitrogen concentrations in private wells, on a township scale, through the Township Testing Program. The MDA has identified townships throughout the state that are vulnerable to groundwater contamination and have significant row crop production. The MDA plans to offer nitrate testing to more than 70,000 private well owners in over 300 townships by 2019.

Winona County Final Highlights

- Number of townships with 10% of wells over the HRL : **4**
- **209** (22%) wells removed from initial data set.

Each selected township is offered testing in two steps, the "initial" sampling and the "follow-up" sampling. In the initial sampling, all township homeowners using private wells are sent a nitrate test kit. If nitrate is detected in their initial sample, the homeowner is offered a follow-up nitrate test, pesticide test and well site visit. Trained MDA staff visit willing homeowners to resample the well and then conduct a site assessment. The assessment helps to identify possible non-fertilizer sources of nitrate and to see the condition of the well. A well with construction problems may be more susceptible to contamination.

The MDA and Winona County Environmental Services worked together to select townships and implement the nitrate testing project. The following townships were selected: **Elba, Fremont, Hart, Hillsdale, Mt. Vernon, Norton, Pleasant Hill, St. Charles, Saratoga, Utica, Warren, Wilson, and Wiscoy.** The initial sampling in Winona County started in 2016 and follow-up sampling ended in 2017.

Results

Two datasets, "Initial" and "Final", are used to evaluate nitrate in private wells. The initial dataset represents private well drinking water regardless of the potential source of nitrate. The final dataset was formed through an assessment process to evaluate wells. In the assessment, wells that had nitrate-nitrogen results over 5 mg/L were removed from the initial dataset to form the final dataset if a potential non-fertilizer source or well problem was identified, there was insufficient information on the construction or condition of the well, or for other reasons which are outlined in the full report (see Appendix E for details). The final dataset represents wells with nitrate attributed to the use of fertilizer. The initial dataset for Winona County contains 940 wells; the final dataset contains 731 wells. A total of 209 wells (22%) were removed.

The results from the initial and final well datasets are summarized in the following table and figures. In the initial dataset nine townships had more than 10% of the wells over the Health Risk Limit of 10 mg/L of nitrate-nitrogen (see map). In the final dataset four of the townships had more than 10%. The final percent of wells over the Health Risk Limit in each township ranged from 0% to 42.9%. The Winona County Final Report is available on the MDA website in 2019: www.mda.state.mn.us/townshiptesting.

Next steps

The MDA uses the TTP data and assessment process and prioritization guidelines in the Minnesota Nitrogen Fertilizer Management Plan (NFMP) to determine next steps. It is MDA's intent to implement the voluntary aspects of the NFMP in townships with elevated nitrate with the highest priority placed on areas with high sampling results. Find more information about the NFMP on the MDA website at www.mda.state.mn.us/nfmp.

Funding for this project is provided by the Clean Water, Land and Legacy Amendment

Table: Winona County Private Well Nitrate Results.

Township	Initial Well Dataset		Final Well Dataset	
	Total Wells*	Percent of Wells ≥10 mg/L Nitrate-Nitrogen	Total Wells	Percent of Wells ≥10 mg/L Nitrate-Nitrogen
Elba	62	16.1%	52	5.8%
Fremont	42	54.8%	28	42.9%
Hart	48	18.8%	31	6.5%
Hillsdale	52	1.9%	44	0.0%
Mt. Vernon	33	15.2%	24	0.0%
Norton	80	11.3%	62	4.8%
Pleasant Hill	58	8.6%	50	4.0%
St. Charles	85	34.1%	62	14.5%
Saratoga	56	19.6%	40	5.0%
Utica	86	46.5%	51	19.6%
Warren	92	28.3%	62	11.3%
Wilson	196	6.1%	179	1.7%
Wiscoy	50	0.0%	46	0.0%
Total	940	19.1%	731	7.1%

* All well types included.

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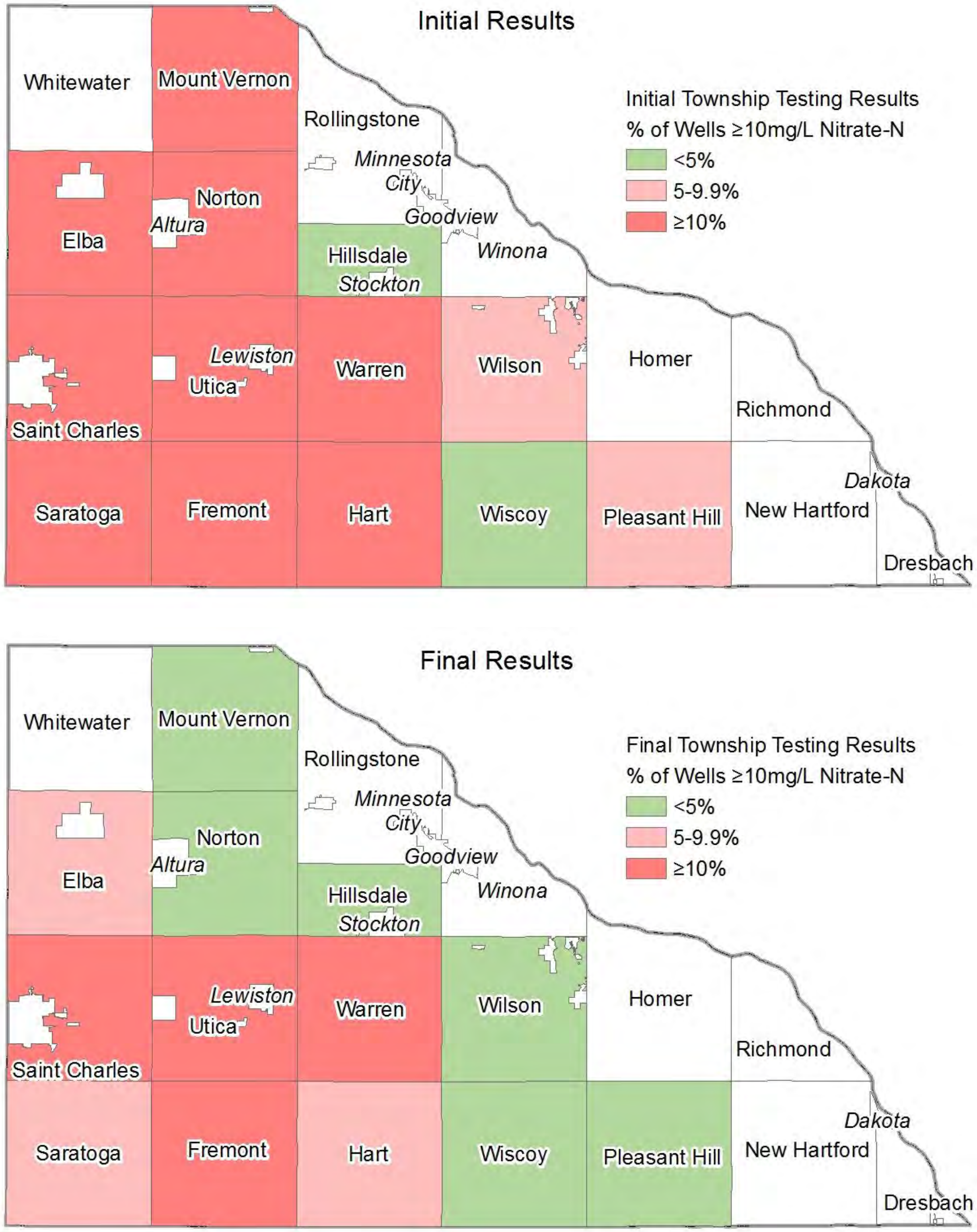
Figure: Winona County Final Well Dataset Map. Clean Water Organizations Comments Exhibit 19



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Southeast Minnesota Volunteer Nitrate Monitoring Network

mda.state.mn.us/southeast-minnesota-volunteer-nitrate-monitoring-network

Drinking water high in nitrate can cause serious health effects in infants. The state's Health Risk Limit (HRL) for nitrate-nitrogen is 10 mg/L. Karst geology makes the region's groundwater especially vulnerable to nitrate contamination. Because of this risk it is important to monitor for high nitrate concentrations in private wells.

In 2006, nine southeast Minnesota counties coordinated planning to develop a Volunteer Nitrate Monitoring Network (VNMN) to monitor long term trends of nitrate concentrations in private drinking water wells throughout southeastern Minnesota. From 2006 until 2012 the Project team included nine southeastern Minnesota counties and multiple state agencies funded by the EPA 319 Program and the MPCA Clean Water Partnership (CWP) Program. The first two years of the project were primarily the planning stage, the first round of samples were collected in 2008. In 2013, the program was changed to incorporate more analytes in selected wells, but was no longer sampling the entire network for nitrate. In 2014, the MDA coordinated with the County Water Planners and Southeast Minnesota Water Resources Board (SEMNWRB) to continue sampling all of the wells in the network on an annual basis to determine long term trends and keep the original network intact where possible.

Homeowners are the cornerstone of this network, this work could not be done without them. Network participants are sent a nitrate test kit directly to their home on an annual basis by the lab. The homeowner simply fills up the bottle and sends it directly back to the lab for analysis. The lab then sends homeowners their results.

In 2022, 376 private drinking water wells were sampled for nitrate. Results from 2022 are similar to previous years:

- 69.4% of nitrate results were < 3 mg/L
- 22.3% of nitrate results were 3<10 mg/L
- 8.2% of nitrate results were ≥10 mg/L

Southeast Volunteer Nitrate Monitoring Network Summaries

The nitrate testing results from this network of private wells is used in combination with other networks to determine the trend of nitrate levels in regional groundwater over time. The nitrate results and trend reports are available in the Minnesota Water Research Digital Library. Links to the most recent reports are listed below.

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Yearly Results

- Southeast Minnesota Volunteer Nitrate Monitoring Network 2022 Results
- Southeast Minnesota Volunteer Nitrate Monitoring Network 2021 Results
- Southeast Minnesota Volunteer Nitrate Monitoring Network 2020 Results

Older reports are available in the Minnesota Water Research Digital Library . Search for reports using the following titles: Southeast Minnesota Volunteer Nitrate Monitoring Network, or Southeast Minnesota Domestic Well Network.

Trend Reports

- Nitrate Results and Trends in Private Well Monitoring Networks (2008-2018)
- Nitrate Trends in Private Well Networks (2017)

An overview:

- Nine counties in the Southeast region participate in the county wide private well network
- In 2020, 381 private drinking water wells were sampled for nitrate , 91% have water that is below the HRL
- Nitrate analysis of approximately 300-600 wells have been completed annually
- This project will help answer the question: Are nitrate concentrations in private drinking water wells increasing, decreasing or staying the same?

Why is this program focused on nitrates?

Nitrate is a water soluble molecule that is made up of nitrogen and oxygen. It is naturally occurring in the environment; however at elevated levels it can have negative effects on human health. According to a 2007 Minnesota Pollution Control report, nitrate is one of most common contaminants in Minnesota's groundwater, and in some areas of the state a significant number of wells have high nitrate levels (Minnesota's Ground Water Condition: A Statewide View, MPCA 2007). The U.S. Environmental Protection Agency (EPA) has established a drinking water Maximum Contaminant Level (MCL) of 10 mg/L for nitrate-nitrogen (EPA, 2009). Although nitrate occurs naturally, it can also originate from man-made sources such as fertilizer, animal manure and human waste.

Regions of Minnesota most vulnerable to nitrate contamination are central and southeastern Minnesota. Central Minnesota counties are vulnerable because of widespread sandy soil and regions of southeast Minnesota are vulnerable because of shallow bedrock, sinkholes and underground caves (referred to as karst geology), which lead to exchanges between surface and ground water resources.

County Partners:

Dodge, Fillmore, Goodhue, Houston, Mower, Olmsted, Rice, Wabasha, and Winona. The Olmstead Soil and Water Conservation District is the local partner contact.

Learn More

Nitrates in Minnesota drainage water

While artificial drainage offers tremendous benefits for crop production, it can also potentially transport nitrates from the soil to surface water. Here, we share strategies to help you avoid these nitrate losses, which can help protect the environment and reduce fertilizer costs.

Understanding nitrate loss

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Nitrogen and its role

Nitrogen (N) is the atmosphere's single largest component and an important building block for all living organisms. It's found in many different forms in the soil depending on the nitrogen cycle.

It's taken up by crops in greater quantities than any other added nutrient. Grass crops, such as corn and wheat, require the addition of N-based fertilizers to maximize productivity. Legume crops, such as soybeans and alfalfa, don't require additional N inputs because they have the ability to fix N from the atmosphere in their root systems.

Overall, N used by crops for plant growth comes from fertilizer, soil organic matter, atmospheric deposition, animal manure and fixation (for legumes only).

Nitrate losses

Losses of nitrate, a mobile form of N, to water systems have been a concern for many years because of human health issues. When mammals—especially human infants under six months old—ingest nitrates, it interferes with the blood's ability to carry oxygen.

Standards

Thus, a standard of 10 parts per million (ppm) of nitrate-N has been established for drinking water by the Environmental Protection Agency. For decades, the primary focus has been on groundwater because of its connection with drinking water. Less attention has been given to nitrate levels in surface water, due to decreased dependence on surface water for drinking.

In addition, phosphorus is typically the limiting nutrient in Minnesota surface waters, rather than excess nitrate, that leads to increased plant and algae growth and significant surface water quality problems.

For decades, there hasn't been an established contaminant standard for nitrate-N in class 2 (aquatic life and recreation) waters in Minnesota. However, standards are currently under development and will be phased in over the next few years.

Scrutiny of agricultural drainage

Hypoxia in the Gulf of Mexico has led to increased scrutiny on nitrate contributions to surface waters from agricultural systems. Scrutiny has primarily focused on subsurface agricultural drainage, or tile drainage.

Tile drainage is a highly visible water pathway that transports nitrate from the landscape to surface waters. Other pathways of water movement from the landscape, such as leaching, shallow groundwater flow and surface runoff, are less visible and more difficult to sample and quantify.

Reducing nitrate in Minnesota surface waters

Figure 1: Artificial drainage isn't the only pathway of nitrate to surface waters, but it's the most easily seen and measured, and therefore under more scrutiny than other transport mechanisms.

The increased attention on the loss of nitrate via agricultural drainage has led many to call for significant changes to both N fertilizer management and agricultural drainage systems (Figure 1).

To make improvements, it's essential to fully understand nitrate fluxes from agricultural systems in Minnesota, and how N management can affect losses. Plans to reduce nitrate in surface waters will need to account for inputs, set reduction goals and develop management strategies on both a watershed and an individual farm level.

Several conservation technologies have been developed, which reduce nitrate from surface waters after it's already present. On this webpage, we look at the impact of managing N fertilizer inputs before it's lost to surface water.

Corn is the most important crop in Minnesota in terms of total acreage and economic value. In addition, it's the single largest user of N fertilizer on the state's landscape. Most corn in Minnesota is either continuous (corn following corn), or in a rotation following soybeans.

Investigations on nitrate loss from Minnesota cropping systems have looked at all aspects of a crop rotation, but focused on corn for the aforementioned reasons.

Minnesota data

]Figure 2: The Southern Research and Outreach Center in Waseca established plots to collect drainage water in 1975. In 2009, the center automated data collection.

Research data on nitrate loss from cropping systems through drainage systems isn't as common as you might think. In the early 1970s, the University of Minnesota Research and Outreach Centers (ROCs) in Waseca and Lamberton established plots for measuring drainage water quantity and quality (Figure 2).

Since then, they've examined many nitrogen management practices. These include N rate, application timing, source and the use of nitrification inhibitors. In addition, they've looked at various crops grown in rotation, tillage practices and mineralization of N from soil organic matter.

The drainage plots at the ROCs measure the total discharge of drainage water and the water's nitrate concentration. Researchers use these numbers to calculate the total edge-of-field outflow of N via the drainage system.

Methods for presenting nitrate loss

Nitrate loss from tile drainage water varies greatly from year to year, primarily based on the total outflow of water from the tiles. In addition, research has shown that soil nitrate storage increased in the soil profile following dry years, but was then subject to loss during wet years.

This is why total nitrate-N loss is usually presented as either an average across years or a total amount over several years. Another method is to calculate nitrate concentration as a flow-weighted (FW) mean, which accounts for variability of total water flow from individual plots.

Annual nitrate loss

A literature review of a large number of worldwide drainage studies shows annual nitrate-N loss via tile lines varies from 0 to 124 pounds per acre. Plots kept devoid of vegetation (fallow) in Waseca measured an average annual loss of nearly 20 pounds of nitrate-N per acre from bare ground.

The source of this nitrate loss was N mineralized from organic matter. Corn grown without adding N fertilizer annually lost around 10 pounds of nitrate-N per acre. Loss rates for soybeans that received no N fertilizer were nearly identical (Table 1).

Generally, annual losses with row crops, where corn received near-optimum rates of N, ranged from 15 pounds of nitrate-N per acre (Table 1) on the low end in Waseca to 40 pounds per acre on the high end in Lamberton (Table 2) during four wet years. A separate project using larger plots at the Southern Research and Outreach Center (SROC) in Waseca located about a mile away confirmed annual losses ranging from approximately 10 to 18 pounds per acre.

The method shown to drastically reduce nitrate loss

In more than 40 years of drainage research at the ROCs, using perennial vegetation (as either native prairie plants or alfalfa) was the only method shown to drastically reduce nitrate loss at the Lamberton site.

Over a four-year period, these plots had an annual average flow-weighted nitrate concentration ranging from near zero to a high of 4 parts per million (ppm). In addition, because the total drainage volume greatly reduced, nitrate-N loss rates averaged only 1 to 1.5 pounds per acre (Table 2).

Table 1: Four-year nitrate-N loss in drainage water in Waseca

Crop rotation	N rate	N application timing	Nitrate-N concentration (four-year average)	Nitrate-N total (four-year average)
Corn-soybean-corn	0 lbs. per acre	--	6.1 ppm	37.7 lbs. per acre
“	60+40 lbs. per acre	Split	7.8 ppm	44.8 lbs. per acre
“	120 lbs. per acre	Preplant	8.2 ppm	52.1 lbs. per acre
Soybean-corn-corn	0 lbs. per acre	--	4.6 ppm	34.0 lbs. per acre
“	60+80 lbs. per acre	Split	7.9 ppm	64.2 lbs. per acre
“	160 lbs. per acre	Preplant	8.8 ppm	62.8 lbs. per acre
Corn-corn-soybean	0 lbs. per acre	--	5.5 ppm	30.5 lbs. per acre
“	0 lbs. per acre	--	8.4 ppm	40.9 lbs. per acre
“	0 lbs. per acre	--	8.7 ppm	38.3 lbs. per acre

Cropping system	Total discharge (four-year)	Nitrate-N: Concentration (four-year)	Nitrate-N: Total (four-year)
Continuous corn	30.4 inches	28 ppm	194 lbs. per acre

Cropping system	Total discharge (four-year)	Nitrate-N: Concentration (four-year)	Nitrate-N: Total (four-year)
Corn-soybean	35.5 inches	23 ppm	182 lbs. per acre
Soybean-corn	35.4 inches	22 ppm	180 lbs. per acre
Alfalfa	16.4 inches	1.6 ppm	6 lbs. per acre
Conservation Reserve Program (CRP)	25.2 inches	0.7 ppm	4 lbs. per acre

Influencing factors

The well-documented increase in the amount of artificial drainage in significant portions of Minnesota can be attributed to the practice's overall profitability, as well as the increased efficiency of farmers' time.

This has been accompanied by scrutiny about potential negative impacts, including nitrate loss. Minimizing nitrate loss via artificial drainage is in everyone's best interests, as it makes sense from both an environmental and economic standpoint.

Figure 3: Corn grain yield and residual soil nitrate-N response as affected by fertilizer N rate on a Webster clay loam soil near Waseca, averaged from 2001 to 2003 (Source: Vetsch & Randall).

Crop response to fertilizer N rate generally follows a curve, where yield is maximized at some point and additional N inputs don't increase crop yield. The point where additional N inputs no longer produce an economic return is called the Economic Optimum N Rate (EONR).

Recommendations are based on EONRs from a large number of sites and years. Further examining the response curve relationship (Figure 3) shows how applying additional fertilizer N at or above the EONR results in little or no additional yield.

This is accompanied by greater accumulation of residual soil nitrate after harvest, which is susceptible to environmental loss. This relationship follows a similar curve but is inverse to the yield response to N. It shows the importance of N rate, as excessive N inputs are highly likely to be lost to the environment.

Fall fertilizer applications

Applying N fertilizer in the fall is a common practice in much of Minnesota. However, current BMPs don't recommend fall application in the southeastern part of the state, where there's very little artificial drainage.

Using urea as a fall fertilizer source is only recommended in the western part of the state, where annual precipitation averages less than 26 inches. A nitrification inhibitor is recommended with fall application of anhydrous ammonia (AA) in south-central Minnesota, where annual precipitation is around 35 inches.

A recent trend toward more continuous corn has resulted in less fall application of N. Most farmers find applying AA in the fall to be difficult due to the presence of corn residue from the previous year, especially with conservation tillage. A 2011 survey showed approximately 40 percent of N fertilizer was applied in the fall in southwestern, west-central and south-central Minnesota.

Research: Fall applications of AA with a nitrification inhibitor

Research has shown, on average, that fall applications of AA with a nitrification inhibitor (where recommended) have similar nitrate-N losses as spring applications. This, of course, varies from year to year based on climatic conditions. Mild falls and wet springs tend to increase nitrate loss.

Research showed that spring applications had greater corn yields than fall applications of AA with an inhibitor (Table 3). Increased yield (although not always statistically significant) is a likely indicator of decreased N loss into the environment.

Table 3: How applying N affects nitrate-N concentrations, losses and yield

N application: Rate	N application: Time	N application: N-Serve	Flow-weighted NO3-N concentration	Nitrate-N lost: Corn	Nitrate-N lost: Soybean	Nitrate-N lost: Total
80 lb/a	Fall	Yes	11.5 milligrams per liter (mg/L)	115 lb/a	90 lb/a	205 lb/a
120 lb/a	Fall	Yes	13.2 mg/L	121 lb/a	99 lb/a	220 lb/a
160 lb/a	Fall	Yes	18.1 mg/L	142 lb/a	139 lb/a	281 lb/a
120 lb/a	Spring	No	13.7 mg/L	121 lb/a	98 lb/a	219 lb/a

Best management practices: N fertilizers

The University of Minnesota established best management practices (BMPs) for applying N fertilizer in the early 1990s, which were updated in 2008.

These detailed guidelines are designed to help producers efficiently use N fertilizer to maximize profit, while minimizing N loss to the environment:

- How to apply nitrogen in Minnesota
- Southwestern and west-central Minnesota
- South-central Minnesota
- Northwestern Minnesota

- Southeastern Minnesota
- Irrigated potatoes
- Coarse-textured soils

Apply nitrogen at the right time

Figure 5: Ultimately, you may need technology and methods to reduce nitrate in surface waters. While you can fine-tune rates and timing, this is limited by time, climatic and crop growth constraints.

The N cycle dictates that conversion of the various forms of organic N must occur before nitrate becomes present in the soil. This conversion, caused by the actions of microorganisms, depends on temperature and time.

Nitrate's subsequent movement depends on the presence of water that exceeds field capacity. A growing crop's water demand lessens the likelihood of a drainage event. Optimum application timing also corresponds with the plant's need for N.

Guidelines

Applying N fertilizer would logically and ideally be as close as possible to when a plant needs the nutrient, to minimize the chance for loss into the environment. Best management practices dictate the minimum requirements to prevent excessive N loss (Figure 5).

You can lessen the chance of a significant leaching event by further delaying application to better correspond with planting or by split-applying so some of the application occurs to a growing crop.

However, take caution when late sidedress (in-season) applications are surface-applied and not incorporated. If meaningful rainfall doesn't occur for 10 to 20 days, you could lose this N to the atmosphere. In addition, it could become positionally unavailable to roots. In either case, yields will suffer due to lack of available N.

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Over-applying N fertilizers is another factor within the farmer's control. Generally, nitrogen loss through tile drainage increases as the N rate increases, especially at N rates greater than the economic optimum.

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As illustrated in Figure 3, changing the N rate from 120 pounds per acre to 150 pounds per acre in corn following soybeans only increased yield by 4 bushels per acre. However, it increased the amount of residual N left in the soil profile by 40 percent, subjecting it to leaching.

Avoid applying nitrogen at rates higher than the EONR. It represents both an economic risk associated with higher-than-necessary fertilizer costs and a local environmental risk associated with potential losses. As the departure from EONR grows, so does the risk of nitrate loss to the environment.

Crop-specific fertilizer recommendations

A note on manure

Research conducted at the SROC found no differences in nitrate-N loss via agricultural drainage between manure and commercial fertilizer, provided recommended rates and application methods were used.

More on manure management

Nitrate reduction targets

The EPA has set a target for a long-term, 45 percent reduction of nitrates in the Mississippi River. Logically, following BMPs with respect to rate, source, timing and use of nitrification inhibitors is an important first step in reaching this goal.

Current rates of BMP adoption aren’t well-documented. Plus, model projections suggest further BMP adoption can only achieve modest improvements. Delaying applications until later in the season may achieve some reduction, but needs to be evaluated and account for the farmer’s ability to accomplish the application at the desired timing.

The recommendations we’ve shared here correspond with the national campaign for fertilizer applications to follow the 4Rs: The right fertilizer source, at the right rate, in the right place, at the right time.

The most effective strategy

In the end, our current cropping systems leak N and only perennial vegetation has been shown to effectively scour N from the soil profile. Note that while the environmental benefits of this practice are clear, an economic system to support these crops doesn’t exist. Therefore, the cost is high.

In the meantime, focus on making both economically and environmentally sound management decisions. These practices are easily within your control. Also, stay informed on new developments or practices that might achieve further reductions.

Water Testing for Nitrates handout (PDF)

Brad Carlson, Extension educator; Jeff Vetsch, researcher, Southern Research and Outreach Center and Gyles Randall, emeritus soil scientist, Southern Research and Outreach Center

Bierman, P., Rosen, C.J., Venterea, R., & Lamb, J.A. (2011). Survey of nitrogen fertilizer use on corn in Minnesota.

Carlson, B.M., & Ganske, L. (2012). A Minnesota farmer's guide to federal and state clean water law (University of Minnesota Extension publication #08680).

Fabrizzi, K., & Mulla, D. (2013). In Wall, Reducing cropland nitrogen losses to surface waters.

Kaiser, D.E., Lamb, J.A., & Eliason, R. (2011). Fertilizer Guidelines for Agronomic Crops in Minnesota (University of Minnesota Extension publication #06240-S).

Kaiser, D.E., Fernández, F., & Coulter, J.A. (2018). Fertilizing corn in Minnesota.

Fernández, F.G., & Kaiser, D.E. (2018). Understanding nitrogen in soils.

Lamb, J.A., Randall, G.W., Rehm, G., & Rosen, C.J. (2008). Best management practices for nitrogen use in Minnesota.

University of Minnesota Extension Manure management website

Mississippi River/Gulf of Mexico Watershed Nutrient Task Force. (2008). Gulf Hypoxia Action Plan 2008 (Environmental Protection Agency publication #842K09001).

Randall, G.W., & Vetsch, J.A. (2011). Minimizing nitrate loss to drainage by optimizing N rate and timing for a C-C-S rotation.

Randall, G.W, Rehm, G., & Lamb, J.A. (2007). Best management practices for nitrogen use in southeastern Minnesota.

Randall, G.W., & Vetsch, J.A. (2005). Nitrate losses in subsurface drainage from a corn-soybean rotation as affected by fall and spring application of nitrogen and nitrapyrin. Journal of Environmental Quality, 34, 590-597.

Randall, G.W., & Vetsch, J.A. (2005). Corn production on a subsurface-drained mollisol as affected by fall versus spring application of nitrogen and nitrapyrin. Agronomy Journal, 97, 472-478.

Randall, G.W. (March 21-24, 2004). Subsurface drain flow characteristics during a 15-year period in Minnesota. In R. Cooke (Ed.), Proceedings of the Eighth International Symposium: Drainage VIII (pp. 17-24, ASAE publication #701P0304).

Randall, G.W., & Goss, M.J. (2008). Nitrate losses to surface water through subsurface, tile drainage. In J.L. Hatfield and R.F. Follett (Eds.), Nitrogen in the environment: Sources, problems, and management (pp. 145-175). Elsevier Sciences B.V.

Randall, G.W., & Mulla, D.J. (2001). Nitrate nitrogen in surface waters as influenced by climatic conditions and agricultural practices. Journal of Environmental Quality, 30, 337-344.

Randall, G.W., Iragavarapu, T.K., & Schmitt, M.A. (2000). Nutrient losses in subsurface drainage water from dairy manure and urea applied for corn. Journal of Environmental Quality, 29, 1244-1252.

Randall, G.W., Huggins, D.R., Russelle, M.P., Fuchs, D.J., Nelson, W.W., & Anderson, J.L. (1997). Nitrate losses through subsurface tile drainage in Conservation Reserve Program, alfalfa, and row crop systems. Journal of Environmental Quality, 26, 1240-1247.

Randall, G.W., personal communication, 2013.

Sands, G.R. (2018). Impact of agricultural drainage in Minnesota.

Sands, G.R., Song, I., Busman, L.M., & Hansen, B.J. (2008). The effects of subsurface drainage depth and intensity on nitrate loads in the northern Cornbelt. Transactions of the American Society of Agricultural and Biological Engineers, 51(3), 937-946.

U.S. Department of Agriculture National Agricultural Statistics Service Field Office (2013). 2012 Minnesota Agricultural Statistics.

Nitrogen | Minnesota Pollution Control Agency

pca.state.mn.us/pollutants-and-contaminants/nitrogen

Nitrogen, like phosphorus, is a nutrient that pollutes in state waters, and its concentration in many rivers has been increasing from historic natural levels over time due to human influences.

Statewide, data on nitrate concentrations in rivers over the past 20 years show a mixed bag:

- Many monitoring sites with variable levels and no trend
- Many sites where levels have increased
- Some sites where levels have decreased

Sources

More than 70% of the nitrate in Minnesota waters is coming from cropland, the rest from regulated sources such as wastewater treatment plants, septic and urban runoff, forests, and the atmosphere. Nitrate leaching into groundwater below cropped fields and moving underground until it reaches streams contributes an estimated 30% of nitrate to surface waters. Groundwater nitrate can take from hours to decades to reach surface waters.

Cropland sources account for an estimated 89% to 95% of the nitrate load in the Minnesota, Missouri, and Cedar Rivers, and Lower Mississippi River basins.

Tile drainage pathway

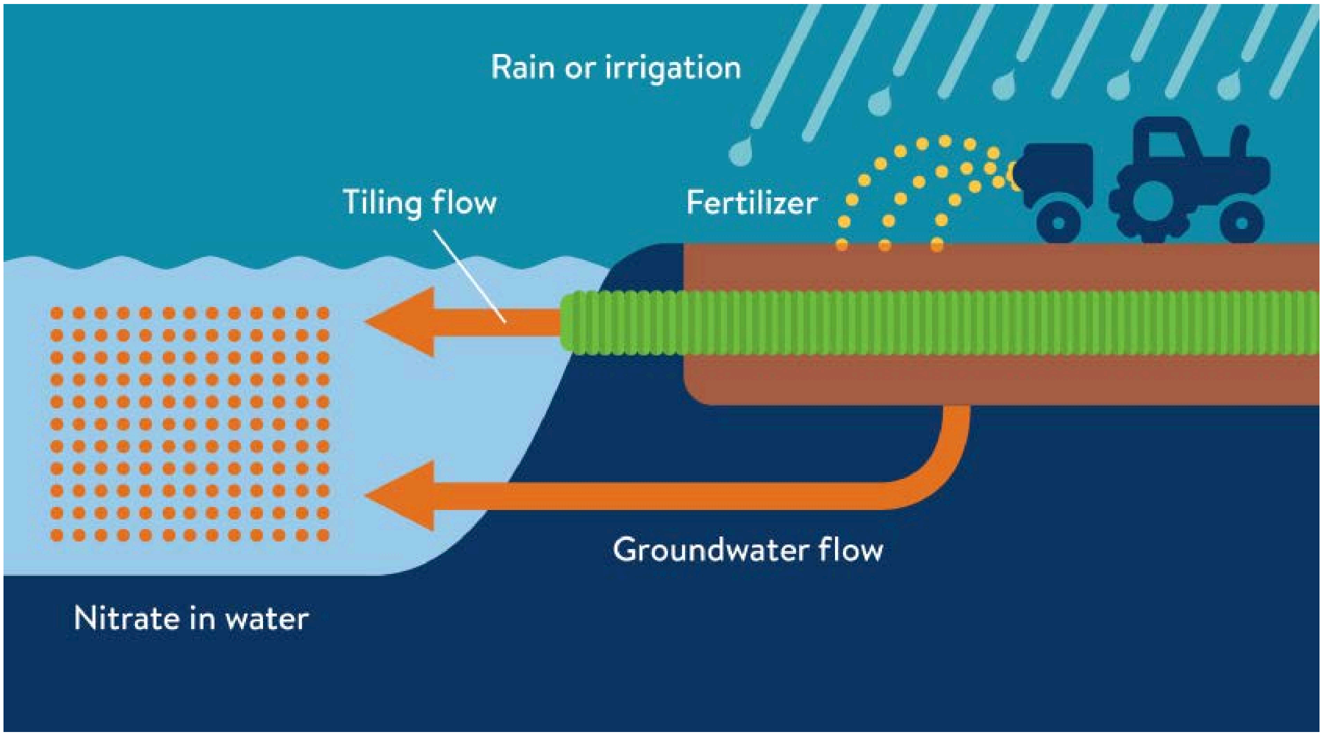
In tiled cropland, most of the rainwater that ends up in surface water (ditches, streams) flows through tile drainage. This water can be high in nitrate, but it is also potentially easier to control.

Groundwater pathway

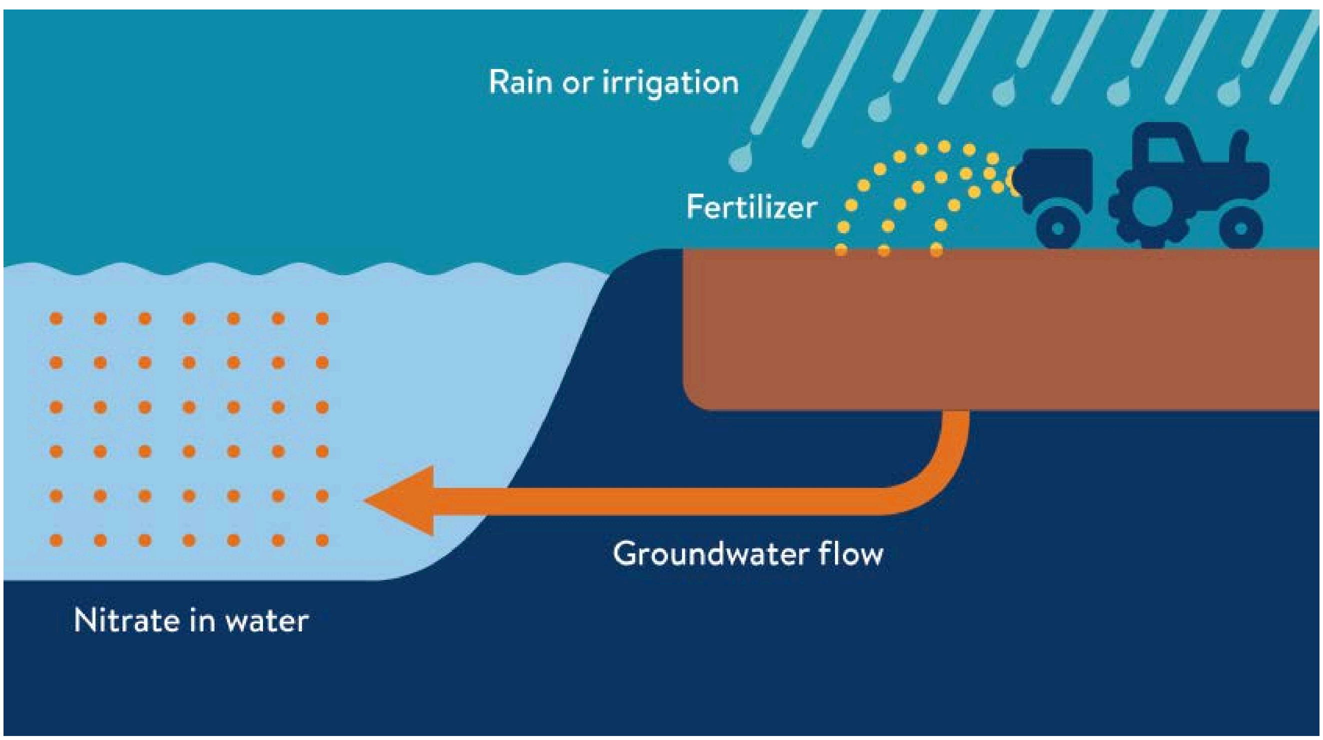
In cropland without tile drainage, most rainwater flows through the ground to get to surface waters. As it travels through the earth, some of the nitrate is removed, resulting in less nitrate reaching our streams and rivers. However, there are fewer options of controlling this kind of nitrate pollution once it moves below the crop roots.

September 3, 2024
Clean Water Organizations Comments Exhibit 22

Crop drainage with tiling



Crop drainage without tiling



Human health and environmental concerns

Nitrate (a form of nitrogen) in lakes, rivers, and streams is toxic to fish and other aquatic life; in drinking water, it's potentially harmful to humans. Proposed reductions in nitrogen will benefit both Minnesota waters and water downstream from us.

Ammonia is a form of nitrogen that is directly toxic to aquatic life. It comes from wastewater treatment plants and animal waste or air pollution and runoff from agricultural land. Water with high concentrations of ammonia allow the chemical to build up in the tissues and blood of fish, and can kill them.

Nitrate in the Mississippi River

On average, 158 million pounds of nitrate leaves Minnesota per year in the Mississippi River — 75% comes from Minnesota watersheds.

Nitrate leaving Minnesota via the Mississippi River contributes to the oxygen-depleted dead zone in the Gulf of Mexico. The dead zone cannot support aquatic life, affecting commercial and recreational fishing and the overall health of the Gulf. Nitrate concentrations have steadily increased in the Mississippi River since the mid-1970s.

Monitoring, reporting, and regulations

The MPCA's research shows elevated nitrate levels in water, particularly in the southern third of Minnesota.

Reducing nitrate

Tactics for reducing cropland nitrate that reaches surface waters fall into three categories:

- **Manage in-field nutrients** – Optimize fertilizer rates, apply fertilizer closer to timing of crop use
- **Manage and treat tile drainage water** – Plan tile spacing and depth, control drainage, construct and restore wetlands for treatment purposes, use bioreactors
- **Diversify vegetation/landscape** – Plant cover crops, plant more perennials on marginal cropland

Nitrate fertilizer efficiency is improving and further refinements in fertilizer rates and application timing could reduce nitrate loads by roughly 13% statewide. But additional and more costly practices will also be needed to make further reductions and meet downstream needs. Statewide reductions of more than 30% are not realistic with current practices.

Bigger reductions would require limiting nitrate leaching across large parts of southern Minnesota, particularly on tile-drained fields and row crops over thin or sandy soils. Only collective incremental changes by many over broad acreages will result in significant nitrogen reductions to downstream waters.

The Department of Agriculture's Nitrogen Fertilizer Management Plan is the state's blueprint for prevention or minimization of the impacts of nitrogen fertilizer on groundwater.

Contact

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Nitrogen Rates

Field to Stream Partnership

The Root River Field to Stream Partnership (RRFSP) is a multi-organizational effort to evaluate agricultural practices and water quality at multiple scales and landscape settings. The strategic selection of these study watersheds allows the findings to be applied to similar areas across southeastern Minnesota.

On-Farm Nitrogen Rate and Timing

The relationship between corn yield, nitrogen rate and timing was studied over a seven-year period in southeast MN. Results across four different counties from 2015-2021 (24 site years) are summarized.

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August 2022

DEPARTMENT OF AGRICULTURE

What's the Best Nitrogen Rate?

- A total of twenty-four nitrogen (N) rate and timing experiments were conducted on corn fields in southeast Minnesota from 2015 through 2021.
- Ten treatments were replicated four times in a randomized, complete-block design. Seven of the ten treatments were N rates applied at planting and three treatments were split applied.

Plot harvest near Grand Meadow in Mower County

- On-farm studies were conducted near the city of Grand Meadow in Mower County, Harmony in Fillmore County, Utica in Winona County and Elgin in Wabasha County. Most plots were located and repeated on the same farm.
- The **M**aximum **R**eturn **T**o **N**itrogen (MRTN) is the nitrogen (N) rate that maximizes return on investment. The MRTN is a data driven, economically and environmentally sound method for making N rate decisions and is a recommended best management practice (BMP) when fertilizing corn in Minnesota.
- The University of Minnesota updated the corn nitrogen fertilizer guidelines in 2022 and are summarized in Table 1. Using the most common N price to corn price ratio of 0.10, the acceptable range of nitrogen to apply is **130-150 lb N/ac** when corn follows soybeans and **160-190 lb N/ac** when corn follows corn. Total nitrogen applied should include credits from other fertilizers containing nitrogen such as MAP, DAP, AMS, starter and nitrogen credits from alfalfa and manure.
- The Corn Nitrogen Rate Calculator can be used identify the most profitable N rates using different nitrogen and corn prices. http://cnrc.agron.iastate.edu/

University Nitrogen Rate Guidelines for Corn

Previous Crop	N Price/Corn Price Ratio	MRTN	Acceptable Range
		-----------lb N/acre----------	
Corn (71 sites)	0.075	190	170-205
	0.100	**175**	**160-190**
	0.125	165	150-175
	0.150	155	145-165
Soybeans (165 sites)	0.075	150	135-165
	0.100	**140**	**130-150**
	0.125	135	125-145
	0.150	130	120-140

Table 1. Nitrogen fertilizer rate recommendations for non-irrigated corn in Minnesota. The most common nitrogen price to corn price ratio, 0.10, is highlighted. A $0.50 nitrogen price and $5.00/bu corn price equates to a 0.10 ratio. Source Aug 2022: *https://extension.umn.edu/crop-specific-needs/fertilizing-corn-minnesota.*

Results

Corn following Soybean

- A total of 13 corn fields were studied over a seven-year period. Most fields were located on well drained silt loam soils in Fillmore, Winona and Wabasha counties. Two sites were located in Mower County on poorly drained soils that contained subsurface drainage tile and high organic matter.
- Figure 1 shows the best rate of nitrogen (N) to apply on sites with well drained soils was 129 lb N/ac with an exceptional corn yield of 249 bu/ac.
- Figure 2 shows the response at a poorly drained site located south of Grand Meadow (GM south). This farm typically responded to more preplant nitrogen and required over 70 lb N/ac more preplant N when compared to well drained sites. The best preplant nitrogen rate at GM south was 202 lb N/ac with a yield 229 bu/ac.
- The zero-rate check produced over 150 bu/ac corn yield in plots with well drained soils while the poorly drained GM south site typically produced 40 bu/ac less yield. This could indicate that less N was supplied by the soil through mineralization.
- Even with drain tile, a natural dense layer of glacial till located at depths below one foot at the GM south site creates anaerobic conditions which likely results in more frequent N loss through de-nitrification and less soil N contributions from mineralization. This dense subsoil could also be affecting corn rooting depth.

Corn following Corn

- A total of 11 different fields were studied. Fields were located in Fillmore, Winona and Wabasha Counties on well drained silt loam soils.
- Across all plots and years, the best preplant rate to apply was 175 lb N/ac with a yield of 223 bu/ac (Figure 3).

Split Applied Nitrogen

- When N was split applied, corn yields were significantly higher at 5 of the 24 sites (21%) when compared to fields that received all N at preplant.
- At the poorly drained Grand Meadow South site, split N application rates were occasionally more profitable and required less N.
- Starting in 2022, enhancements to this study will provide new and better insights to MRTN values for split applied N applications.

Residual Soil Nitrate (RSN)

- Figure 4 shows the relationship between RSN and nitrogen rates above or below the MRTN. RSN samples were collected to a depth of four feet after harvest. Elevated RSN can increase the risk for nitrate movement to groundwater and surface water.
- RSN rarely exceeded 60 lb N/ac when rates were applied near the MRTN (within +- 25 lb N/ac). When N rates were applied above the MRTN (right side of the vertical line), the amount of RSN increased rapidly.

Summary

- When averaged across similar sites, the MRTN was consistent with University N rate guidelines for sites with well drained soils, but typically underestimated preplant N needs for a poorly drained site in Mower County. Continuation of this study will provide valuable information for growers and crop advisors that is current and specific to southeast Minnesota.

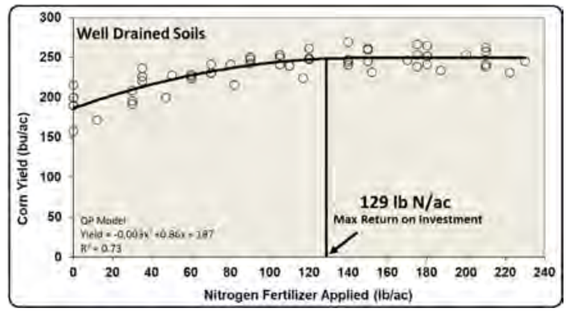

Figure 1. Corn following soybean yield as affected by nitrogen rate on well drained soils from 2015-2021 (8 site years).

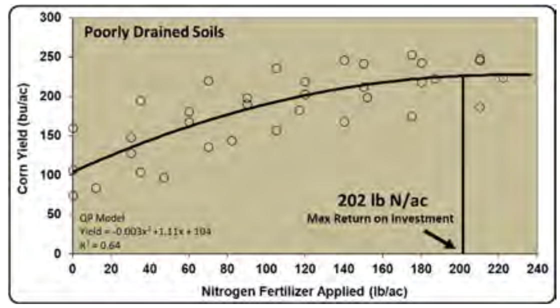

Figure 2. Corn following soybean yield as affected by nitrogen rate on a poorly drained site south of Grand Meadow (GM south) from 2017-2021 (5 site years).

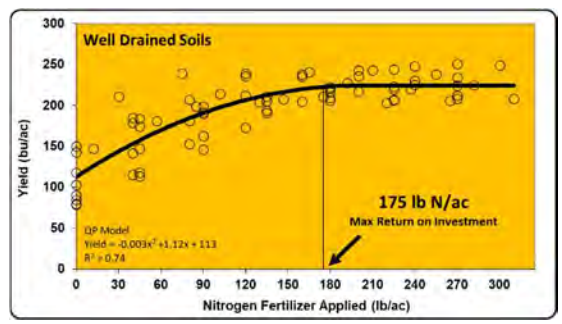

Figure 3. Corn following corn yield as affected by nitrogen rate on well drained soils from 2015-2021 (11 site years).

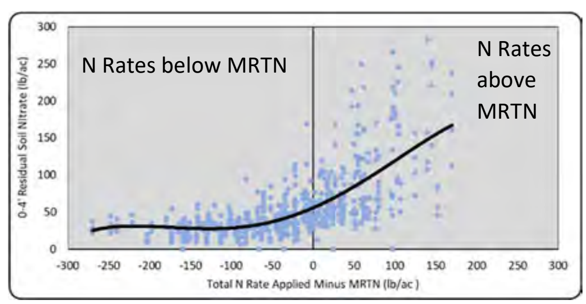

Figure 4. Relationship between residual soil nitrate and N rates above or below the MRTN from 2015-2021 (24 site years).

CLEAN WATER LAND & LEGACY AMENDMENT

Root River Field to Stream Partnership

Minnesota Department of Agriculture
Minnesota Agricultural Water Resource Center
The Nature Conservancy

Mower SWCD
Fillmore SWCD
Root River SWCD

September 24, 2024
Clean Water Organizations Exhibit 23

FIELD RUNOFF

Root River Field to Stream Partnership

PRIMARY PROJECT GOAL

Determine the range of sediment and nutrient losses associated with runoff from representative farming systems and small watersheds in southeastern Minnesota.

Status:

Data collected from four fields, collected over seven years (2010–2018).

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DEPARTMENT OF AGRICULTURE

April 2019

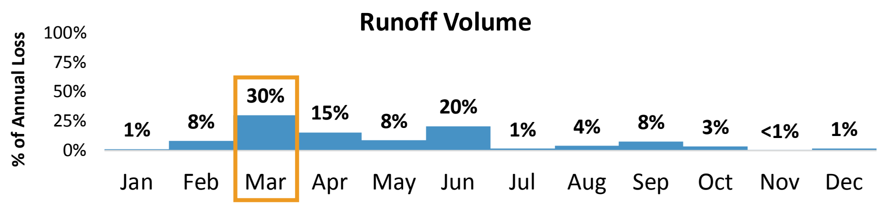
WHERE DOES THE WATER GO?

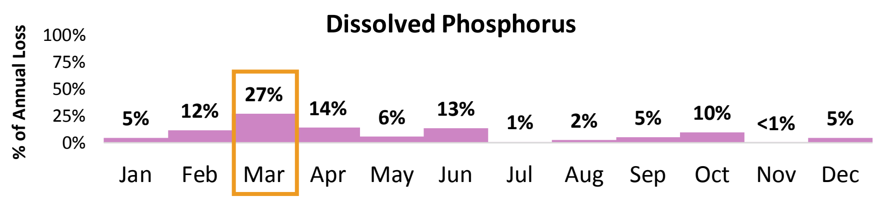
On average, 36 inches of precipitation was received annually. During the study, 7% of this total was measured as field surface runoff with a range of less than 1% in a dry year and up to 24% during a very wet year. How we manage this runoff can make a big difference for clean water.

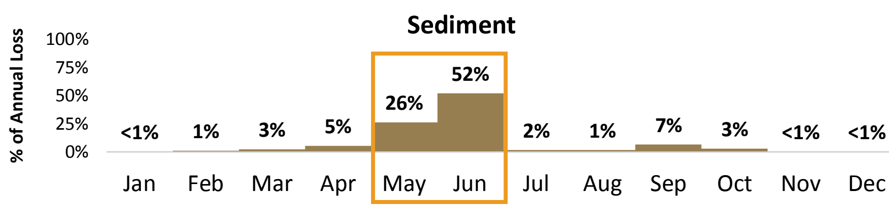
- **On average, 40% of the total runoff volume occurred when the soil was frozen.**
- Over 50% of the annual nutrient and sediment losses typically occurred during 1-2 rain events each year.

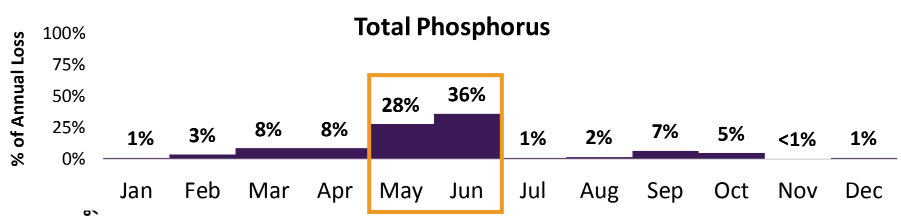
High Risk Periods

Sediment and nutrient losses peak at varying times of the year. Understanding these risk periods is key to reducing loss.





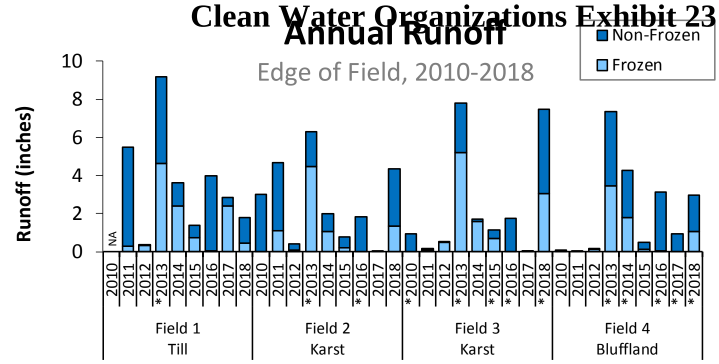




- Dissolved phosphorus losses were highest in March and often occur when the ground is frozen. **Incorporation of fertilizer and proper management of soil test phosphorus levels will help reduce these losses.**
- Nearly 80% of the sediment loss occurred during May and June. Total phosphorus loss is closely linked to soil loss. **Good soil conservation practices will help reduce these losses.**

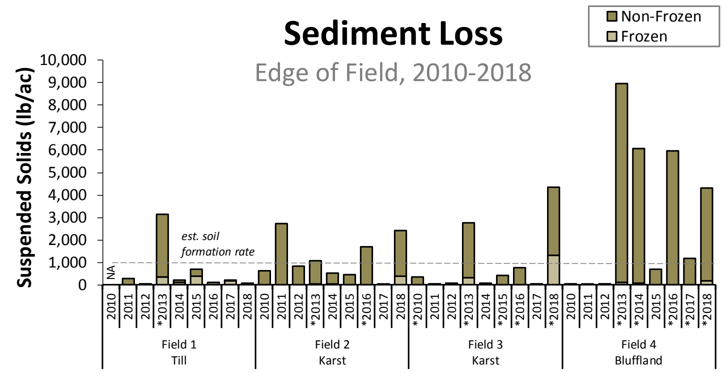
Precipitation & Runoff

- Precipitation averaged 4% above normal during the study period with a mix of dry, normal and wet conditions.
- Field runoff averaged 2.7 inches (7% of annual precip.) with 40% occurring during frozen soil conditions.
- Field surface runoff has been observed in every month averaging 20 runoff events each year. Runoff does not occur every time it rains.



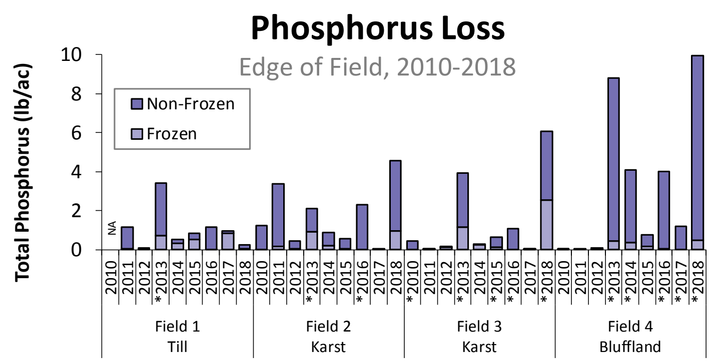
Field Sediment Loss

- **Average sediment loss:** 1,461 lb/ac. (0.7 tons/ac.) Range: <1 to 8,969 lb/ac.
- **Sustainable soil loss:** < 1,000 lb/ac./year If erosion is visible, losses likely exceed this.
- 78% of annual loss occurred during select storms in May & June. During this critical time, fields were prepared for planting, but not at full canopy.



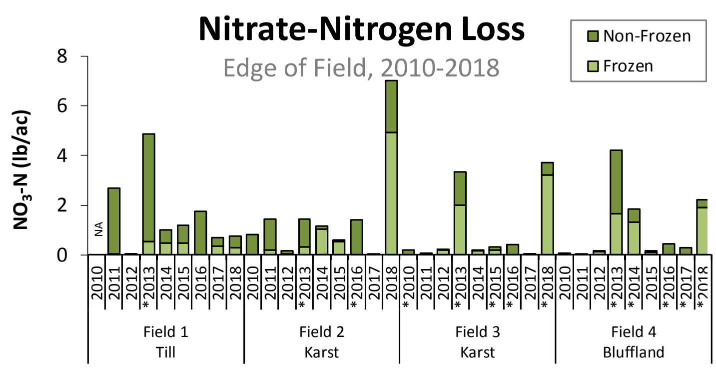
Field Phosphorus Loss

- **Average total phosphorus (P) loss:** 1.9 lb/ac. Range: <0.1 to 10.0 lb/ac.
- **Dissolve P (not attached to sediment):** Accounts for 16% of total P loss (44% of this loss occurs when the ground is frozen).
- **Particulate P (attached to sediment):** 64% of loss occurred in May & June.
- For every 1,000 lb/ac. of sediment loss about 1.0 lb/ac. of P is lost. Goal is to keep this loss to less than 1.0 lb/ac./yr.



Field Nitrogen Loss

- **Average Total Nitrogen (TN) loss:** 9.8 lb/ac. (includes organic form of N) if substantial soil loss occurs, TN in surface runoff can exceed 37 lb/ac.
    - **Nitrate-N form:** 17% of TN Range: <0.1 to 4.9 lb/ac. **Surface** average runoff loss: 1.6 lb/ac. **Sub-surface** average tile loss: 41 lb/ac., max 63 lb/ac.
- **Surface Runoff:** Total nitrogen transported in surface runoff can be controlled through soil conservation.
- **Sub-Surface Leaching:** Most nitrogen is lost this way and is detected as nitrate-nitrogen in tile drainage, springs, streams, rivers, and groundwater.



*Loss was underestimated during overtop events

Reducing nitrate leaching losses will be challenging, but it is a very important task. Fine-tuning nitrogen rates, split applying nitrogen, crediting legumes and manure, growing perennials, and using cover crops are important practices.

Guidelines for manure application rates

extension.umn.edu/manure-management/manure-application-rates

Quick facts

- Manure nutrient management planning is important for maximizing crop productivity while protecting water quality
- Guidelines for manure application rates vary depending on crop and cropping history
- Manure application rates should consider all nutrient sources that will be or have been applied to a field. For example, if commercial, inorganic fertilizers will be applied or if manure was applied in the previous two years, take credit!

Credit: MPCA

Animal manure is a good source of nutrients for crops, including nitrogen (N), phosphorus (P), and potassium (K). The proportion of the nutrients in manure are typically not the same as needed by the crops, however. Manure application based on one nutrient may over- or under apply other required crop nutrients. Nitrogen is required in the largest quantities by non-legume crops. Applying manure to meet crop N needs will likely overapply P, and possibly K, for a crop such as corn. On the other hand, using manure to meet P needs of the crop will likely result in a lower application rate and will underapply N and possibly K. Commercial fertilizers will then be needed to balance out N and K needs. Consider the pros and cons of these two options when choosing a manure application rate.

Nutrients in manure are not 100% available in the first year. First-year plant-available N (PAN) will depend on animal species and how the manure is applied. Plant-available P (PAP) is assumed to be 80% of the total P applied in the first year. You can learn more about calculating PAN and PAP, including first-year PAN and PAP, from our “calculating manure application rates” recommendations. The guidelines for manure application rates below are based on PAN or PAP, not total N and P.

Nitrogen guidelines for manure

The rates below are the maximum amounts of N that should be applied when manure is used, whether it is all manure or a combination of manure and inorganic commercial fertilizers. Lower rates may be considered based on the productivity of the soils in your fields, economics, or environmental concerns. In all cases, all sources of N should be taken into consideration when estimating how much N to apply, including:

- N from irrigation water.
- Credits from manure, or other organic N sources, that was applied in the past 2 years.
- Credits from legumes like edible beans, red clover, etc.

Why is that? Research across the US Midwest has shown that applications of N above the economically optimum N rate (EONR) for a crop significantly increase the potential for N losses. For example, once N leaches past the plant root zone into the ground water, it becomes a concern for drinking water and will eventually end up in lakes, rivers, and streams. On the other hand, excess N that is not taken up by crops can also be lost as a gas through denitrification. When manure N becomes plant available, it behaves exactly the same in the environment as N from commercial inorganic fertilizer, so it is important that all forms of N applied to the soil are taken into consideration. Don’t waste your manure!

|

The maximum rate of plant-available nitrogen (PAN) that should be applied with manure to non-irrigated corn, depending on the crops prior to corn, can be found in the table below.

Nitrogen recommendation for non-irrigated corn

Crop prior to corn	Crop 2 years prior to corn	Maximum lbs of PAN to apply
Corn (or other non-legume crop)	Not applicable	195
Corn	Alfalfa (1-year-old stand)	120
Corn	Alfalfa (>2-year-old stand)	80
Soybean	Not applicable	150
Alfalfa (1-year-old stand)	Not applicable	80
Alfalfa (>2-year-old stand)	Not applicable	40

Corn grown under irrigation is a special case because it is usually done on coarse-textured (or sandy) soils. Under these conditions, there is a higher risk of N loss due to the high leaching potential of these types of soils. With manure, there are other nutrients to consider that could potentially also be lost through leaching. Because of this, we suggest applying a lower rate of manure (as an example, see the section on “Phosphorus Guidelines for Manure” below), then supplement with commercial N fertilizers to meet total N needs. See the table below for the total N rate guidelines.

A good rule of thumb is to apply a lower rate of manure (195 lbs of plant-available N [PAN] or lower), then add the remaining N as commercial fertilizer.

Nitrogen recommendation for irrigated corn

Crop prior to corn	Pounds of nitrogen to apply
Soybean	205
Other crops	235

The maximum amount of PAN you should apply to non-legume crops with manure should follow University of Minnesota guidelines for nitrogen fertilizers.

Details for each crop:

- Barley
- Buckwheat
- Canola
- Grasses
- Grass-legume mixtures
- Oat
- Potato (irrigated)
- Rye
- Sugarbeet
- Sunflower
- Wheat

If manure is applied to a legume crop, you can apply as much PAN as the crop will likely take up in the harvested portion. You can find out how much N will be taken up per harvestable unit in the table below Multiply this number by the amount of yield you expect from that field to get your application rate.

Amount of nitrogen removed per unit of harvested yield

Crop	Yield unit	Crop N removal (lbs per yield unit)
Alfalfa	Tons (air dry)	50.4
Red clover	Tons (air dry)	45.1

Crop	Yield unit	Crop N removal (lbs per yield unit)
Soybean	Bushels	3.5

Example: Assume that field conditions have been poor, so you need to apply manure in the fall to a field where soybean will be planted the following spring because it is the only dry field you have. You expect the soybean yield to be about 60 bushels per acre (this is the typical yield you get from this field). If you multiply 60 bushels per acre by 3.5 lbs of N per bushel, you will find that the crop will take up 210 lbs of N. This means you can apply a manure rate of 210 lbs of PAN per acre.

Phosphorus guidelines for manure

In cases where manure is readily available frequently, using a P-based manure application rate may make the most long-term, economic sense because the crops will use nutrients more efficiently. For manure, it is recommended to apply as much plant-available phosphorus (PAP) as the crop will use.

|

Where do our guidelines come from?

Inorganic commercial fertilizers are often used to figure out crop nutrient needs in experiments across Minnesota. These fertilizers are designed to release 100% of the N and P in the first year, so it makes it easier to determine how much to apply to get the optimized yields. As an example, N guidelines for corn are based on 170+ experiments across the state, most of which occurred in the past five years. As new experiments are completed, the data on optimal N needed are added to the overall database, and N guidelines are adjusted accordingly.

With manure, we can calculate the estimated plant-available nutrients that will be available in a given year. Once nutrients from manure are plant-available, they behave in the environment exactly the same as a nutrient from a commercial fertilizer. Thus, our guidelines for manure application are based on optimal nutrient rates needed, which is known from fertilizer experiments, and how much plant-available nutrient will be available in the first year after application.

Guidelines for Manure Application Rates (printable PDF, 2022)

Melissa Wilson, Extension manure management specialist
Reviewed in 2022

Fertilizing corn in Minnesota

extension.umn.edu/crop-specific-needs/fertilizing-corn-minnesota

Nitrogen guidelines

Minnesota corn growers receive a substantial return for money invested in nitrogen (N) fertilizers. For many situations, the most profitable yield cannot be achieved unless N fertilizers are used.

There are many management decisions involved in the use of N fertilizers. The most important decision is the selection of an N rate that will produce maximum profit while limiting the potential for environmental degradation. The choice of an appropriate rate of fertilizer N is not easy because of the transient nature of N in soils.

|

The consideration of soil productivity, price/value ratio and previous crop are used to arrive at the fertilizer N guidelines for corn. This represents a significant change compared to previous approaches. This process has been in place since 2005 and is the product of a multi-state effort to use a similar philosophy/approach for determining N rate guidelines for corn.

September 3, 2024
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Because of technology improvements in corn production practices such as weed and pest control, expected yield is not as important of a factor in determining N rate as it has been in the past.

Soil productivity has become a better indicator of N need. A majority of Minnesota soils are highly productive and have generally produced maximum economic corn yield with similar N rates over the last 15 years.

Some soils have a reduced yield potential due to erosion, reduced water holding capacity caused by lower organic matter content, sandy soil texture, poor drainage and restricted root growth. The fluctuation in fertilizer price affects the economic optimum N rate. To account for this change, the ratio of the price of N per pound to the value of a bushel of corn has been added to the N rate decision.

An example calculation of the price/value ratio is if N fertilizer costs $0.40 per lb N (or $656 per ton of anhydrous ammonia), and corn is valued at $4.00 per bushel, the ratio would be 0.40/4.00 = 0.10.

The maximum return to N value (MRTN) shown in Table 1 is the N rate that maximizes profit to the producer based on the large number of Minnesota experiments supporting these guidelines. Once the soil productivity and price/value ratio have been determined, a producer’s attitude towards risk must be factored into the process.

A producer who is risk-averse and cannot tolerate risk associated with less-than-maximum yields in some years, even though economic return to N may not always be highly profitable, may want to use the N rates near the high end of the acceptable range shown in Table 1.

On the other hand, if corn is grown on medium or fine-textured soils considered to be of low or medium productivity and/or localized N response data support lower N rates, producers may choose N rates near the low end of the acceptable range in Table 1 if they are willing to accept the possibility of less-than-maximum yield in some years without sacrificing profit.

The acceptable range gives the producer flexibility in arriving at an acceptable and profitable N rate that is calculated as the rate +/- $1 from the MRTN rate.

Table 1: Guidelines for use of nitrogen fertilizer for corn grown following corn or soybean when supplemental irrigation is not used

Prior crop	N price/Crop value ratio	MRTN	Acceptable range
Corn	--	lbs N/acre	lbs N/acre

Prior crop	N price/Crop value ratio	MRTN	Acceptable range
	0.075	190	170-205
	0.100	175	160-190
	0.125	165	150-175
	0.150	155	145-165
Soybeans	--	lbs N/acre	lbs N/acre
	0.075	150	135-165
	0.100	140	130-150
	0.125	135	125-145
	0.150	130	120-140

The N rate guidelines in Table 1 are used if corn is grown in rotation with soybean or following corn when NOT irrigated. Corn grown on sandy soils deserves special consideration.

If irrigated, the guidelines listed in Table 2 are appropriate when corn is grown in rotation with corn. If corn is grown following soybean on irrigated sandy soils, a credit of 30 lbs of N per acre should be taken from the suggestions given in Table 2.

Table 2: Guidelines for use of N fertilizer for corn following corn when grown on irrigated sandy soils

N price/Crop value ratio	MRTN	Acceptable range
0.05	235 (lbs N/acre)	210-255 (lbs N/acre)
0.1	210	190-225
0.15	190	175-210

N price/Crop value ratio	MRTN	Acceptable range
0.2	180	165-190

For non-irrigated corn grown on soils with a loamy fine sand texture and less than 3% organic matter, use the guidelines provided in Table 3.

Soils considered medium productivity in the past were given special consideration. More recent data has not shown strong support for a separate suggested application rate of N for medium-productivity soils.

The rate of N can be adjusted based on the acceptable range if a soil is considered to be medium productivity and has shown to be more or less responsive to fertilizer N.

Table 3: Nitrogen guidelines for corn grown on non-irrigated loamy fine sands with less than 3% organic matter

N price/Crop value ratio	Corn/Corn	Soybean/Corn
0.05	100 (lbs N/acre)	70 (lbs N/acre)
0.1	90	60
0.15	80	50
0.2	70	40

Alfalfa, which includes pure stands of alfalfa and alfalfa-grass mixtures with at least 50% alfalfa in the stand, can eliminate or greatly reduce the need for N from fertilizer or manure during the two subsequent years if corn is grown.

Past guidelines assigned N credits to corn based on alfalfa stand density, but analyses of field trials from across Minnesota and the Midwest indicate that the frequency and level of yield response to N in first and second-year corn following alfalfa are more closely associated with soil texture, age of alfalfa at termination, alfalfa termination timing and weather conditions.

It is well established that first-year corn following alfalfa rarely responds to N except on sandy soils, on fine-textured soils when there are prolonged wet early-season conditions and on medium-textured soils when following very young alfalfa stands or in some cases when following spring-terminated alfalfa.

In past field trials from across Minnesota and the Midwest, yield of second-year corn following alfalfa did not respond to N in half of the fields studied.

Suggested rates of N for first and second-year corn following alfalfa are in Table 4. In some cases, the optimal rate of N can vary greatly due to weather-related variability in soil N mineralization. In such cases, limit the amount of N from fertilizer and manure applied before and near corn planting and apply additional N to corn during the growing season if necessary based on weather and crop conditions.

Table 4: Nitrogen suggestions for first and second-year corn following alfalfa^a

Soil texture[b]	Irrigated or non-irrigated	Alfalfa age[c]	Alfalfa termination time	First-year corn following alfalfa	Second-year corn following alfalfa
Coarse	Irrigated	1 year	Fall or spring	140-170 (lbs N/acre)	140-170? (lbs N/acre)
Coarse	Irrigated	2 or more years	Fall or spring	70-150	70-150
Coarse	Non-irrigated	1 year	Fall or spring	40-80[d]	80-120[d]
Coarse	Non-irrigated	2 or more years	Fall or spring	0-20	0-80
Medium	Both	1 year	Fall or spring	40-80[d]	80-120[d]
Medium	Both	2 or more years	Fall	0-20	0-80

Soil texture[b]	Irrigated or non-irrigated	Alfalfa age[c]	Alfalfa termination time	First-year corn following alfalfa	Second-year corn following alfalfa
Medium	Both	2 or more years	Spring	0-40	0-80
Fine	Both	1 year	Fall or spring	40-80[d]	80-120[d]
Fine	Both	2 or more years	Fall	0-20[d]	0-80[d]
Fine	Both	2 or more years	Spring	0-40[d]	0-80[d]

[a] Includes pure stands of alfalfa and alfalfa-grass mixtures with at least 50% alfalfa in the stand.
[b] Coarse = sands and sandy loams; medium = loams and silt loams; fine = clays, clay loams and silty clay loams.
[c] Alfalfa age at termination, including the establishment year if alfalfa was direct-seeded without a small grain companion crop.
[d] An additional 30 to 40 lbs N/acre can be applied to corn during the growing season if necessary based on the Corn calculator for supplemental nitrogen.

To arrive at a guideline following other crops, an adjustment (credit) is made to the corn following corn guidelines. The adjustments can be found in Table 5.

In Table 5, several crops are divided into Group 1 and Group 2. The crops for each group are listed in Table 6.

Table 5: Nitrogen credits for different previous crops for first-year corn

Previous crop	1st year N credit
Group 1 crops	75 (lbs N/acre)
Group 2 crops	0
Edible beans	20
Field peas	20

The N rates listed in Tables 1 and 2 define the total amount of fertilizer N that should be applied. All N applied should be accounted for in the calculation, including N in starter fertilizer, weed and feed program, DAP (di-ammonium phosphate) or MAP (mono-ammonium phosphate) applied late fall (after 4” average soil temperatures stabilize at 50^{o}F) on non-sandy soils or for all soil types in spring, and with sulfur.

It is generally accepted that legume crops provide N to the next crop in the rotation. Some forage legumes provide some N in the second year after the legume was grown.

Red clover is the only crop other than alfalfa that may provide a second-year N credit. If red clover was grown two years before the current crop, 35 lbs of N per acre should be subtracted from the N rate when corn follows the crops listed in Group 2, Table 5.

Table 6: Crops in Group 1 and Group 2

Crop	Group number
Alsike clover	1
Birdsfoot trefoil	1
Grass/legume hay	1
Grass/legume pasture	1
Fallow	1

Crop	Group number
Red clover	1
Barley	2
Buckwheat	2
Canola	2
Corn	2
Grass hay	2
Grass pasture	2
Oats	2
Potatoes	2
Rye	2
Sorghum-sudan	2
Sugar beet	2
Sunflower	2
Sweet corn	2
Vegetables	2
Wheat	2

The use of manure as a fertilizer source can raise questions about adequate nitrogen rates. The economics of manure application are not straightforward when on-farm sources are used in corn production.

Manure presents challenges as not all of the nutrients are 100% available to crops in the first year of application. Plant available N (PAN) is a term used when applying manure to identify the amount of N applied that is plant available in any given year and may be less than the total N applied.

Suggestions for N application when manure is the primary nutrient source are given in Table 7. If commercial fertilizer is used along with manure, the suggested rates in Table 7 should not be exceeded. Lower application rates similar to the 0.10 price ratio may be considered based on the productivity of the soils in your fields, economics or environmental concerns.

Table 7: Nitrogen suggestions for corn when manure is used as a fertilizer source

Crop grown prior to corn	Crop 2 years prior to corn	Field irrigated?	Suggested PAN to apply (lbs N/acre)
Corn		No	195
Corn		Yes	235
Corn	Alfalfa (1 year old stand)	No	
Corn	Alfalfa (2 or more year old stand)	No	80
Soybean		No	150
Soybean		Yes	205
Alfalfa (1 year old stand)		No	80
Alfalfa (2 or more year old stand)		No	40

The pre-plant soil nitrate test (PPNT) can be a useful tool for assessing situations where residual soil nitrate can be credited to the corn crop. The PPNT should not be used when commercial fertilizer or manure was applied in the previous fall or in the spring prior to the sample being taken.

Western Minnesota

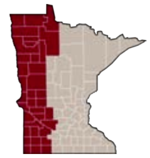

Fig. 1. The fall pre-plant nitrate test is appropriate for the maroon-shaded counties.

The use of the fall or spring PPNT is a key management tool for corn producers in western Minnesota. The suggestion that residual N in the fall can impact the need for nitrogen is contingent on the fact that the evapotranspiration of water historically has exceeded precipitation in this area of the state.

Use of the fall PPNT is appropriate in the maroon counties shown in Figure 1. The PPNT is particularly useful for conditions where elevated residual nitrate-N is suspected. Figure 2 is a decision tree that indicates situations where the nitrate-N soil test would be especially useful.

For the PPNT, soil should be collected from a depth of 6 to 24 inches in addition to the 0 to 6-inch sample that is used to test for pH, phosphorus and potassium.

Corn growers in western Minnesota also have the option of collecting soil from 0 to 24 inches and analyzing the sample for nitrate-nitrogen (NO_3-N). This 0 to 24-inch sample should not be analyzed for pH, phosphorus and potassium because the results cannot be used to predict lime needs or rates of phosphate and potash fertilizer needed.

When using the spring or fall PPNT, the amount of fertilizer N required is determined from the following equation:

NG = (Table 1 value for corn/corn) - (0.60 x STN(0-24in.))

- NG = Amount of fertilizer N needed (lbs N/acre)
- Table 1 value = the amount of fertilizer needed to be adjusted for soil potential, value ratio and risk
- STN(0-24 inch) = Amount of nitrate-N measured by using the fall PPNT (lbs N/acre)

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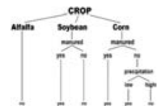

Figure 2: Flow chart decision-aid for determining probability of having significant residual nitrate-nitrogen in the soil following specific crop and situations where manure has been applied in a field within two to three cropping years prior to soil sample collection.

South-central, southeastern, east-central Minnesota

Research has led to the inclusion of a spring PPNT to adjust fertilizer N guidelines in south-central, southeastern and east-central Minnesota (gray counties in Figure 1). Soil nitrate-N, measured in the spring before planting from a two-foot sampling depth, is an option that can be used to estimate residual N.

In implementing this test, the user should first evaluate whether conditions exist for residual N to accumulate. Factors such as previous crop, soil texture, manure history and preceding rainfall can have a significant effect on the accumulation of residual N.

A crop rotation that has corn following corn generally provides the greatest potential for significant residual N accumulation. In contrast, when soybean is the previous crop, much less residual N has been measured. The PPNT should not be used following alfalfa.

The spring PPNT works best on medium and fine-textured soils derived from loess or glacial till. The use of the soil N test on coarse-textured soils derived from glacial outwash is generally not worthwhile because these soils consistently have low amounts of residual nitrate-nitrogen.

The amount of residual nitrate-nitrogen in the soil is also dependent on the rainfall received the previous year. In a year following a widespread drought (2012 for example) a majority of fields will have significant residual nitrate. However, following relatively wet years, little residual nitrate can be expected.

Nitrogen fertilizer guidelines for corn can be made with or without the soil N test. The University of Minnesota’s N guidelines (Table 1) are still the starting point. A five-step process is suggested when the soil nitrate-nitrogen test is considered.

1. Determine N rate guideline using Table 1 using soil productivity, price/value ratio, and previous crop for the specific field. The prescribed (rate assumes that best management practices (BMPs) will be followed for the specific conditions).

2. Determine whether conditions are such that residual nitrate-nitrogen may be appreciable. Figure 2, which includes factors such as previous crop, manure history and previous fall rainfall can provide insight as to the applicability of testing for nitrate-nitrogen. If conditions are such that the probability of residual nitrate is small and soil testing for nitrate is not recommended, use the N guideline derived in Step 1.
3. If conditions suggest that a soil nitrate test is warranted, collect a pre-plant, 0-2 ft. soil sample taking enough soil cores from a field so that the sample is representative of the entire field. The sample should be sent to a laboratory and analyzed for nitrate-nitrogen.
4. Determine residual N credit based on the measured soil nitrate-nitrogen concentrations. Use Table 8 to determine this credit.
5. Calculate the final N rate by subtracting the residual N credit (Step 4) from the previously determined N guideline (Step 1). The resulting fertilizer N rate can then be applied either pre-plant and/or as a side-dress application.

Table 8: Residual N credit values based on the concentration of nitrate-N measured before planting in the spring from the top two feet of soil

Soil nitrate-N	Residual N credit
0.0-6.0 (ppm)	0 (lbs N/acre)
6.1-9.0	35
9.1-12.0	65
12.1-15.0	95
15.1-18.0	125
Over 18.0	155

Because of the diversity of soils, climate and crops in Minnesota, there are no uniform statewide guidelines for the selection of a source of fertilizer N, placement of the N fertilizer and use of a nitrification inhibitor.

In order to accurately address this diversity, Minnesota has been divided into five regions and BMPs for N use in each region have been identified and described. The listing of these management practices for all regions is not appropriate for this publication, but they are available at the Minnesota Department of Agriculture.

Currently, the use of these BMPs is voluntary. Corn growers should implement BMPs to optimize N use efficiency, profit and protect against increased losses of nitrate-nitrogen to the environment.

Authors: Daniel Kaiser, Fabian Fernandez and Melissa Wilson, Extension nutrient management specialists; Jeffrey Coulter, Extension corn agronomist; and Keith Piotrowski, director of the soil testing laboratory

Taking soil samples for nitrogen analysis could pay big this year

blog-crop-news.extension.umn.edu/2022/03/taking-soil-samples-for-nitrogen.html

By: Brad Carlson, Extension educator

Record high nitrogen (N) fertilizer prices have received plenty of attention over the past several months. While farmers are scratching their heads trying to keep input costs down, an unusual opportunity is presenting itself this spring. Last year's exceptionally dry weather may have led to a nitrogen carryover credit that is not normally there.

The 2021 drought and soil nitrate levels

The nitrogen cycle naturally converts nitrogen in soil to the nitrate form. The nitrate ion is negatively charged, like soil particles, and therefore is not bound to the soil. Nitrate moves readily with water beyond the rooting zone or it can be lost via "denitrification" to the atmosphere if the soil stays saturated for long periods of time. Some nitrate naturally accumulates in the soil after the crop matures but before the soil cools down. This accumulated nitrate, together with any leftover fertilizer from the previous growing season, is usually lost during the spring before the next year's crop can take it up. It is for this reason that N fertilizer recommendations do not consider a nitrogen credit for this late season accumulated nitrate under normal circumstances. However, when there is enough of a water deficit in the soil profile that melting snow and spring rains do not

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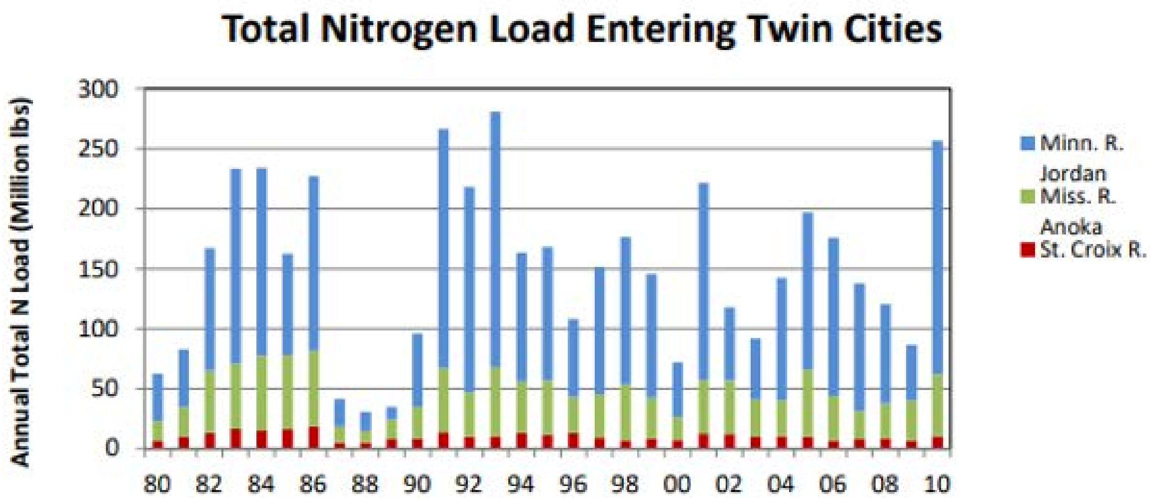
saturate the soil, there is less risk of N loss, meaning you may be able to take an N credit. Historical records show that nitrate concentration in surface water spikes in years following drought or excessively dry conditions. After the soil finally saturates, this accumulated soil nitrate flushes into surface water. It is anticipated that this may be the case at some point either this year or next year following the dry conditions experienced in much of the state in 2021.



This chart shows how nitrogen loads in Minnesota's rivers spiked following the drought of the late 1980s (MPCA 2013). A similar situation could unfold this year or next year if residual soil nitrate levels aren't accounted for and N fertilizer is overapplied.

Clues from last fall

Minnesota Valley Testing Labs conducted soil nitrate tests last fall and generously shared their data with us. Over 70% of the nearly 240 samples analyzed had an N credit of at least 35 pounds. Nearly 30% of the samples had N credits of 155 pounds or more. It should be noted that this is not a random sampling of sites, but rather an indication of soil N status where a carryover is suspected on the western side of the state where a fall test is considered acceptable. Data provided by Centrol Crop Consulting for tests run in advance of planting sugar beets shows a much smaller prevalence of N credits, with less than 5% showing a credit following soybeans, and about one third of samples indicating a credit following corn. However, there are some fundamental differences between the pre-sugar beet test and the pre-plant soil nitrate test (PPNT) for corn, and the samples were from the Red River Valley in northwest Minnesota where conditions were not nearly as dry as the southern third of the state.

Table 1. *Fall 2021 MVTL soil nitrate test results (239 samples, 0-24 inch samples)*

Nitrate level (ppm)	% of samples	N credit (lbs./ac)
0-6	28%	0
6-9	14%	35
9-12	10%	65
12-15	10%	95
15-18	5%	125
18+	28%	155

Pre-plant soil nitrate test (PPNT) tips

University of Minnesota research going back to the early 1990s resulted in the recommendation to use a soil nitrate test to measure this effect and credit residual N against the next year's fertilizer inputs under certain circumstances. The situations where a credit is likely are:

1. Fields that have a long-term manure history
2. Continuous corn following a drought

It should be noted that the test will work on any field where corn is going to be grown this year; it is just less likely that you will find an N credit in other circumstances, so it may not be worth the cost of testing. Also, it is important to note that portions of western and northern Minnesota received enough precipitation toward the end of, or after, the growing season to bring soils to field capacity, meaning you are less likely to find an N credit.

Minnesota's PPNT recommendations call for taking samples two feet deep to capture any nitrate that has already moved but still within the rooting zone. With the ability to variable-rate apply, it makes sense to break a field into management zones where there are likely to be differences (like one would do for any soil test). Be sure to take enough cores to ensure a good average, mix thoroughly, and dry quickly. Our research has shown that, in this case, more is always better. We suggest a minimum of 10 cores in a composite sample for the test results to be representative of the portion of the field or area of interest.

There are a few points to keep in mind if you are going to use the PPNT. Since nitrate is subject to leaching or denitrification loss, you want to take the sample as late as possible to ensure that what is measured is still there at the time the plants need it.

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Furthermore, if it becomes extremely wet after a sample is collected, the credit may disappear, so be prepared to compensate for this with additional sidedress N.

If you're growing corn this year, remember to request and use the PPNT, which gives results in ppm nitrate, and not the pre-sugar beet test, which gives results in pounds per acre. The interpretation of the results for corn are only calibrated for the PPNT, not the pre-sugar beet test. For similar reasons, you should not use recommendations from out-of-state, as the interpretation of the test results may not be correlated to the test protocol used in Minnesota.

Another point to remember is that the test only finds nitrate, so it will not accurately measure any fertilizer already applied or available N from a manure application. And lastly, Do not confuse the PPNT with the pre-sidedress nitrate test (PSNT), which is taken in-season and is most useful for fields with substantial potential for mineralization because of previous manure applications or where alfalfa was terminated.

More detailed instructions for taking the PPNT, as well as a chart to interpret results, can be found in our corn fertilizer guidelines.

For the latest nutrient management information, subscribe to the Minnesota Crop News email newsletter, like UMN Extension Nutrient Management on Facebook, follow us on Twitter, and visit our website.

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Manure Overload | Environmental Working Group

ewg.org/research/manure-overload

Manure Plus Fertilizer Overwhelms Minnesota's Land and Water

In almost all of Minnesota's farm counties, the combination of manure plus commercial fertilizer is likely to load too much nitrogen or phosphorus or both onto crop fields, threatening drinking water and fouling the state's iconic lakes and rivers, according to an Environmental Working Group investigation.

The problem arises from the extraordinary expansion and intensification of both livestock and crop production in the state. Since 1991, the number of large concentrated animal feeding operations, or CAFOs, in Minnesota has tripled. At the same time, fertilizer sales have increased by more than a third, fueled by the nearly 1.5 million additional acres devoted to corn.

Every year, feedlots of all sizes in the state produce nearly 50 million tons of manure – rich in nitrogen and phosphorus, the same chemicals in the more than three million tons of commercial fertilizer applied annually. Nitrogen and phosphorus are essential crop nutrients, but when they run off the fields, they can pollute drinking water sources and other bodies of water.

Using advanced geospatial techniques, EWG simulated and mapped every crop field across Minnesota likely to receive manure from nearby cattle, hog or poultry feedlots, to estimate the amount of manure applied in each county. We then added those amounts to the nitrogen and phosphorus in the fertilizer sold in the county.

The results are bad news for the state's water quality.

- In 69 of Minnesota's 72 agricultural counties, nitrogen from manure combined with nitrogen in fertilizer exceeded the recommendations of the Minnesota Pollution Control Agency, or MPCA, and the University of Minnesota. In 13 counties, nitrogen from the two sources surpassed the recommendations by more than half. (Table 1.) This excess nitrogen is the major cause of nitrate pollution in drinking water, which is linked to elevated rates of cancer.
- In nine counties, phosphorus pollution from manure is of high concern. These nine counties account for over half of the nearly 1.5 million acres where application of manure adds at least 10 pounds per acre more phosphorus than needed by crops. (Table 2.) Four of those counties are also among the 13 with the most excess nitrogen. Phosphorus pollution of lakes and rivers can trigger algae blooms, which are not only ugly but can also produce toxic bacteria harmful to human and animal health.

TABLE 1. MINNESOTA COUNTIES WITH HIGH RISK OF NITROGEN OVERLOAD

COUNTY	PERCENT N RECOMMENDATION MET BY MANURE APPLIED	PERCENT N RECOMMENDATION MET BY FERTILIZER SOLD	PERCENT N RECOMMENDATION MET BY MANURE AND FERTILIZER COMBINED	TONS OF N OVERLOAD
Martin	69%	107%	176%	14,368
Stearns	69%	91%	160%	12,564
Fillmore	33%	122%	154%	7,641
Goodhue	38%	122%	160%	7,180
Rock	73%	87%	159%	6,808
Morrison	84%	91%	175%	6,646
Nicollet	50%	107%	157%	6,111
Waseca	46%	107%	154%	5,376
Pipestone	68%	87%	155%	5,136
Winona	73%	122%	194%	4,977
Todd	67%	91%	157%	4,266
Wabasha	40%	122%	162%	4,150
Houston	57%	122%	179%	2,476

Source: EWG via Minnesota Pollution Control Agency, USDA-ARS Agricultural Conservation Planning Framework Database, Midwest Plan Service, University of Minnesota Extension and Minnesota Department of Agriculture.

TABLE 2: COUNTIES WITH HIGH RISK OF PHOSPHORUS OVERLOAD

COUNTY	AVERAGE P EXCESS ON MANURED ACRES *(LBS/ACRE)*	NUMBER OF MANURED ACRES	TONS OF EXCESS P ON MANURED ACRES
Morrison	25	132,566	1,730
Todd	19	114,027	1,092
Kandiyohi	19	128,282	1,331
Stearns	18	295,547	2,608
Winona	16	68,490	609
Otter Tail	14	126,474	873
Meeker	12	97,893	667
Fillmore	10	88,502	358
Goodhue	8	93,823	359

Source: EWG via Minnesota Pollution Control Agency, USDA-ARS Agricultural Conservation Planning Framework Database, Midwest Plan Service, University of Minnesota Extension, Minnesota Department of Agriculture and USDA National Agricultural Statistics Service.

Water Pollution Is Increasing

The statewide overload of nitrogen and phosphorus is taking its toll.

- An earlier EWG investigation found that 63 percent of Minnesota public water utilities with elevated levels of nitrate saw worsening contamination between 1995 and 2018.
- In the Sauk River watershed, the MPCA has listed nine lakes and four stream reaches as “impaired” because of bacteria, excess nutrients – mainly phosphorus – and algae blooms.
- After assessing all of the state’s major watersheds, the MPCA estimates that 56 percent of surface waters do not meet basic water quality standards, and that non-point source pollution, such as that from crop and livestock production, contributes to 85 percent of the state’s water pollution.

Since 1991, the number of large CAFOs in Minnesota has swelled from 468 operations to 1,497. (Figure 1.) Of the new operations, 86 percent were for feeding hogs, although the number for all other animals also grew. These operations are also getting bigger: Eight of the 67 dairy CAFOs built since 1991 house more than 8,000 cows, compared to just one of that size in 1991.

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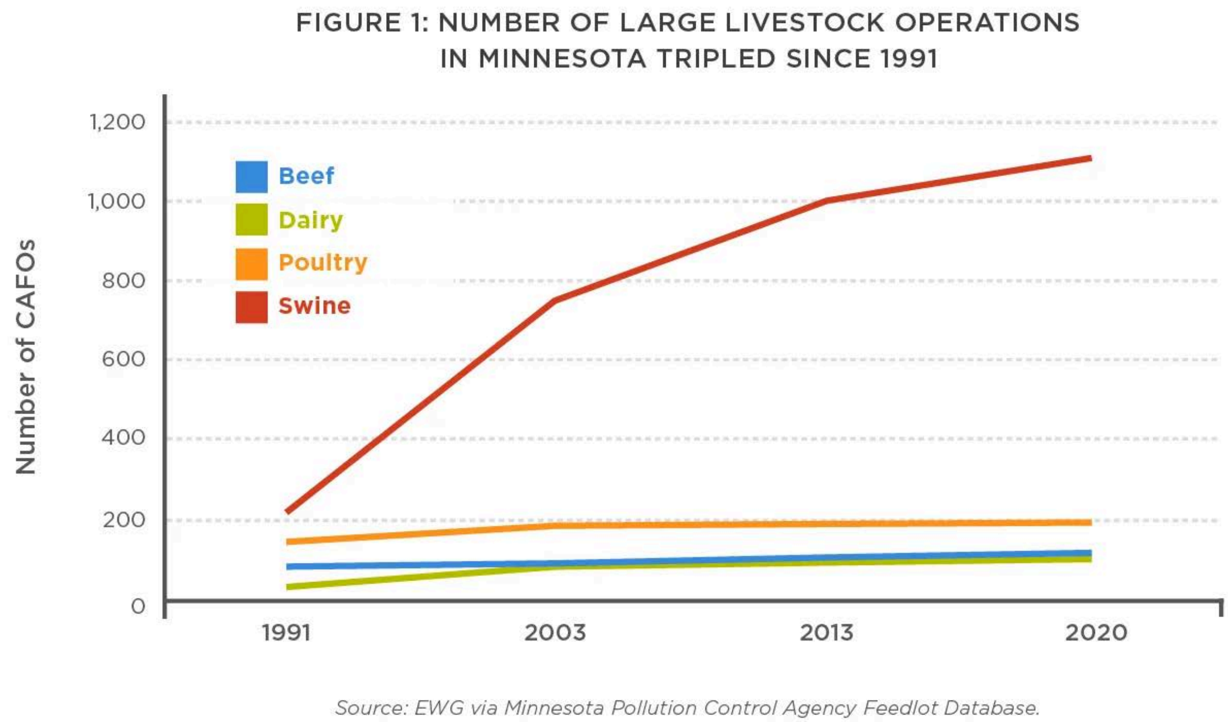
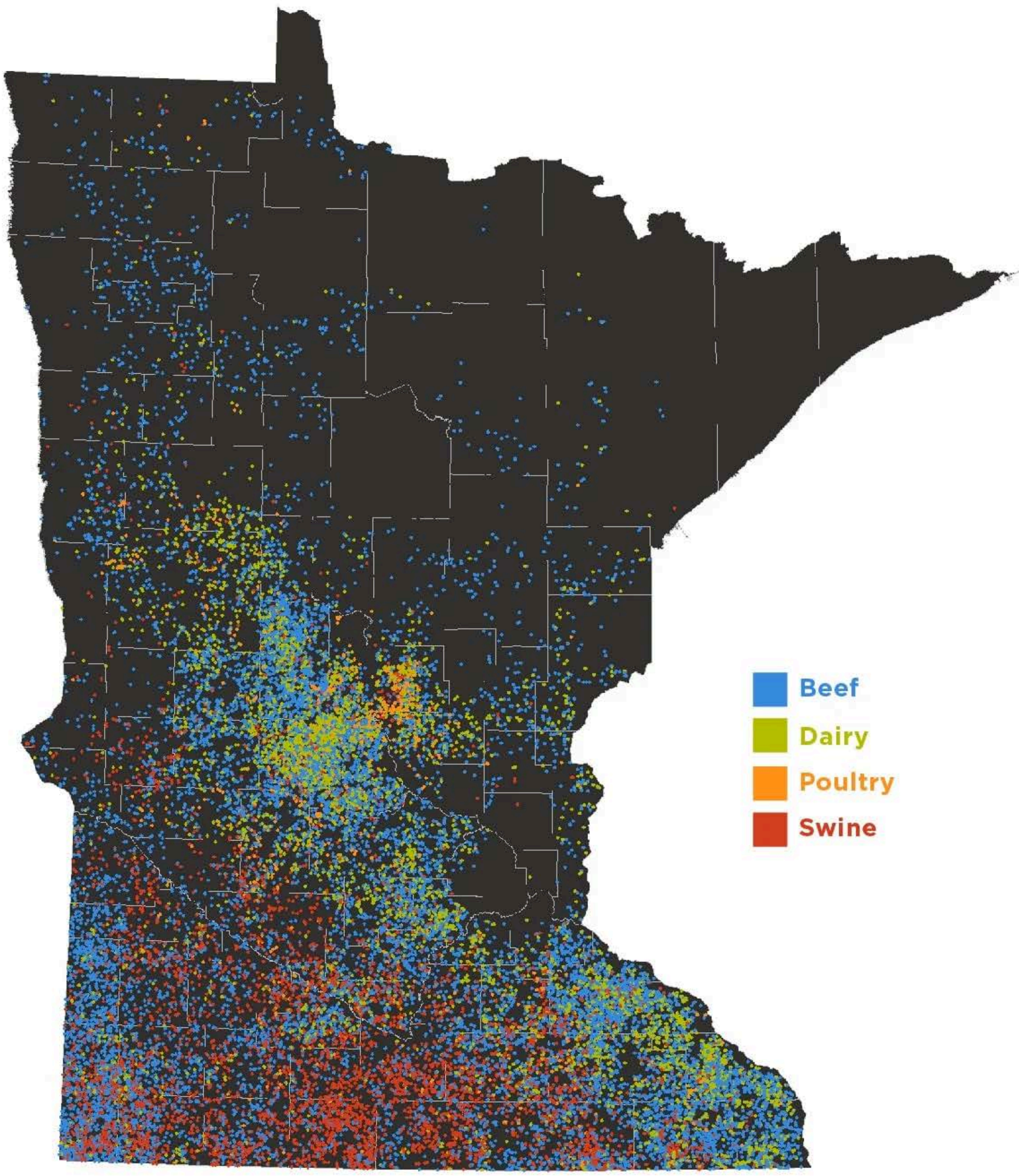


This extraordinary expansion raises concerns about the environmentally safe disposal of manure. Large CAFOS are just 4 percent of feeding operations in the state, but they produce nearly a third of the manure. Medium-size feedlots are 18 percent of all operations and contribute another 43 percent of the manure that goes on Minnesota fields every year.

Today Minnesota has 23,725 feedlots of all sizes. Packed into counties in southern and central Minnesota, these operations house up to 1.2 million dairy cows, 1.6 million beef cows, 10.9 million hogs, and 66 million turkeys and chickens. These feedlots produce an estimated 49 million tons of manure annually – the equivalent of the waste from 95 million people, 17 times the state’s human population.

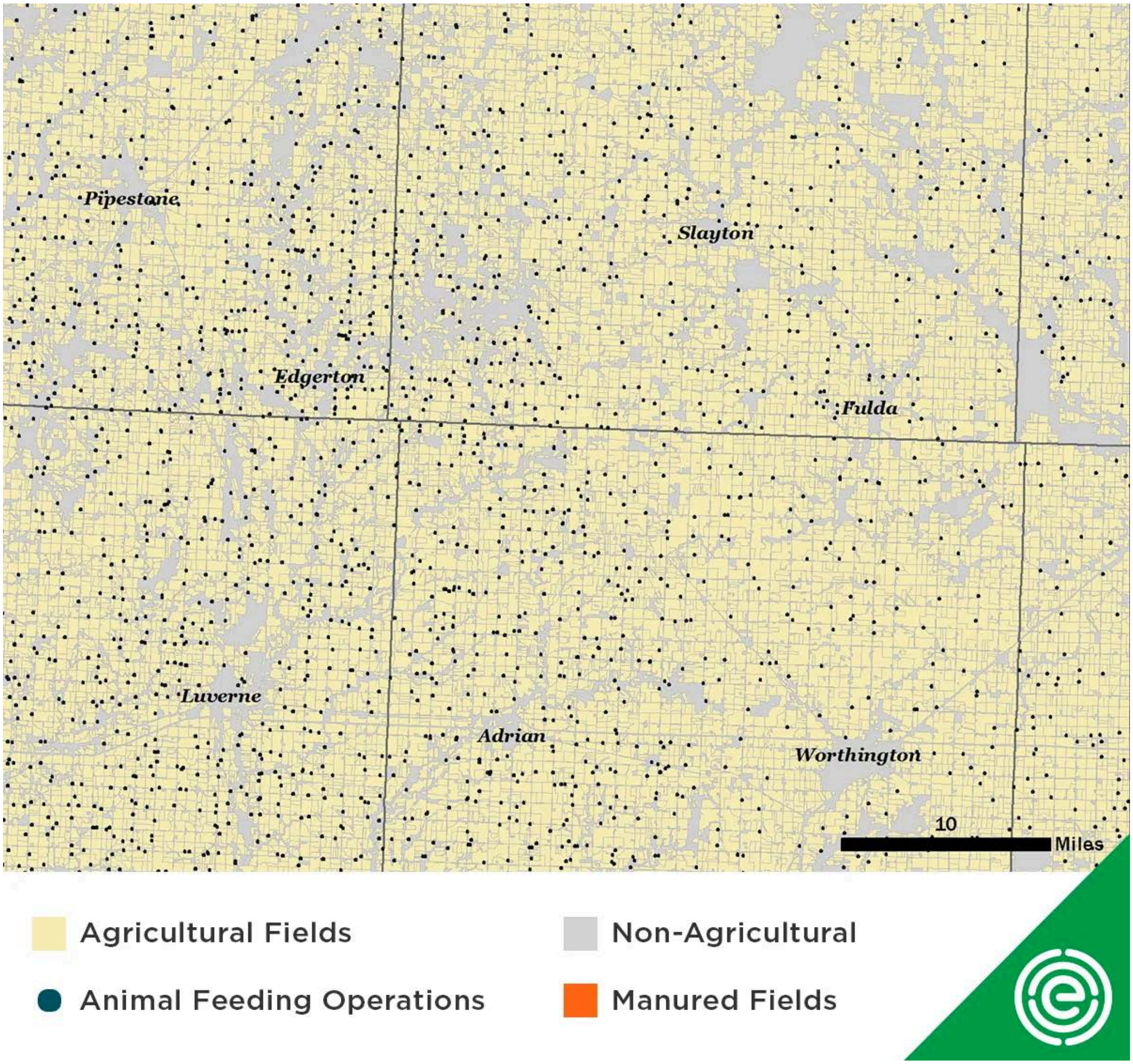
FIGURE 2: MINNESOTA IS HOME TO NEARLY 24,000 FEEDLOTS



Source: Minnesota Pollution Control Agency Feedlot Database.

EWG simulated which individual fields could safely accept manure, based on distance from the feedlot and the amount of nitrogen recommended for growing crops. Nitrogen rates were based on MPCA guidelines and University of Minnesota fertilizer recommendations.

Figure 3: How Manure Moves From Feedlots to Fields



Source: EWG via Minnesota Pollution Control Agency, USDA-ARS Agricultural Conservation Planning Framework Database, Midwest Plan Service, University of Minnesota Extension and Minnesota Department of Agriculture.

In areas with a dense concentration of livestock, nearly every single crop field is needed if all the manure produced by nearby feedlots is to be used safely, without overloading nitrogen. In a few isolated areas, there is simply too much manure to dispose of within a reasonable distance. EWG's simulation likely understates the risk of this overload, because we assumed every field within 5 miles of a cattle or hog feedlot and 25 miles of a poultry feedlot was available to take manure.

Moreover, research shows that much of the nitrogen considered lost to the atmosphere during manure storage and application ends up redeposited on the land nearby, adding to the potential overload.

The concentration of feedlots leaves little or no room to adapt to year-to-year changes in cropping patterns and fluctuating manure composition. It also increases the risk of overloading fields with phosphorus.

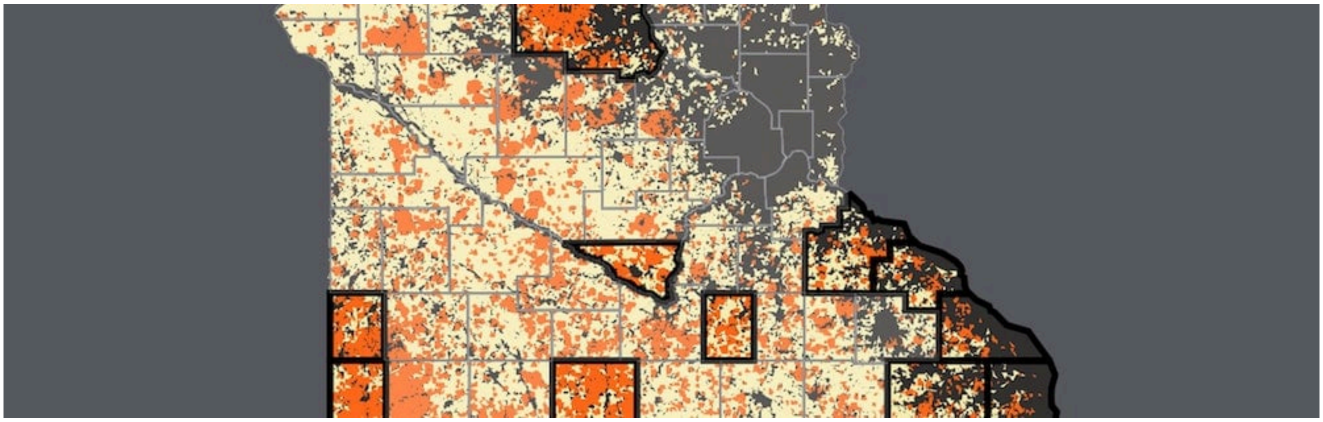
Manure Is Only Half the Story

You might expect fertilizer sales to be low in counties with dense concentrations of livestock, where manure alone can take care of the need for nitrogen fertilizer. Instead, we found little relationship between manure produced and fertilizer sold. Table 1 above lists 13 counties that are hot spots for nitrogen overload, where nitrogen from manure combined with nitrogen in fertilizer sold in the county exceeded crop recommendations by more than 50 percent.

Fertilizer sold in a county does not necessarily mean it was used there: A county might have half a neighboring county's crop acreage yet sell twice as much fertilizer. To account for this, we grouped fertilizer sales for counties within Minnesota's major crop regions, then allotted this regional sales data to counties based on fertilizer needs.

The interactive map below shows areas with an overload of nitrogen, as identified by our simulation.

Explore the Map



It’s not surprising that the counties we identified are dealing with nitrate overload issues. Southwest Minnesota has struggled with nitrate-contaminated water for decades. In 2014, the MPCA declared that most bodies of water in the area did not meet standards for supporting aquatic life and recreation, and the town of Adrian has been forced to shut down a water treatment plant after nitrate levels exceeded the U.S. Environmental Protection Agency’s legal limits. In Minnesota’s farthest southwest corner, Rock County’s water system’s average nitrate concentration increased by a staggering 890 percent from 1995 to 2018, according to EWG calculations.

Most of the CAFO growth in the state has been in Martin County, in south central Minnesota, home to 15 lakes on Minnesota’s 2020 list of nutrient-impaired water bodies. The list includes Budd Lake, which serves as the drinking water source for the town of Fairmont.

In townships in Morrison and Winona counties, the Minnesota Department of Agriculture found that more than 40 percent of private wells sampled had nitrate levels above the federal health limit of 10 micrograms per cubic liter. Many high-risk counties are located in vulnerable areas of the state, where karst bedrock or sandy soils make it easy for pollutants to reach groundwater.

The Phosphorus Problem

An inherent problem with manure is the imbalance between nitrogen and phosphorus relative to crop needs. When manure is applied to meet the nitrogen recommendation for crops, phosphorus is often overapplied. This nutrient imbalance is worse for poultry and cattle manure. The University of Minnesota Extension states that when turkey manure is applied to meet the nitrogen recommendation for corn, the crop gets more than five times the phosphorus needed.

Applying more phosphorus than the growing crop needs can lead to a buildup in the soil and greatly increases the risk of pollution. This risk is elevated in steep fields or those closer to lakes and streams. Long-term research in South Dakota showed that cattle manure applied to meet the nitrogen recommendation of crops dramatically increased soil phosphorus levels in less than 10 years. Eight pounds an acre of excess phosphorus can increase the level of phosphorus in the soil by 1 part per million, or ppm, which can quickly create problems for fields receiving manure year after year.

In Minnesota, soil phosphorus levels above 150 ppm (or 75 ppm near bodies of water) triggers action that requires farmers to lower the phosphorus levels from manure application. Other states, such as Indiana, have set this level even lower, suggesting that soil phosphorus is a concern once levels pass 50 ppm.

Our simulation found that on over 2.6 million Minnesota crop acres, or 57 percent of fields that received manure, more phosphorus was applied than removed. On nearly 1.5 million acres, this excess was more than 10 pounds per acre. On 590,000 acres, or 14 percent of manured fields, the excess was more than 25 pounds an acre.

Of the manured fields with a phosphorus excess greater than 10 pounds an acre, more than half fell in nine counties, as shown in Table 2, above. All nine counties are located in central and southeast Minnesota, and all have high densities of poultry and dairy operations.

In four counties – Morrison, Stearns, Todd and Winona – phosphorus from manure alone exceeds total crop requirements. Compounding the problem are the tons of additional phosphorus fertilizer sold in these same counties. Manure plus fertilizer phosphorus exceeds crop requirements in all but one of the counties in Table 2 (Otter Tail) and ranged from 90 percent to just over twice the phosphorus needed for the crop.

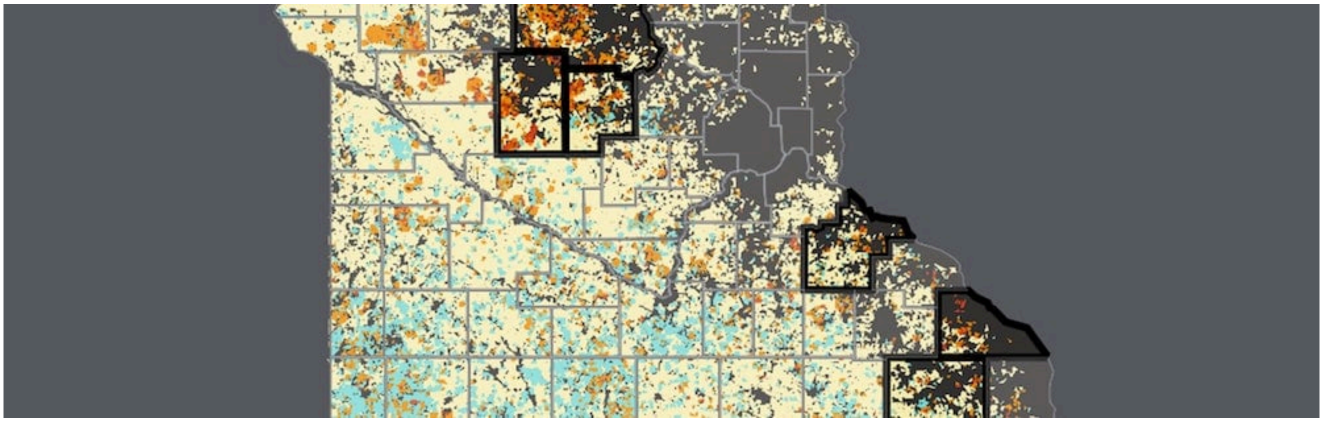
To limit phosphorus pollution from manure, farmers should apply manure to meet the phosphorus, not nitrogen, requirements of the crop. But because manure has much more nitrogen than phosphorus, far more acres are needed to apply manure at the proper rate for phosphorus. This can be twice as many acres needed for swine, compared to five times as many acres for turkey manure. In areas already saturated with manure, it is unlikely that this additional land is available.

Phosphorus pollution is the primary driver of algae growth in lakes. In the Sauk River watershed, in the heart of central Minnesota, the MPCA has set a Total Maximum Daily Load, or TMDL, to address bacteria, excess nutrients (mainly phosphorus) and nuisance algae blooms. Lake Osakis, a well-visited recreation area in the Sauk River watershed, was identified as a priority lake for water quality improvements.

Algae blooms are not only unsightly, they also have the potential to produce toxic cyanobacteria that are harmful to both human and animal health. Not far from Lake Osakis, in 2015 a child swimming in Lake Henry was hospitalized after exposure to blue-green algae. This followed the death of two dogs exposed to blue-green algae in nearby Red Rock Lake.

These examples are in central Minnesota, but algae blooms are common across all areas of the state with dense concentrations of cropland and livestock. The interactive map below shows the areas our simulation identified as having an overload of phosphorus.

Explore the Map



Manure Overload and Public Health

Contamination of water resources poses a real threat to Minnesota drinking water and public health. Growth and consolidation of animal agriculture intensifies this threat. Accurately crediting the amount of nitrogen and phosphorus in manure before any fertilizer is applied will improve soil health, protect drinking water and improve Minnesota's lakes, rivers and streams while saving farmers millions of dollars in reduced commercial fertilizer costs. The data strongly suggest, however, that isn't happening – especially in areas with dense concentrations of livestock.

A Minnesota Department of Agriculture survey revealed that almost three-fourths of farmers did not know how much nitrogen their manure contained, a basic requirement for good manure and fertilizer management. The same survey showed that almost two-thirds of farmers apply manure in the fall, a practice that increases the risk of nitrogen and phosphorus loss from manured fields, especially for liquid manure produced by hog and large dairy operations. Meanwhile, conservation practices that could reduce pollution from manure, such as cover crops, are drastically underused.

A comprehensive assessment of the capacity of Minnesota's landscape to handle its manure and fertilizer load is essential to ensure current and future residents have clean water. That assessment must drive decisions about where to site new or expanded feedlots and set standards for fertilizer and manure management, especially in areas with dense livestock.

For methods and detailed results, click here.

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Sources and Risk Factors for Nitrate and Microbial Contamination of Private Household Wells in the Fractured Dolomite Aquifer of Northeastern Wisconsin

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See "Quantitative Microbial Risk Assessment for Contaminated Private Wells in the Fractured Dolomite Aquifer of Kewaunee County, Wisconsin" in volume 129, 067003.
See "Farm to Faucet? Agricultural Waste and Private Well Contamination in Kewaunee County, Wisconsin" in volume 129, 114001.
Go to:

Abstract

Background:

Groundwater quality in the Silurian dolomite aquifer in northeastern Wisconsin, USA, has become contentious as dairy farms and exurban development expand.

Objectives:

We investigated private household wells in the region, determining the extent, sources, and risk factors of nitrate and microbial contamination.

Methods:

Total coliforms, *Escherichia coli*, and nitrate were evaluated by synoptic sampling during groundwater recharge and no-recharge periods. Additional seasonal sampling measured genetic markers of human and bovine fecal-associated microbes and enteric zoonotic pathogens. We constructed multivariable regression models of detection probability (log-binomial) and concentration (gamma) for each contaminant to identify risk factors related to land use, precipitation, hydrogeology, and well construction.

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Results:

Total coliforms and nitrate were strongly associated with depth-to-bedrock at well sites and nearby agricultural land use, but not septic systems. Both human wastewater and cattle manure contributed to well contamination. Rotavirus group A, *Cryptosporidium*, and *Salmonella* were the most frequently detected pathogens. Wells positive for human fecal markers were associated with depth-to-groundwater and number of septic system drainfield within 229m. Manure-contaminated wells were associated with groundwater recharge and the area size of nearby agricultural land. Wells positive for any fecal-associated microbe, regardless of source, were associated with septic system density and manure storage proximity modified by bedrock depth. Well construction was generally not related to contamination, indicating land use, groundwater recharge, and bedrock depth were the most important risk factors.

Discussion:

These findings may inform policies to minimize contamination of the Silurian dolomite aquifer, a major water supply for the U.S. and Canadian Great Lakes region.

https://doi.org/10.1289/EHP7813
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Introduction

The paradox presented to the 13.1 million households in the United States that rely on private wells for supplying their drinking water (NGWA 2020) is that the household owns the well and the land on which the well is constructed, but it does not control the source, movement, and quality of the pumped groundwater. Anthropogenic disturbances on neighboring properties, such as changes in land cover, building development, agricultural practices, septic systems, and groundwater withdrawals, can alter the supply and quality of groundwater on which the household depends. Thus, as a shared natural resource, groundwater is susceptible to the “tragedy of open access” (Bromley and Cernea 1989), where without appropriate institutional safeguards the resource (i.e., groundwater) can become diminished and degraded.

This tension of having competing land uses affect the shared groundwater resource is particularly noteworthy in northeastern Wisconsin, where both dairy farms and exurban development have expanded atop the underlying Silurian dolomite aquifer. The aquifer is the water source for at least 85% of private wells in the region (K. Bradbury, Wisconsin State Geologist, personal communication). In the region’s four main agricultural counties, Brown, Calumet, Kewaunee, and Manitowoc, the number of milking dairy cows increased from 132,558 to 180,860 between 2002 and 2017, a 36% increase (USDA NASS 2002, 2017). This number of milking cows produces approximately 5.9×109 kg of excrement (manure and urine) per year (Nennich 2005), which in northeastern Wisconsin is all applied to the landscape (Erb et al. 2015). Population growth in the four-county region between 1950 and 2000 increased exurbanization by as much as 60% (Brown et al. 2005). Dairy farms and exurban homes are in greater proximity than years ago, each land use potentially contributing to the degradation of the common groundwater resource on which they depend.

Compounding the effects of more intensive land use on groundwater quality is the highly vulnerable nature of the Silurian dolomite aquifer, which is an important water supply for the region (Figure 1). The dolomite bedrock is densely fractured in both horizontal and vertical directions, and in many regions the surficial sediment overlying the bedrock is thin, i.e., 6m or less (Sherrill 1978). Groundwater recharge is extremely rapid because soil macropores and the extensive vertical fracture network allow rain and snowmelt water to infiltrate easily (Muldoon and Bradbury 2010). Infiltrating water carries contaminants originating at the land surface to the water table, after which groundwater flow in horizontal fractures can be rapid, providing little attenuation to contaminant transport (Bradbury and Muldoon 1992; Muldoon et al. 2001).

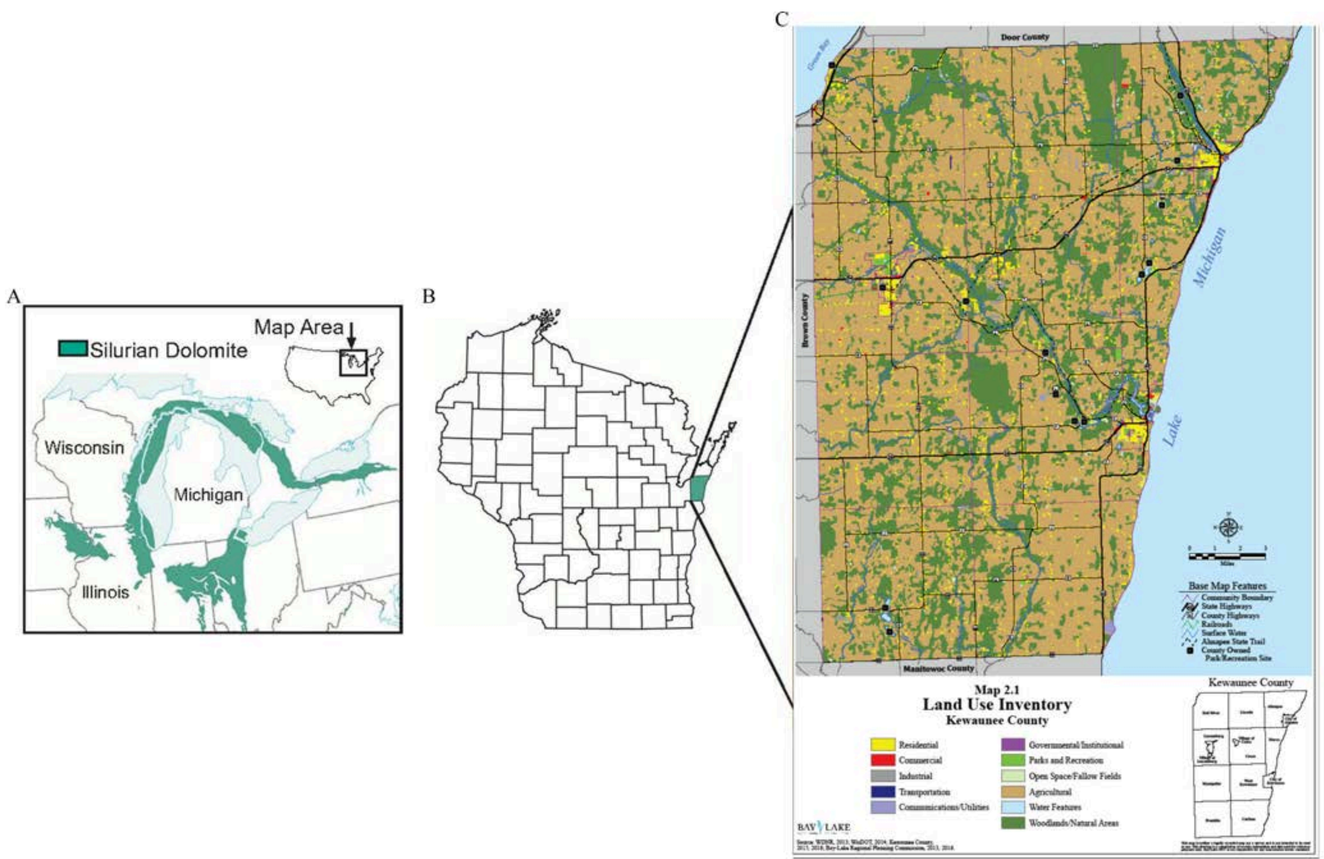

Figure 1.
Location of study site including (A) map of generalized Silurian dolomite subcrop shown as shaded area (modified from Shaver et al. 1978); (B) location of Kewaunee County, Wisconsin, United States; and (C) map of land use within the county. Land use map reprinted with permission from Bay Lake Regional Planning Commission, Green Bay, Wisconsin.

Contamination of private household wells open to the Silurian dolomite aquifer has been evaluated primarily by standard indicator bacteria for water sanitary quality (i.e., total coliform bacteria and *Escherichia coli*) and nitrate–nitrogen (NO_3^--N) In the five-county region where the aquifer is most vulnerable (Brown, Calumet, Door, Kewaunee, and Manitowoc Counties), 14% of 7,521 samples from private wells exceeded the U.S. Environmental Protection Agency (U.S. EPA) health advisory of 10mg/L for NO_3^--N for public water supplies (U.S. EPA 2020). Twenty-three percent of 6,739 samples tested positive for total coliforms, and 2% of 6,583 samples were positive for *E. coli* (Center for Watershed Science and Education Wisconsin 2018). Although these analyses may indicate the extent of contamination, they do not provide information on the source of contamination.

The most obvious contamination events happen when manure enters the aquifer and is pumped from a household well into indoor taps as odoriferous brown water (Figure 2). Manure-containing brown water incidents are more likely during groundwater recharge when snow is melting and after dairy manure is applied to agricultural fields (Erb et al. 2015). Erb et al. (2015) documented 25 brown water incidents between 2008 and 2014 in domestic wells located in Brown, Calumet, Kewaunee, and Manitowoc counties, and these incidents can present a health risk (Wisconsin Department of Health Services n.d.).

Figure 2.
“Brown water” event at a Kewanee County household with a private well. Note: Photo provided and permission granted by Chuck Wagner.

As the “tragedy of open access” of the groundwater resource in northeast Wisconsin was unfolding, public debate centered on two questions: *a*) what is the true extent of groundwater contamination? and *b*) what are the sources of contamination, septic systems or dairy manure? Through interactions with stakeholders, we learned that historical total coliform and nitrate data were considered biased by some because it was believed samples were submitted only from problem wells that were not representative of groundwater conditions. As for the source question, opposing sides generally took positions without having data in hand, because the technology of microbial source tracking (MST) to identify fecal sources has rarely been applied to household wells. To help resolve these questions and bring information to bear on potential solutions, we proposed three study objectives: *a*) conduct random sampling of private wells, stratified by depth-to-bedrock, for indicator bacteria and nitrate; *b*) from the subset of wells in Objective 1 that were positive for total coliform bacteria or had NO_3^--N>10mg/L, conduct random sampling for enteric pathogens and MST markers indicating whether fecal contamination was from septic systems or dairy manure; and *c*) perform statistical analyses to identify land use, weather, hydrogeology, and well construction risk factors that were associated with private well contamination.

Go to:

Methods

Study Area

The study area was Kewaunee County located in northeast Wisconsin, USA (Figure 1). The county's population is 20,600, of which 11,300 (55%) live in 4,900 rural homes served by septic systems and private wells (Bay Lake Regional Planning Commission 2016). Land cover in the 2808-km2 county is predominantly agriculture (63%), natural areas (29%), and residential (3%) (Bay Lake Regional Planning Commission 2016). Dairy farming and associated crop production are the primary agricultural activities. Cattle and calves number approximately 107,000 on 306 farms (USDA NASS 2017). The climate is continental, modified by the proximity of Lake Michigan, with precipitation (rain and snow) of 78cm water per year (NOAA n.d.). Soils are medium- to fine-textured, underlain by Pleistocene glacial deposits; unconsolidated sediments vary in thickness from several centimeters to more than 30m over the bedrock (Erb et al. 2015). Karst features such as open fractures are present, albeit many are covered with soil (Erb et al. 2015).

Indicator Bacteria and Nitrate

Private household wells were selected by stratified random sampling for tests of total coliforms (hereafter coliforms), *E. coli*, and nitrate. Candidate wells were identified from a list of property parcels that *a*) were not served by municipal water systems and *b*) had improvement values greater than USD $30,000, which indicated that a residence (and therefore private well) was likely present (n=4,896). Parcels with mailing and property addresses that did not match were excluded to prevent confusion regarding sample location (n=948).

Water sampling was conducted during two synoptic events, 13–14 November 2015 and 29–30 July 2016. Strata were defined by depth-to-bedrock (i.e., the depth of unconsolidated sediment overlying bedrock at the well site) because earlier work suggested this parameter influenced groundwater contamination (Final Report of the Northeast Wisconsin Karst Task Force 2007). Using ArcMap software (version 10.3.1; ESRI), candidate wells were grouped into three strata based on an existing depth-to-bedrock map (Sherrill 1979): <1.5m (n=269), 1.5–6.1m (n=473), and >6.1m (n=3,206). (Depth-to-bedrock data were not available for individual wells at the time of well selection.) Letters inviting participation were mailed, and all willing well owners (approximately 50% of invitees) received a sampling kit. After accounting for unreturned kits, 323 and 401 private well samples were submitted for the fall and summer sampling events, respectively. Some wells (103) were sampled in both events (see Figure S1 for well recruitment, exclusion, and dropout). All study wells were completed in the Silurian dolomite or overlying sediment.

Samples were collected by well owners following written instructions to sterilize the sample tap with a flame for 15 s or by alcohol swab and run the water run for at least 5 min prior to filling two polypropylene bottles provided in the sampling kit. The 60-mL nitrate bottle contained 160μL of 96% sulfuric acid for preservation. Samples were collected on the scheduled dates and on the same day delivered to designated receiving locations in the county where they were transported that day on ice to the laboratory. Coliforms and *E. coli* were analyzed by Colilert Quanti-Trays (IDEXX) within 48 h of sample collection. Nitrate was measured on an AQ1 Discrete Analyzer (SEAL Analytical) by cadmium reduction and reaction with sulfanilamide in conjunction with N-(1-naphthylethylenediamine) dihydrochloride (Method 4500-NO_3^-F; American Public Health Association 1995).

Microbial Source Tracking and Pathogen Occurrence

Wells positive for coliforms or with NO_3^--N>10mg/L were eligible for additional sampling to assess sources of fecal contamination and the occurrence of enteric pathogens. From this group, wells were selected for five sampling events: 18–22 April, 1–3 August, and 31 October–2 November in 2016 and 23–24 January and 27–29 March in 2017. For each event, selection was randomized and stratified by the three depth-to-bedrock categories. We sampled 22 to 30 wells during each event, resulting in 138 samples from 131 wells; seven wells were sampled in two events.

Sampling was conducted by trained staff using dead-end ultrafiltration (Smith and Hill 2009) with Hemodialyzer Rexeed-25s ultrafilters (Asahi Kasei Medical MT Corp.). Water taps were flame-sterilized before ultrafilter attachment; all ultrafilter tubing and fittings were new for each sample. Well water was collected prior to softening or other treatment systems. Mean sample volume was 839L (range: 522–1,517L, n=138). Ultrafilters were bagged, placed on ice, and back-flushed in the laboratory within 72 h.

Ultrafilters were back-flushed using a 500-mL solution containing 0.01% sodium polyphosphate (NaPP), 0.5% Tween 80, and 0.001% antifoam Y-30 (Smith and Hill 2009). Bacto beef extract (ThermoFisher Scientific Catalog No. 211520) was added to the back-flushed eluate at a 1% weight to volume ratio (typically 6.5g of beef extract into 650mL of eluate) to provide an organic matrix for sample archival at −80°C and to aid flocculation of the secondary concentration step by polyethylene glycol (PEG) flocculation (Lambertini et al. 2008). Briefly, samples were incubated overnight at 4°C following addition of 8% PEG 8,000 and 0.2M NaCl. Samples were centrifuged for 45 min at 4,700×g at 4°C, and the pellet was resuspended in TE buffer to a final concentrated sample volume (FCSV) of 3–26mL (4mL average). FCSVs were stored at −80°C until extraction of nucleic acids. Nucleic acids were extracted from 280μL of final concentrated sample volume with the

QIAamp DNA blood mini kit and buffer AVL using a QIAcube® (Qiagen). Final volume of the nucleic acid suspension was 140μL. Three extractions were performed per sample to produce sufficient template for all gene markers assayed.

Virus RNA was reverse-transcribed (RT) by adding 25.8μL nuclease-free water and 2.1μL random hexamers (ProMega) to 25.8μL of the extracted nucleic acids. This mixture was heated for 5 min at 95°C and then mixed with 96.3μL RT master mix consisting of the following components reported as final concentrations in the 150μL total reaction volume: 50 mM Tris-HCl (pH 8.3), 75 mM KCl, 3 mM $MgCl_2$, 0.6 mM dithiothreitol, 70μM of each deoxynucleoside triphosphate (ProMega), 1U/μL RNasin® (ProMega), 0.5U/μL SuperScript® III reverse transcriptase (Invitrogen Life Technologies). Reaction incubation was 42°C for 60 min followed by 5 min at 95°C and then held at 4°C until polymerase chain reaction (PCR) amplification.

Samples were analyzed by quantitative real-time polymerase chain reaction (qPCR) for 33 gene markers specific to 30 microbial taxa or groups (see Table S1). The microbes tested were all fecal-associated and, based on the biology of the microbe or validation studies reported in the scientific literature, placed in one of three host-specificity categories: human-specific, bovine- or ruminant-specific, and no host specificity. qPCR was performed with a LightCycler® 480 instrument (Roche Diagnostics) using the LightCycler 480 Probes Master kit for all markers except for human *Bacteroides*, which used TaqMan Environmental Master Mix 2.0® (Applied Biosystems). Six μL extracted DNA or cDNA from reverse transcription was added to 14μL of master mix, producing a 20-μL reaction volume. Primers and hydrolysis probes (Integrated DNA Technology), and their concentrations are reported in Table S1. For all markers except human *Bacteroides*, thermocycling began at 95°C for 5 min followed by 45 cycles of 10 s at 95°C and 1 min at 60°C with ramp rates of 4.4 and 2.2°C per second, respectively. Thermocycling for human *Bacteroides* began at 95°C for 10 min followed by 45 cycles of 30 s at 95°C, 2 min at 56°C, and 1 min at 72°C with ramp rates of 2.2, 1.1, and 2.2°C per second, respectively. Two qPCR technical replicates were performed per marker. If both replicates were negative the result is reported as 0. If only one was positive, that concentration is reported. If both replicates were positive, the average concentration is reported.

To ensure laboratory contamination was absent (i.e., no false positives), we performed negative controls (i.e., no-template controls) of every gene marker for the extraction, reverse transcription, and qPCR steps for every batch of these process steps, and we tested for every marker in every batch of ultrafilter backflush solution. All tests had to be negative [i.e., no cycle quantification (Cq) value] for sample data to be accepted.

Inhibition was evaluated following the approach of Gibson et al. (2012), using as controls Hepatitis G virus RNA oligonucleotide (IDT) and G-lambda DNA (New England Biolabs) for reverse transcription and qPCR inhibition, respectively. Samples with Cq values of controls that increased two or more were considered inhibited. Twelve of 138 samples were qPCR-inhibited, requiring dilution with AE buffer (Qiagen).

Extraction positive controls were bovine herpes virus vaccine for DNA and bovine respiratory syncytial virus vaccine for RNA (both vaccines from Zoetis Inc.), the latter serving also as the reverse transcription positive control. qPCR positive controls were gBlocks® or Ultramers® (IDT) of each marker, with sequences modified to distinguish from wild type while maintaining the same guanine and cytosine content.

Standard curves were generated by serially diluting the positive controls in AE buffer with 0.02% bovine serum albumin, creating a concentration range of 1 to 106 gene copies (gc)/reaction. Quantification cycle (Cq) values were calculated using the second derivative maximum method and regressed against the decimal logarithm of marker concentration using the nonlinear function provided by the LightCycler® 480 software. Standard curve parameters and 95% limits of detection are reported in Table S2 and Table S3, respectively.

Samples positive by qPCR for rotavirus group A were further analyzed following the methods of Iturriza-Gómara et al. (2004) and Madadgar et al. (2015) to determine human and bovine G and P genotypes using seminested PCR assays targeting the *VP7* and *VP4* structural viral protein genes. In brief, nucleic acid extraction and reverse transcription were performed as described above. The first PCR amplified the *VP7* or *VP4* gene using VP7-F/VP7-R or Con-3/Con-2 primers, respectively. The 20-μL reaction contained 6μL of cDNA from reverse transcription, 14μL of Roche LightCycler 480 master mix, and 200 nM of each primer. A separate seminested reaction was run for each human and bovine G- and P-type (19 type-specific reactions). For all seminested reactions, 2μL of amplicon from the first reaction were added to 18μL of master mix containing one of the initial primers and a type-specific primer at 200 nM each for a final reaction volume of 20μL. (See Table S4 for all primers and their concentrations and Table S5 for thermocycling conditions for each reaction.)

PCR products (20μL) were visualized by gel electrophoresis on 1.5% agarose gel (100 V for 90 min). A negative control and two positive controls [RotaTeq® vaccine-positive human fecal specimen and bovine CalfGuard® vaccine (Zoetis)] were included in each analysis batch along with the DNA ladder (ProMega). Gel bands matching specific genotypes were purified with illustra™ GFX PCR DNA and Gel Band Purification Kit (GE Healthcare), and identity was confirmed by sequencing. Direct sequencing of the amplicons was performed in both directions using the seminested reaction primers (see Table S4). We used the BigDye® Terminator V3.1 Cycle Sequencing Kit (Applied Biosystems) for the sequencing reaction, and the University of Wisconsin–Madison Biotechnology Center performed the reads on an ABI 3730xl DNA Analyzer. Consensus sequences were constructed with Lasergene (DNAStar) and submitted for identification using BLAST (National Center for Biotechnology Information, Bethesda, MD). Genotypes were used to classify all rotavirus group A detections as human or bovine for inclusion in human and bovine-specific outcome measures: G1P[8] and G10P[11] were considered human- and bovine-specific genotypes, respectively (Pitzer et al. 2011; Papp et al. 2013).

Samples positive for human-specific *Bacteroides* (HF183/BacR287; Green et al. 2014) or ruminant-specific *Bacteroides* (Rum-2-Bac; Mieszkin et al. 2010) were reanalyzed by PCR (676 bp amplicon) and sequencing, following the method of Bernhard and Field (2000), to confirm *Bacteroides* identity. *Bacteroides* DNA was extracted by the method described above and 6μL DNA extract was added to 14μL LightCycler 480 Probes Master including 500 nM of primers Bac32F and Bac708R (Bernhard and Field 2000). PCR commenced at 94°C for 5 min followed by 35 cycles consisting of 94°C for 30 s, 53°C for 1 min, and 72°C for 2 min, followed by a final 6-min extension at 72°C. PCR product (10μL) was visualized on 1.5% agarose gel. If the amplicon band was absent or faint, sensitivity was increased by reamplifying 1–6μL of amplicon under the same thermocycling conditions. Product purification from the gel, the sequencing reaction, and analyses were performed as described above for rotavirus A genotyping. Direct sequencing of the amplicons was performed in both directions using primers 32F and 708R.

Risk Factor Variables

Well construction variables were obtained from well driller reports filed at the Wisconsin Geological and Natural History Survey or Wisconsin Department of Natural Resources. Reports were available for 65% of sampled wells. As described above, initial well selection was stratified using existing depth-to-bedrock maps. However, for the statistical analyses, the exact depth-to-bedrock value for each well was obtained from its construction report. When a report was not available (n=116 and 135 for fall and summer sampling events, respectively), bedrock depth was estimated by interpolation from reports of nearby wells. Well elevation was obtained from the county digital elevation model.

Groundwater depth was measured continuously in U.S. Geological Survey monitoring well KW-183 (USGS 443535087345401 KW-25/24E/34-0183) and data are available in the USGS National Water Information System (USGS 2020). The well is located in Kewaunee County near an agricultural field. Relative to the ground surface, depth-to-bedrock is 2.1m, borehole depth is 9.14m, and casing depth is 3.05m (Muldoon and Bradbury 2010).

Groundwater recharge was estimated by the water table fluctuation method (Healy and Cook 2002), using graphical extrapolation of the antecedent recession curve and a specific yield of 0.04 based on previous assessments of recharge in the fractured rock in this area (Bradbury and Muldoon 1992). Cumulative recharge was obtained by summing individual recharge events for the 2-, 7-, 14-, and 21-d periods preceding sample collection.

Quantitative precipitation estimates (QPE) for each sampled well location (in 4-km grids) were provided by the North Central River Forecast Center of the U.S. National Weather Service. Because QPE values include snow, and frozen snow will not infiltrate soils, we excluded precipitation measurements for all well locations for days when snow without rain was recorded at the nearby National Weather Service station in Green Bay, Wisconsin. Cumulative precipitation was calculated by summing hourly QPE values over 2, 7, 14, and 21 d prior to sampling. Precipitation was not included in analyses of coliform and nitrate data because the synoptic design precluded variation in precipitation over the short time samples were collected.

Geographic Information System (GIS) data layers maintained by the Kewaunee County government reported locations of septic systems, agricultural fields, manure storages, and surface bedrock features. Agricultural field data included whether the field had a nutrient management plan (NMP) and therefore likely received manure applications.

Septic systems were divided into three categories for analysis: *a*) septic systems, included active systems of all types; *b*) drainfield, included inspected and uninspected systems that are designed to release effluent to the subsurface (i.e., excludes holding tanks); and *c*) not inspected, included only those systems that had not been inspected by county staff. Systems not in use were excluded from all three categories. The risk factor “distance to nearest septic system” excluded the system on the same property as the well, whereas counts of septic systems included the system on the same property.

Using ArcMap and Python script, fecal contamination sources and bedrock features were enumerated for each study well in two forms: *a*) distance from the well to the nearest contamination source or bedrock feature; and *b*) the count or areal size of the source or feature within three circular areas surrounding the well. The circular areas were defined by three radii from the well: 229, 457, and 914m (equal to 750, 1,500, and 3,000 ft, respectively), corresponding to 16, 66, and 262 ha (approximately 40, 160, and 640 acres). These area sizes were selected prior to data analysis based on an earlier study of septic system counts in similar-sized areas that were associated with childhood infectious diarrhea (Borchardt et al. 2003a).

Statistical Analyses

Stratified random sampling was employed to generate estimated contamination rates of coliforms, *E. coli*, and nitrate. Sampling strata were defined by depth-to-bedrock (<1.5, 1.5–6.1, and >6.1m). Smaller strata were oversampled relative to a simple random sample. This approach, in conjunction with the use of corresponding analytic weights and finite population correction factors in the analyses, resulted in more precise estimates for the smaller depth-to-bedrock strata without sacrificing the ability to estimate a countywide contamination rate. The analytic weight was defined as the product of the inverse of the sampling probability and the inverse of the response rate (i.e., the proportion of sampled well owners who agreed to participate in the study) within the appropriate depth-to-bedrock stratum. Rao-Scott likelihood ratio chi-square tests (Lohr 2010) were used to test associations between contamination rates and depth-to-bedrock as well as compare fall 2015 (groundwater recharge period) and summer 2016 (no recharge period) estimated contamination rates, both overall and within depth-to-bedrock strata. Statistical computations accounted for the complex sampling design.

Risk factors for well contamination were evaluated for independent variables relating to land use, precipitation, hydrogeology, bedrock, and well construction. Variables were tested for association with *a*) well contaminant detection and *b*) well contaminant concentration (among wells where contaminants were detected). Five contaminants (or contaminant groups) were tested for associations with risk factors: coliform bacteria, nitrate, human fecal markers, bovine fecal markers, and any fecal marker. Tests for coliform bacteria and nitrate associations were performed for each sampling period, groundwater recharge and no recharge.

For dichotomous (detect/nondetect) dependent variables, univariable screening for inclusion in the multivariable modeling process was performed using logistic regression. Each independent variable was represented as a linear (in the logit) term in the models. For independent variables with >10% zero values, a dichotomous (zero vs. greater than zero) term was included in the screening model in addition to the linear term. A plot of the estimated detection probability across the observed range of values for the independent variable being evaluated was also generated as part of the screening process. The same univariable screening process was performed for the well contaminant concentration dependent variables except that gamma regression with a natural log link function was used (Garson 2013), the model terms were linear in the log, and plots of estimated mean concentrations were generated.

For both univariable and multivariable analyses, outliers were excluded from the models for some of the concentration dependent variables. Specifically, 4 and 11 outliers were excluded from the analyses of coliform concentration for groundwater recharge and no recharge periods, respectively. And one, two, and four outliers were excluded for human, bovine, and any fecal marker concentration models, respectively. The criterion for excluding data points from the analyses was that their inclusion in the model caused the fitted curve to deviate meaningfully from the pattern exhibited by the remaining data. Concentration values for outliers were generally orders of magnitude larger than those in the remaining data points.

To be included in the multivariable model for a particular dependent variable, risk factors had to meet several criteria: *a*) strength of association (i.e., $p \leq 0.15$); *b*) plausibility, the association had to be biologically or physically possible; and *c*) internal consistency, where variables of the same measurement but at different levels (e.g., count of septic system drainfields within 229, 457, or 914m of a well) had similar directions of association (positive or negative) and strengths of association. When two variables of different measurements (e.g., well elevation and depth to bedrock) were correlated, the variable that most satisfied criteria 1, 2, and 3 was selected.

Additional screening was applied for inclusion in multivariable modeling when risk factors of the same measurement but at different levels were all associated with well contamination. Levels could differ in time (2, 7, 14, or 21 d) or area (within 229, 457, or 914m from a well). Under this situation, the risk factor with the greatest strength of association was selected. For example, 2-, 7-, and 14-d cumulative precipitation variables were all strongly associated with well contamination of human-specific markers. However, the 2-d cumulative precipitation variable had the largest regression coefficient and lowest *p*-value, so it was selected for inclusion.

Once the independent variables for a given multivariable model were identified, a screening process for interaction terms among these variables was undertaken. Only interactions deemed plausible and relevant were assessed. A screening model contained a term for the interaction and main effect terms for the individual risk factors comprising the interaction. As with the univariable screening of main effects, the independent variables comprising the interaction were represented as linear terms in the models; an interaction term was included in the multivariable model when its *p*-value was ≤ 0.15.

For multivariable analyses, the same procedure was used for both well contaminant detection and well contaminant concentration. Gamma regression was employed for all multivariable analyses of well contaminant concentration. Prior to performing multivariable regression analyses, each independent variable retained after the screening process was reassessed at the univariable level to establish whether a more complex representation than linear (e.g., quadratic or spline) would be appropriate in the multivariable model. To decide on an appropriate representation, a plot of the logit of the detection probability (log of the mean concentration) across the observed range of values for the independent variable was generated and examined, with the independent variable represented as a natural cubic spline (Hastie et al. 2001) in the corresponding logistic (or gamma) regression model. If a more complex representation was deemed appropriate, it was used in both main effect and interaction terms in the multivariable models.

All risk factors and interaction terms retained after the above screening processes were included in each final multivariable model. We did this in order that the independent effects of each risk factor could be evaluated in the presence of (i.e., adjusting for) the other model terms.

The final multivariable models were fit using log-binomial (or gamma) regression to facilitate interpretation of the results (McNutt et al. 2003). These models permit direct estimation of ratios of detection probabilities (or mean concentrations). This is in contrast to logistic regression models, which estimate ratios of odds rather than probabilities. When presence of the dependent variable is not rare (roughly <10%), which is typical in studies of well contaminant detection, the odds ratio does not closely approximate the corresponding ratio of detection probabilities and must be interpreted with caution.

For each multivariable model, procedures specific to generalized linear models were used to determine whether the information matrix was ill-conditioned (http://support.sas.com/kb/32/471.html). This approach entailed examining whether collinearity in the weighted risk factors was present, where the weights were determined by the model fitting algorithm.

Separate multivariable models for well construction risk factors were created because a number of wells were missing well construction reports. Had all risk factors been combined into a single model, only those wells without missing construction data would have been included, reducing statistical power to evaluate the other risk factors.

SAS version 9.4 was used to conduct all analyses (SAS Institute Inc.).
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Results and Discussion

Groundwater Levels during Sampling

Groundwater levels during the first study year followed the pattern typical for the upper Midwest with rising levels in the fall and spring and falling levels in the summer and winter (Figure 3). However, there was a prolonged recharge period from fall 2016 to spring 2017 (Figure 3). In January 2017, snowmelt raised groundwater levels during a long warm period (NOAA n.d.). Coliform and nitrate sampling corresponded with fall recharge (hereafter “recharge”) and with the summer decline when groundwater was at nearly its deepest level (hereafter “no recharge”). Sampling for microbial source tracking occurred during recharge (3 events) and no-recharge (2 events) periods.

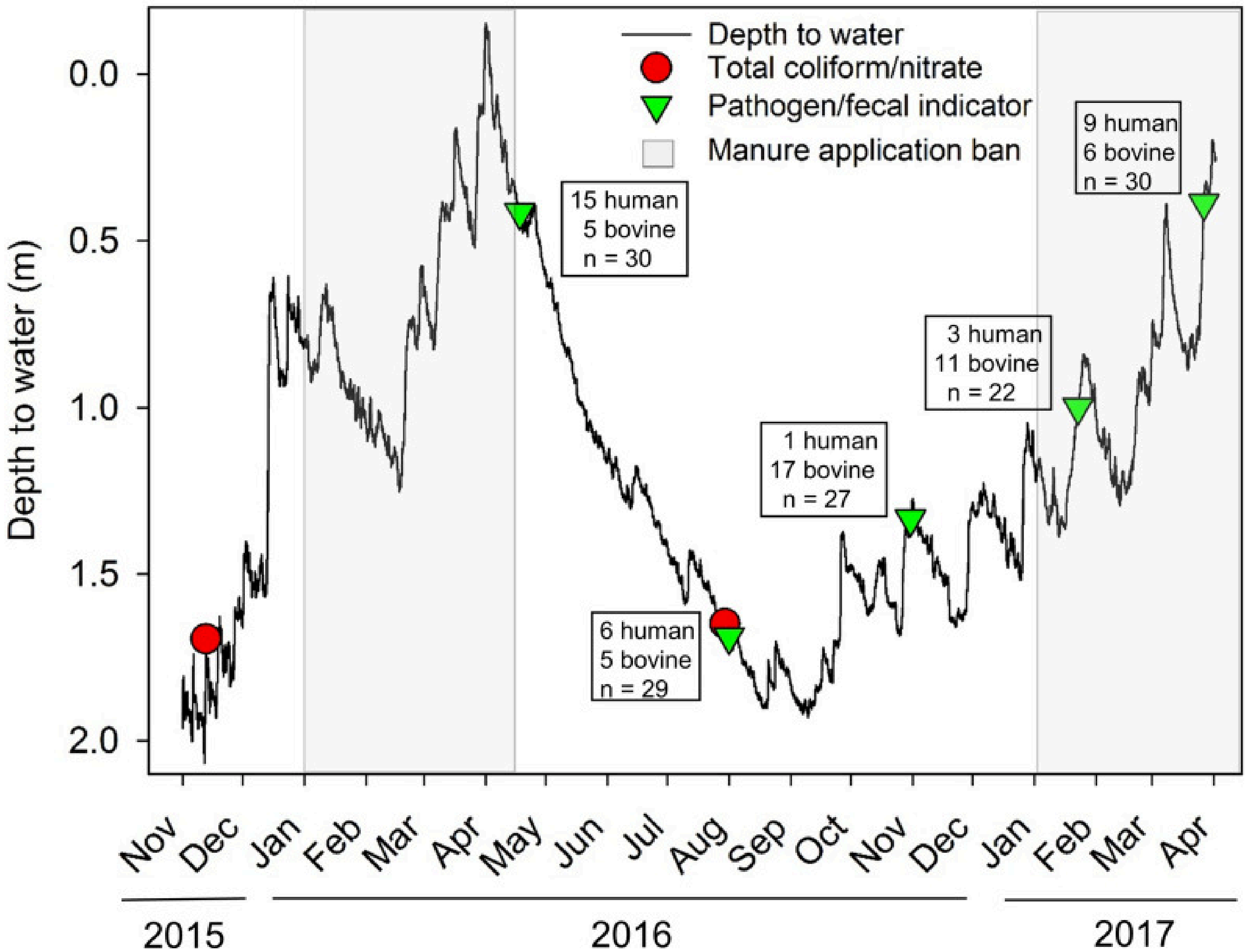

Figure 3.
Sampling periods in relation to groundwater level in Kewaunee County monitoring well KW-183 (USGS 443535087345401; USGS 2020). Sampling times indicated by red circles (total coliforms and nitrate) and green triangles (pathogens and fecal indicators). Boxes indicate the number of wells positive for human-specific or bovine-specific markers; $n = \text{total number of wells sampled}$. Gray shaded areas designate seasonal manure application ban for fields with bedrock depths $< 6.1\text{m}$.

Bacteria and Nitrate Contamination Rates

The countywide private well contamination rates for coliforms, *E. coli*, and NO_3^--N>10mg/L were similar to the average rates for the state of Wisconsin (Table 1). However, for wells in the two shallowest bedrock depth strata (<1.5m and 1.5–6.1m), contamination rates were generally greater than the statewide averages, and rates were consistently greater than rates for wells in the deepest stratum (>6.1m to bedrock). The greater the bedrock depth and transport distance through surficial sediments, the less likely these contaminants will reach bedrock fractures that allow rapid transport (Final Report of the Northeast Wisconsin Karst Task Force 2007; Rasmuson et al. 2020).

Table 1

Estimated contamination rates (percent positive wells) for total coliform bacteria, *Escherichia coli*, or nitrate-N>10mg/L.

Sampling period or reference data	Region or depth-to-bedrock category[a]	Number of wells sampled	Percent positive wells (95% confidence interval)			
			Total coliforms	*E. coli*	Nitrate-N>10mg/L	Total coliforms or nitrate-N>10mg/L
Groundwater recharge	<1.5m to bedrock	26	46 (30, 63)	4 (0, 9)	7 (0, 15)	50 (34, 66)
	1.5–6.1m to bedrock	120	28 (18, 37)	1 (0, 2)	20 (7, 33)	42 (28, 55)
	>6.1m to bedrock	167	19 (11, 26)	0.3 (0, 0.6)	6 (1, 10)	23 (15, 31)
	Kewaunee County	313[b,c] 316[c,d]	21 (14, 27)	0.4 (0.1, 0.7)	7 (3, 11)	26 (19, 34)
No groundwater recharge	<1.5m to bedrock	24	23 (6, 39)	7 (0, 15)	10 (0, 20)	33 (12, 53)
	1.5–6.1m to bedrock	122	29 (16, 41)	1 (0, 3)	19 (9, 28)	40 (28, 53)
	>6.1m to bedrock	252	21 (15, 27)	26 (19, 32)		
	Kewaunee County	396[b,c] 400[c,d]	22 (17, 28)	1 (0.1, 2)	7 (4, 10)	28 (22, 33)
Reference data	Wisconsin[e]	534	23	3	7	—
	Wisconsin[f]	3,838	18	—	10	—

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Note: —, no data available. Estimates and corresponding 95% confidence intervals account for the stratified random sampling design employed in the study.

[a]The estimated number of wells in each bedrock depth category are 76, 575, and 4,156 wells at <1.5, 1.5–6.1, and >6.1m, respectively, totaling 4,807 wells in Kewaunee County. Our final estimates of the number of wells in each bedrock depth category are different than the initial estimates at the study beginning using the bedrock map created by Sherrill (1979).
[b]*n* for coliforms and *E. coli*.

[c]The *n*'s do not equal the number of samples analyzed (see Figure S1) because some wells had missing depth-to-bedrock values (six wells for the groundwater recharge period and one well for the no recharge period) for which analytic weights could not be generated.

[d]*n* for nitrate.

[e]Data for private wells; U.S. General Accounting Office 1997.
[f]Knobeloch et al. 2013.
Groundwater recharge and no-recharge periods did not have significantly different contamination rates, regardless of contaminant type or level of data aggregation (Table 1). There was one exception; coliform contamination during recharge was greater than the no-recharge period for wells with bedrock depths <1.5m (p=0.042).

Table 2 reports descriptive statistics for coliforms, *E. coli*, and nitrate-N concentrations of positive samples. In both recharge and no-recharge periods, 25% of wells positive for nitrate-N had concentrations greater than 9mg/L.

Table 2

Descriptive statistics of coliform bacteria, *Escherichia coli*, and nitrate concentrations.

Sampling period	Measurement	Number of positive samples	Number of non-detects	Concentration of positive samples[a]					
				Mean	Median	Minimum	25th percentile	75th percentile	Maximum[b]
Groundwater recharge	Coliforms	87	232	73.2	5.2	1.0	2.0	17.3	>2,419.6
	E. coli	5	314	5.0	2.0	1.0	2.0	4.1	16.1
	Nitrate-N	203	119	6.3	4.7	0.2	1.6	9.0	29.7
No groundwater recharge	Coliforms	87	310	116.8	6.2	1.0	2.0	55.4	>2,419.6
	E. coli	10	387	105.0	3.1	1.0	1.3	8.8	1011.2
	Nitrate-N	205	196	6.5	5.2	0.2	2.1	9.1	33.3

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Note: MPN, most probable number.

[a]Coliforms and *E. coli*, MPN/100mL; nitrate-N, mg/L.

[b]2,419.6 MPN/100mL was the upper limit of quantification.

Coliforms, although nonpathogenic, are the standard indicator of drinking-water sanitary quality in the United States. Studies of coliform-positive private wells have observed (DeFelice et al. 2016) and not observed (Strauss et al. 2001) associations with acute gastrointestinal illness. High nitrate in drinking water can cause methemoglobinemia, and in some studies it has been linked with colorectal cancer, thyroid disease, and central nervous system birth defects (Ward et al. 2018). The U.S. National Primary Drinking Water Standards apply only to public water systems, not private wells. Nonetheless, the U.S. drinking water Maximum Contaminant Level Goals (MCLG) for coliforms and nitrate-N provide public health benchmarks, which are zero and 10mg/L, respectively (U.S. EPA 2020). Multiplying the MCLG exceedance rates for coliforms or nitrate-N (Table 1) by the estimated number of wells in each bedrock depth category in Kewaunee County [76, 575, and 4,156 wells at <1.5, 1.5–6.1, and >6.1m, respectively (Borchardt et al. 2019)], we estimate approximately 1,300 wells (27%) during the study period did not meet U.S. EPA public health goals for safe drinking water.

Calculating well contamination rates by county, state, or other governmental units has the advantage of matching policy-making jurisdictions. However, aggregating data in this manner can overlook factors underlying contamination "hotspots," in this case, bedrock depth. For example, the statewide averages for coliform and nitrate MCLG exceedances in Wisconsin, irrespective of bedrock depth, are 18% and 10%, respectively (Knobeloch et al. 2013). Using the multivariable models for coliforms and nitrate for recharge and no-recharge periods, respectively (see below and Figures 4B and and4C),4C), the statewide percentages are equivalent to detection probabilities at bedrock depths of 10m (coliforms) and 14m (nitrate) in Kewaunee County. We estimate the number of wells with shallower bedrock depths, and therefore higher detection probabilities than the statewide averages, to be 1,562 (coliforms) and 2,464 (nitrate), which is 32% and 50% of the county's private wells. This assessment is consistent with the high rates of coliform and nitrate exceedances for carbonate aquifers (e.g., Silurian dolomite) and agricultural areas observed in private well data nationally (DiSimone 2009).

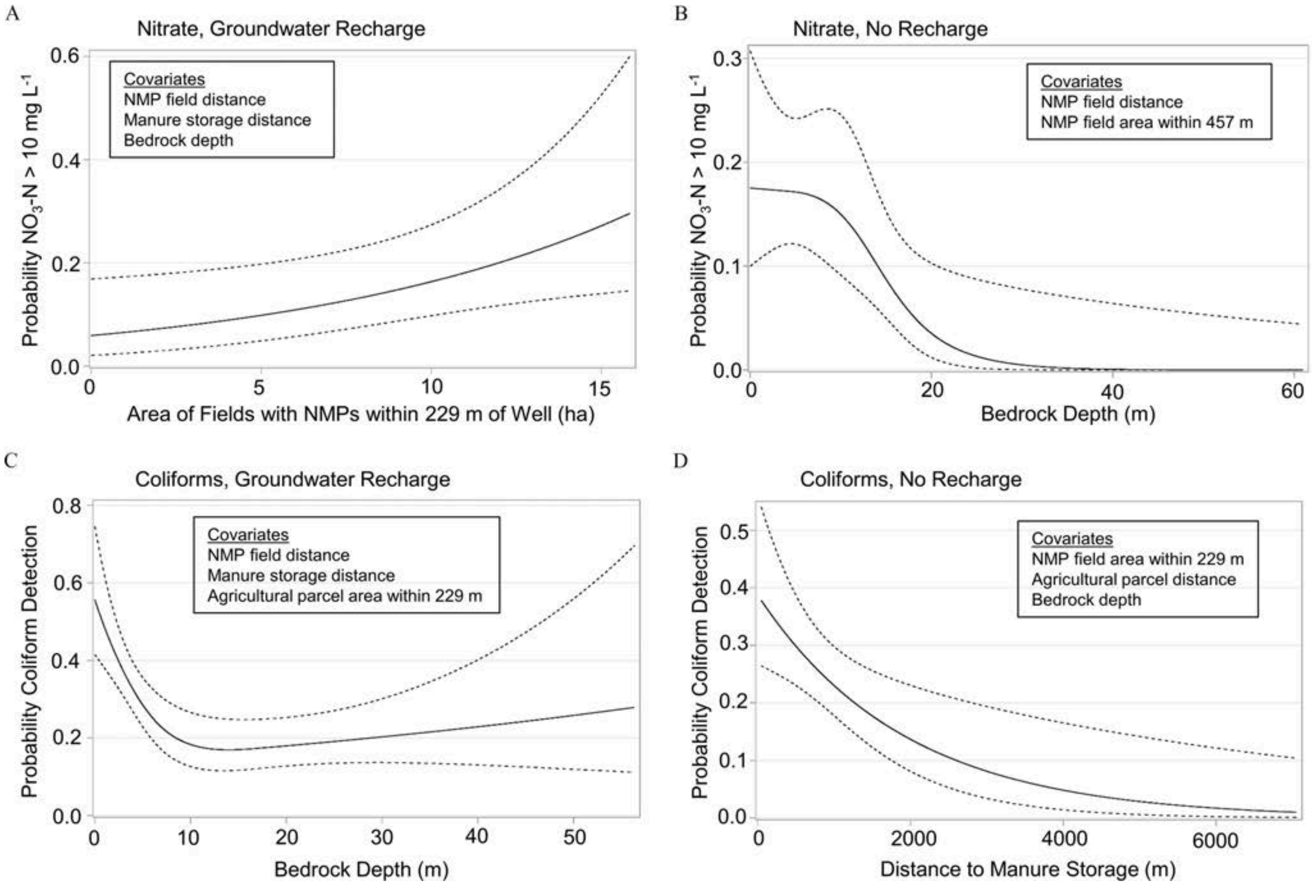

Figure 4.

Detection probabilities for NO3-N>10mg/L and coliform bacteria in private wells regressed (log-binomial) on key risk factors during groundwater recharge and no recharge periods. Coefficients and *p*-values are reported in Table 4. Black line: estimated probability of detection. Dashed lines: 95% pointwise confidence limits. Covariates in the multivariable models were fixed at their median values for the purpose of plotting. Fields with NMPs likely receive manure and inorganic fertilizer inputs. Note: NMP, nutrient management plan.

Microbial Source Tracking and Pathogen Occurrence

Of 138 samples from 131 wells, 82 samples (59%) from 79 wells (60%) were positive for markers of fecal-associated microbes (Table 3). Among the 79 wells with fecal contamination, 32 wells had markers for pathogens that could infect humans (human-specific and zoonotic pathogens without host specificity). Seventy wells were positive for two or more markers. Well water concentrations of fecal-associated markers were generally low; *Bacteroidales*-like CowM2 and *Bacteroidales*-like CowM3 had the highest median concentrations (Table 3).

Table 3

Gene markers of fecal-associated microbes detected in samples (n=138) from private household wells (n=131).

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Host specificity	Microbe[a]	Gene marker[b]	Number of positive wells[c]	Number of positive samples[c]	Concentration of positive samples (gene copies/L)	
					Median	Range
Human-specific	*Bacteroidales*-like Hum M2	Glycosyl hydrolase family 92	7	8	4	<1–1,050
	Human *Bacteroides*	16s rRNA (HF183/BacR287)	27	28	<1	<1–34
	Cryptosporidium hominis	18s rRNA	1	1	<1	<1
	Adenovirus A	hexon	1	1	1	1
	Rotavirus group A, G1 P[8]	*NSP3*	7	7	<1	<1–3
	Rotavirus group A, G1 P[8]	*VP1*	3	3	1	<1–22
	Any human marker	—	33	34	<1	<1–1,050
Bovine- or ruminant-specific	*Bacteroidales*-like Cow M2	DHIG domain protein	2	2	472	29–915
	Bacteroidales-like Cow M3	HD super family hydrolase	4	4	174	3–49,818
	Ruminant *Bacteroides*	16s rRNA (Rum-2-Bac)	36	36	1	<1–42,398
	Bovine polyomavirus	*VP1*	8	8	4	<1–451
	Bovine enterovirus	5’ non-coding region	1	1	2	2
	Rotavirus group A, G10 P[11]	*NSP3*	12	12	12	2–4,481
	Rotavirus group A, G10 P[11]	*VP1*	5	5	23	<1–732
	Any bovine or ruminant marker	—	44	44	3	<1–49,818

Host specificity	Microbe[a]	Gene marker[b]	Number of positive wells[c]	Number of positive samples[c]	Concentration of positive samples (gene copies/L)	
					Median	Range
No host specificity	Pepper mild mottle virus	replication-associated protein	13	14	14	2–3,811
	Cryptosporidium spp.	18s rRNA	2	2	<1	<1–1
	Cryptosporidium parvum	18s rRNA	13	13	<1	<1−14
	Giardia duodenalis group B	β-giardin	2	2	<1	<1
	Campylobacter jejuni	*mapA*	1	1	<1	<1
	Salmonella spp.	*invA*	3	3	6	<1–13
	Salmonella spp.	*ttr*	5	5	10	5–59
	E. coli (pathogenic)	*eae*	1	1	4	4
	Shiga toxin producing bacteria	*stx1*	1	1	16	16
	Shiga toxin producing bacteria	*stx2*	1	1	1	1
	Rotavirus group C	*VP6*	3	3	50	45–1,301
	Any nonspecific marker	—	37	46	5	<1–3,811
All	Any fecal marker	—	79	82	2	<1–49,818

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Note: —, Any of the gene markers within the specified group.

[a]Microbial markers analyzed but not detected: human adenovirus groups B, C, D, and F; human enterovirus; human norovirus genogroups I and II; human polyomavirus; *Cryptosporidium bovis*; bovine adenovirus; bovine coronavirus; and bovine viral diarrhea virus types 1 and 2.

[b]Primers, probes, and references for qPCR assays are reported in Table S1.

[c]Totals are less than the sum of individual markers because some wells and samples were positive for more than one marker.

The 60% fecal contamination rate could be an overestimate because we limited well selection to those wells previously positive for coliforms or with nitrate-N concentrations >10mg/L to favor successful completion of the study objective, that is, identify fecal sources of contamination. On the other hand, 60% could be an underestimate, because 95% of the wells were sampled only once, and detection probability was shown to increase the more frequently a well was sampled in one study (Atherholt et al. 2015).

Comparing the fecal contamination rate of our study wells with rates from other studies is confounded by differences in hydrogeological setting, well type, sampling season, the number of wells, the number of samples per well, and the types and number of fecal microorganisms tested. Five studies approximate our study design, setting, or type and number of fecal microbes and can provide some context. Among 50 private wells in seven hydrogeological districts of Wisconsin, 8% were positive for human enteric viruses (Borchardt et al. 2003b). Private wells completed in fractured Silurian dolomite in Ontario, Canada (11 wells), and fractured bedrock in Pennsylvania, USA (5 wells), had microbes of fecal origin in 45% and 100%, respectively (Allen et al. 2017; Murphy et al. 2020). Ninety-six percent of public wells tested in Minnesota, USA, for similar types and number of fecal organisms were positive (Stokdyk et al. 2020), and, as in the present study, *Cryptosporidium* was the most frequently detected pathogen, suggesting it is more common in groundwater than previously thought (Stokdyk et al. 2019). Last, in a comprehensive review of groundwater studies conducted in Canada and the United States, Hynds et al. (2014a) reported that of 12,616 public and private wells tested, at least one enteric pathogen was detected in 15%. Although comparisons among studies are abstruse, the weight of evidence suggests fecal contamination of drinking water wells is not uncommon.

Fecal contamination stemmed from both human wastewater and bovine manure sources. Human wastewater was present in 33 wells, and bovine manure was present in 44 wells (Table 3). Nine wells were contaminated by both fecal sources, human and bovine. Of the 37 wells (46 samples) positive for nonspecific markers, 11 wells (13 samples) did not have coincident detections for human- or bovine-specific markers, indicating that for these wells and samples the fecal source was unknown.

Previous studies have found human-specific and bovine-specific *Bacteroidales* genetic markers detected together in the same private wells (Krolik et al. 2014; Felleiter et al. 2020) and wells and springs (Diston et al. 2015). Nine private wells completed in the dolomite aquifer of six Wisconsin counties were positive for *Bacteroidales* markers specific to human, bovine, or swine fecal material (Zhang et al. 2014).

Identifying which fecal source, human or bovine, was the greatest contributor to groundwater fecal contamination in the county is not possible from our MST data. The proportion of samples positive for human or bovine markers varied by sampling period, which is to say by season, groundwater level, and timing of manure applications (Figure 3). Beginning 1 January 2016, Kewaunee County

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banned manure applications during the 1 January–15 April period on all fields with bedrock depths <6.1m. The proportion of wells positive for bovine-specific markers likely depends on the timing and location of well sampling relative to the ban regulations. Groundwater recharge is also important (see below). Therefore, both human and bovine fecal sources contribute to contamination, and the fecal source that appears to bear the most responsibility for contamination depends on sample timing.

Human-specific HF183 *Bacteroides* (28 samples) and ruminant *Bacteroides* (36 samples) were the most common fecal markers, and all samples positive for these were successfully sequenced to confirm *Bacteroides* host identities (see Table S6, Table S7). The Rum-2-Bac marker is specific to ruminants, not cattle alone. However, two lines of evidence suggest the detected Rum-2-Bac markers were indeed from dairy manure: *a*) All amplicons (676 bp) from Rum-2-Bac-positive samples matched *Bacteroidales* or *Bacteroides* species from cattle feces with percent identities greater than 98% and E-scores of zero; and *b*) The only other abundant ruminants in Kewaunee County are approximately 16,000 white tail deer (Wisconsin Department of Natural Resources 2018). Deer excrete 261g/d fecal material (McCullough 1982), which for the Kewaunee County landscape equals 1.3×106 kg/y. In comparison, the land-applied cattle manure in the county is 1.76×109 kg/y (see Supplemental Material, Cattle Manure Volume Produced Annually in Kewaunee County), more than 1,000 times greater than that of deer, suggesting the more probable groundwater contaminant is cattle manure.

Rotavirus group A subtyping was successful for distinguishing human from bovine fecal sources in our study, but that may not always be possible. The human rotavirus vaccine, RotaTeq, contains five human–bovine reassortment strains (Matthijnssens et al. 2010), and because the G6 (bovine) strain can be shed in human stool after oral vaccination (Higashimoto et al. 2018), the fecal source cannot be distinguished when that strain is detected (i.e., vaccine shed into septic systems or G6 wild type in dairy manure). However, our study wells were not positive for the G6 strain, because subtyping analysis revealed rotavirus G1 [P8], which is typically associated with human rotavirus infection (Pitzer et al. 2011), or G10 [P11], a subtype associated with rotavirus infections in cattle (Papp et al. 2013). (Two wells were positive for both subtypes.) Whether the G1 [P8] rotavirus we detected is wild type or vaccine is uncertain, but it indicates a human fecal source regardless.

The human pathogens we detected in private wells have been previously reported in groundwater, except rotavirus group C. Rotavirus group C is zoonotic (unlike group A) and has been found in American cattle and children (Tsunemitsu et al. 1992; Jiang et al. 1995). One-third of young adults in the United States may experience infection in their lifetimes (Riepenhoff-Talty et al. 1997). Twenty wells (15%) were positive for rotaviruses (groups A and C), and rotavirus group C and bovine-related rotavirus group A had the highest concentrations (Table 3), suggesting groundwater in northeastern Wisconsin may be a common reservoir for the sharing and possible reassortment of rotavirus strains among people and cattle.

Risk Factors for Private Well Contamination–Univariable Association Tests

All univariable association tests between private well contamination outcomes and risk factors are reported in Tables S8–S13. Summary statistics of risk factor values are reported in Tables S14–S16.

Sinkholes and rock ledges were associated with well contamination of all five investigated contaminants (coliforms, nitrate, human-specific, bovine-specific, and any fecal markers), but these risk factors were excluded from multivariable analyses for several reasons: *a*) sinkholes and rock ledges were highly correlated with bedrock depth; *b*) sinkhole and ledge locations were determined by field inspections by county staff, and 20% of fields had not been inspected; and *c*) inspections did not include residential properties, biasing the data toward agricultural fields.

Risk Factors for Well Contamination with Nitrate or Coliforms

All land use risk factors eligible for multivariable modeling of nitrate and coliform contamination were related to agriculture (Table 4), suggesting agricultural activities were the primary sources for these contaminants. Septic system density in univariable tests was, at times, associated with coliform and nitrate contamination (see Tables S8 and S9). However, the associations were negative (i.e., implausible and therefore not eligible for model inclusion), likely because more land with housing and septic systems meant there was less land nearby with agricultural activities. Rayne et al. (2019) made a similar observation, showing that when an agricultural field near Madison, Wisconsin, was developed into a housing subdivision with septic systems, the number of monitoring wells with NO_3^--N>10mg/L declined.

Table 4

Multivariable modeling of land use and bedrock risk factors as related to detection probabilities and concentrations of coliforms and nitrate in private wells.

Sampling period	Contaminant and outcome measurement[a] (n)[b]	Risk factor	Univariable model p-value	Multivariable model			
				Risk factor median[c]	Risk factor range[c]	Coefficient or trend[d,e]	p-value[f]
Groundwater recharge	Coliforms detection (315)	Bedrock depth	0.0090	7.6	0–56.4	Negative	0.0001
		NMP field distance[g]	0.036	42	0–723	−0.002	0.20
		Manure storage distance	0.14	899	46–3,728	−0.00008	0.63
		Agricultural field area within 229m	0.072	12.7	0–16.4	−0.008	0.77
	NO−3-N>10mg/L detection (318)	NMP field area within 229m	0.0013	7.1	0–15.9	0.1	0.024
		NMP field distance	0.14	42	0–724	0.002	0.38
		Manure storage distance	0.082	928	46–3,728	−0.0002	0.49
		Bedrock depth	0.0028	7.6	0–56.4	Negative	0.082
	NO−3-N concentration (200)	NMP field area within 914m	0.071	141.7	10.2–235.7	Positive	0.29
		Bedrock depth	0.0063	5.0	0–56.4	Negative	0.0065

Sampling period	Contaminant and outcome measurement[a] (*n*)[b]	Risk factor	Univariable model p-value	Multivariable model			
				Risk factor median[c]	Risk factor range[c]	Coefficient or trend[d,e]	p-value[f]
No groundwater recharge	Coliforms detection (395)	Manure storage distance	0.0014	878	48–7,054	−0.0005	0.0062
		Agricultural field distance, dichotomous	0.15	NA	NA	0.3	0.24
		Agricultural field distance, continuous	0.081	24	0–805	−0.003	0.34
		NMP field area within 229m	0.059	7.4	0–15.6	0.008	0.75
		Bedrock depth	0.12	12.2	0–61	−0.006	0.42
	Coliforms concentration (76)	NMP field distance	0.0026	36	0–554	Negative	0.0050
	NO_3^--N>10mg/L detection (399)	Bedrock depth	<0.0001	12.2	0–61	Negative	0.021
		NMP field area within 457m	0.014	33.3	0–62.4	0.008	0.48
		NMP field distance	0.082	40	0–836	−0.001	0.66

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Note: NA, Not applicable; NMP, nutrient management plan. Univariable model *p*-values used for selecting risk factors are included for reference; complete univariable statistics are provided in Tables S8 and S9. Risk factor eligibility for inclusion in multivariable models is described in statistical methods.

[a]Univariable analyses for: *a*) coliform concentration, groundwater recharge; and *b*) nitrate concentration, no recharge, showed no eligible variables for multivariable modeling; therefore, these models are missing from the table.

[b]n=number of samples in multivariable model.

[c]Units for distance and depth are meters; area is hectares.

[d]In lieu of reporting multiple coefficients for spline-represented variables, we report the overall trend (positive or negative).

[e]Interpretation of coefficient linear terms: change in ln(detection probability) or change in ln(concentration) for a unit change in the risk factor.

[f]The composite *p*-value is reported for spline-represented variables.

[g]Fields with NMPs likely receive manure and inorganic fertilizer inputs.

The area of fields with NMPs within 229m was positively associated with having a well with NO_3^--N>10mg/L during groundwater recharge. This association was adjusted for three other risk factors: distance to manure storage, distance to NMP field, and bedrock depth (Table 4). For instance, wells surrounded by 15 ha of NMP fields within 229m, compared with zero hectares, had a 458% increase in the probability of having NO_3^--N concentrations >10mg/L (27.2% vs. 5.9%) (Figure 4A). Approximately 80% of the agricultural field area in Kewaunee County follows NMPs (D. Bonness, Kewaunee County Land and Water Conservation Director, personal communication). Because we did not have data on manure and inorganic fertilizer applications, we used county records of NMPs to identify fields likely receiving these inputs.

During the no-recharge period, bedrock depth had the strongest association with the detection of wells with NO_3^--N>10mg/L (adjusted for distance to NMP field and area of NMP fields within 457m). Wells with bedrock depths ≥40m had nearly 0% probability of NO_3^--N>10mg/L compared with 18% probability for wells with bedrock depths of zero (Figure 4B). Bedrock depth was also a significant risk factor for nitrate concentrations in wells during recharge (Table 4).

In a U.S. nationwide study of nitrate in 1,230 wells, Nolan (2001) identified risk factors within 500-m radii encircling wells and tested associations by multivariable logistic regression, an approach similar to ours. Significant risk factors were nitrogen fertilizer loading, percent cropland, population density, percent well-drained soils, depth to the seasonally high water table, and rock fractures within an aquifer. Our results are consistent with other studies that have associated groundwater nitrate contamination with agricultural-related risk factors, including agricultural land use (Eckhardt and Stackelberg 1995; Lichtenberg and Shapiro 1997; Nolan and Hitt 2006; Lockhart et al. 2013; Zirkle et al. 2016), animal feeding operations (Toetz 2006; Wheeler et al. 2015), dairy manure lagoons (Lockhart et al. 2013), and swine manure lagoons (Messier et al. 2014), but contrast with studies that associated nitrate with septic systems (Lichtenberg and Shapiro 1997; Gardner and Vogel 2005). Our study differs from previous nitrate work in that we dichotomized the nitrate outcome for log-binomial regression using the U.S. EPA health-based MCLG as the threshold; other studies used much lower thresholds, 4mg/L or lower (Eckhardt and Stackelberg 1995; Nolan 2001; Gardner and Vogel 2005).

Coliforms multivariable modeling showed the primary risk factors for detection were bedrock depth during groundwater recharge and distance to the nearest manure storage during the no-recharge period (Table 4). The concentration of coliforms was associated with only one risk factor: distance to the nearest NMP field (Table 4).

Coliform detection in wells during recharge became less likely the deeper the bedrock to depths of 10m (Figure 4C). Wells in locations with 10-m bedrock depth were 67% less likely to have coliform detections in comparison with wells with bedrock at the land surface (18.3% vs. 55.6%).

During the no-recharge period, coliform detection decreased with increasing distance between private wells and manure storage sites (Figure 4D). For example, in comparison with wells located 48m from manure storage (the minimum distance observed), the coliform detection probability for wells 4,000m distant decreased 87% (37.8% vs. 4.8%). Distance to manure storage was also a covariate in the multivariable models for coliform detection and nitrate detection during groundwater recharge (Table 4).

According to records maintained by the Kewaunee County Land and Water Conservation Department, there are 277 manure storage structures in the county, mostly lagoons ranging in size from 0.01 to 2.06 ha and typically 3.7m deep. Lagoon design specifications allow bottom leakage rates of 47,000L/ha/d (NRCS 313), equivalent to 3.4×107L/y for a 2-ha lagoon. Coliform concentrations in dairy manure are on the order of 106 CFU/g wet manure (Blaustein et al. 2015). Groundwater velocities in the Silurian dolomite fractures have been measured as high as 115 to 600m/d (Bradbury and Muldoon 1992; Bradbury et al. 2001), suggesting leaked manure could deliver coliforms to private wells 1,600m distant (1 mi) in 3 to 14 d.

However, one confounder to consider is a possible negative association between manure storage distance and land-applied manure volume. Transporting manure by tanker truck for land application is costly and time-consuming. More distant fields may receive less land-applied manure. Data on manure application volumes and locations in Kewaunee County are sparse, so discriminating between mechanisms (lagoon leakage vs. applied manure volume) is not possible.

Although we cannot identify the mechanism underlying the association between coliform contamination and manure storage, the relationship is consistent with previous studies (Li et al. 2015; Yessis et al. 1996). Previous studies have also linked the occurrence of coliforms and other indicator bacteria in wells to other agriculture-related factors, including proximity to farm animal operations (Allevi et al. 2013) or agricultural point sources (e.g., farmyards, animal holding facilities, manure storage) (Hynds et al. 2014b; Fennell 2017; Goss et al. 1998; Li et al. 2015) and the density of livestock (Invik et al. 2019; O’Dwyer et al. 2018). Moreover, Óhaiseadha et al. (2017) showed that laboratory-confirmed verotoxigenic *E. coli* infections in Ireland were positively associated with private well usage and cattle density. Our study differed from previous work in that we used GIS to measure continuous-scaled (i.e., not dichotomous or ordinal) “distance to” and “area of” agricultural activities with respect to study well locations.

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Risk Factors for Well Contamination with Human Fecal Markers

Human fecal contamination of private wells was modeled with four variables, of which the median groundwater depth 14 d prior to sampling had the strongest association with contamination (Table 5). For example, the detection probability for human fecal contamination increased to 35% from 11%, with a 1.4-m decrease in median groundwater depth 14 d prior to sampling. Density of neighboring septic system drainfields was another risk factor. These two risk factors are in agreement with the fact that septic systems are the primary source of human fecal wastes on the rural county landscape, and that shallower groundwater depth gives microbes shorter travel distance from the bottom of septic drainfields to the top of the groundwater table. Likewise, bedrock depth, which reflects the distance microbes must travel to reach the fractured bedrock, was associated with the concentration of human markers (Table 5).

Table 5

Multivariable modeling of land use and bedrock risk factors as related to detection probabilities and concentrations of genetic markers of host-specific and fecal-associated microbes in private wells.

Fecal marker source and outcome measurement (n)[a]	Risk factor	Univariable model p-value	Multivariable model			
			Risk factor median[b]	Risk factor range[b]	Coefficient or trend[c,d]	p-value[e]
Human marker detection (137)	Drainfield septic systems, count within 229m	0.038	2	0–10	0.09	0.11
	Groundwater depth, 14-d antecedent, median	0.0003	1.2	0.3–1.6	−0.9	0.011
	Rainfall, 2-d antecedent, cumulative	0.0093	14	0–37	Positive	0.69
	Bedrock depth	0.051	6.1	0–46.6	Negative	0.13
Human marker concentration (33)	Bedrock depth	0.011	4.3	0.3–36.6	Negative	0.011
Bovine marker detection (138)	Groundwater recharge, 7-d antecedent, cumulative	0.0041	50	0–60	Positive	0.0092

Fecal marker source and outcome measurement (n)[a]	Risk factor	Univariable model p-value	Multivariable model			
			Risk factor median[b]	Risk factor range[b]	Coefficient or trend[c,d]	p-value[e]
Bovine marker concentration (41)	Agricultural field area within 229m	0.029	11.6	3.7–16.4	Positive	0.024
	Bedrock depth	0.0019	5.2	0–29	−0.1	0.0006
Any fecal marker[f] detection (137)	Drainfield septic systems, count within 229m	0.0036	2	0–10	Positive	0.036
	Rainfall, 2-d antecedent, cumulative	0.12	14	0–37	Positive	0.19
	Manure storage distance[g]	0.94	687	71–3,728	−0.0004	0.036
	Bedrock depth	0.027	6.1	0–46.6	−0.06	0.0058
	Manure storage distance times bedrock depth interaction	0.045	NA	NA	Negative	0.024
Any fecal marker concentration (77)	Agricultural field area within 229m	0.035	12.7	1.1–16.4	Positive	0.097
	Manure storage distance	0.083	762	113–3,728	−0.0001	0.76
	Bedrock depth	0.0003	4.6	0–36.6	−0.08	0.002

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Note: NA, Not applicable. Univariable model *p*-values used for selecting risk factors are included for reference; complete univariable statistics are provided in Table S10. Risk factor eligibility for inclusion in multivariable models is described in statistical methods.

[a]n=number of samples in multivariable model.

[b]Units for distance and depth are meters; rainfall and recharge are millimeters; area is hectares.

[c]In lieu of reporting multiple coefficients for spline-represented variables we report the overall trend (positive or negative).

[d]Interpretation of coefficient linear terms: change in ln(detection probability) or change in ln(concentration) for a unit change in the risk factor.

[e]The composite *p*-value is reported for spline-represented variables.

[f]"Any fecal marker" includes all microorganisms regardless of host specificity.

[g]Included in multivariable model because of its significant interaction with bedrock depth.

One other possible human fecal source was septage (i.e., wastewater pumped from septic tanks) land-applied to approved agricultural fields. Tests of association between septage-applied fields and well contamination were ambiguous, suggesting septage was not an important risk factor (see Supplemental Material, Septage Land-Applied Fields—Univariable Associations). County records show during the study period only 10 fields equaling 110 ha received 2.57×106L septage. In contrast, septic systems are located throughout the county and the volume of untreated effluent released to the subsurface was calculated to be 6.79×108L per year (see Supplemental Material, Septic System Effluent Volume Released Annually in Kewaunee County).

Septic system effluent contamination of groundwater with fecal indicator bacteria and pathogenic viruses and bacteria is well documented in the literature (Hagedorn et al. 1981; Yates 1985: Nicosia et al. 2001; Katz et al. 2010; Hynds et al. 2012; Lusk et al. 2017). In one study, vaccine poliovirus was introduced into the tank of a new conventional septic system, and the virus was cultured in multiple samples over time in a monitoring well 6m down-gradient from the edge of the drainfield (Alhajjar et al. 1988). More recently, detection in groundwater of the human-specific markers HF183 and HumM2 has been linked with septic system effluent (Schneeberger et al. 2015; Murphy et al. 2020). Groundwater-borne disease outbreaks (Yates 1985; Beller et al. 1997; Borchardt et al. 2011) and endemic diarrheal illness (Borchardt et al. 2003a) have also been associated with septic systems.

As early as 1977 the U.S. EPA recommended that to minimize groundwater contamination septic system density should not exceed 40 systems per square mile (1 system/6.5 ha or 0.15 systems/ha) (U.S. EPA 1977). Three subsequent studies have suggested septic system density should not exceed 5, 1–2.5, and 3.5–6 systems/ha (Reneau 1979; Gardner et al. 1997; Morrissey et al. 2015). In the fractured dolomite aquifer of our study, as the number of septic drainfields within 229m of private wells increased from zero to 10, the probability of human fecal contamination increased 2.5 times, from 13% to 33% (Figure 5A), with the upper limit (10 septic drainfields) equivalent to 0.6 systems/ha. This relationship was adjusted for groundwater depth, rainfall, and bedrock depth (Table 5). (In Figure 5A the count of one drainfield represents the well contamination probability from a household's own drainfield, 14%.)

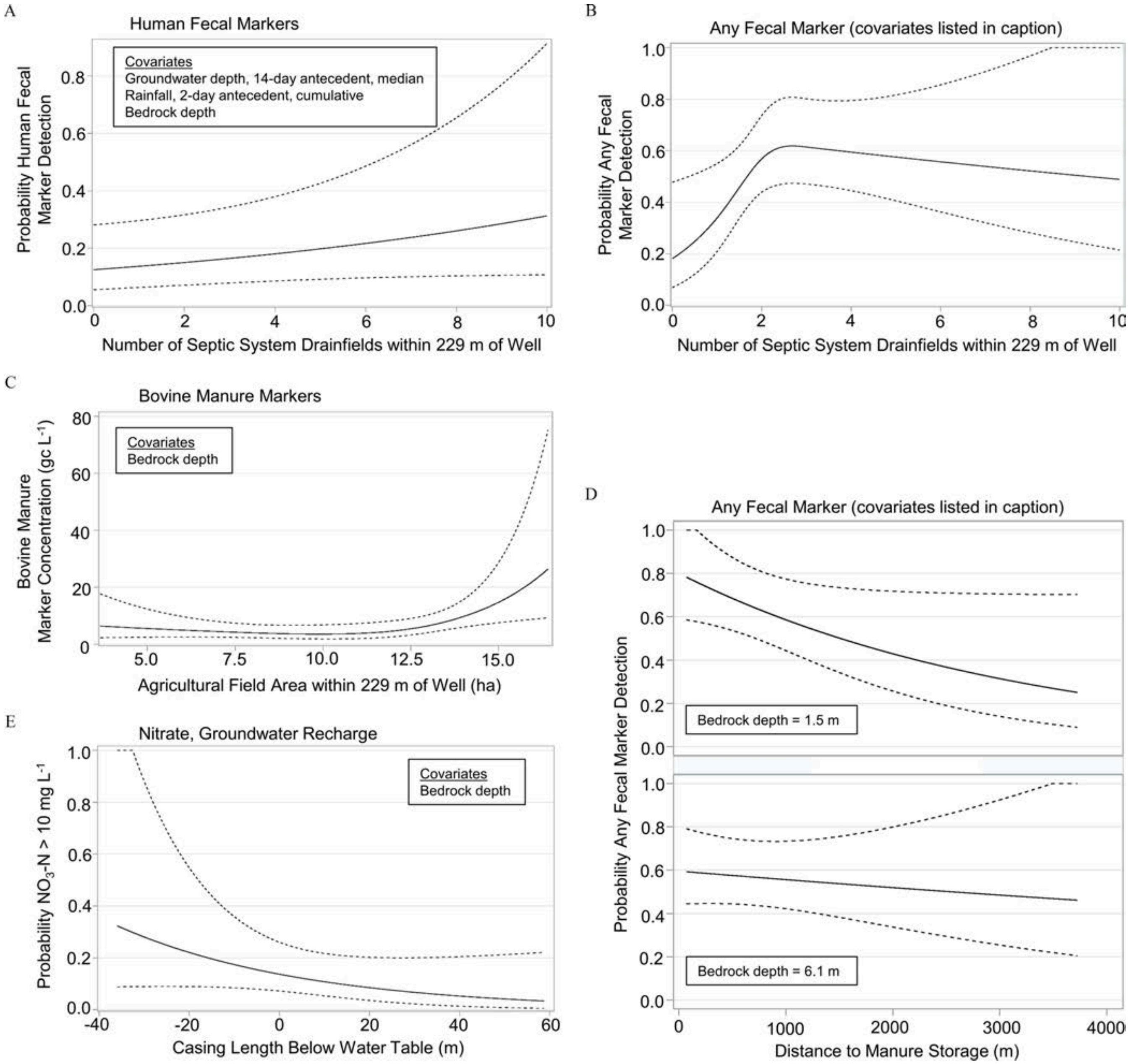

Figure 5.

Key risk factors regressed on private well contamination probability (log-binomial regression) or concentration (gamma regression): (A) detection probability for human-specific markers; (B) detection probability for any fecal marker; covariates: manure storage distance, bedrock depth, manure storage distance times bedrock depth interaction, rainfall 2-d antecedent cumulative; (C) estimated bovine-specific marker concentration (mean sum); (D) interaction between manure storage distance and bedrock depth for any fecal marker detection probability; covariates: septic system drainfields within 229m of well, rainfall 2-d antecedent cumulative; (E) detection probability of $NO-3-N>10mg/L$. Black line: regression estimates. Dashed lines: 95% pointwise confidence limits. Coefficients and *p*-values are reported in Table 5. Covariates in the multivariable models were fixed at their median values for the purpose of plotting.

Considering other vulnerable aquifers, Blaschke et al. (2016) estimated the distance between septic systems and private wells needed for 12-log10 virus removal to achieve a risk of 10^{-4} infections/person/y, and their lower setback distance estimates for gravel and coarse gravel aquifers were 66m and 1,000m, respectively (equivalent to densities of 0.7 and 0.003 systems/ha). For limestone aquifers similar to our study site, Morrissey et al. (2015) derived a recommendation of 3.5 systems/ha from groundwater flow modeling of indicator bacteria and nitrate, and Masciopinto et al. (2008) estimated the setback required for 7-log10 virus reduction from municipal wastewater injected into sinkholes was 8,000m. Although previous work was based on indicators and nitrate or log removal of viruses, our model is based on the probability of contamination by fecal waste specific to humans.

Risk Factors for Well Contamination with Bovine Manure Markers

The detection probability of bovine-specific markers increased during periods of groundwater recharge (Table 5), as infiltrating precipitation and snowmelt carried manure from the surface to the water table. An increase from 0 to 40 millimeters cumulative recharge 7 d prior to sampling increased the detection probability of bovine markers from 13% to 50%.

Agricultural risk factors were not associated with the detection probability of bovine markers but were associated with those markers' *concentrations* (see Table S10), and of these the area of agricultural fields within 229m of wells had the strongest association. When the area exceeded 13 ha, bovine marker concentration increased (Figure 5C).

The reason we found associations between fecal sources and detection probability of human markers but not bovine markers likely stem from differences in release patterns between septic systems and manure. Septic system locations are fixed and known with certainty; the systems operate every day, continually releasing household wastewater to the subsurface. In contrast, manure applications vary in location, timing, and volume; manure could be applied near a well on one day and then not again that year. Unlike manure field applications, manure storages are like septic systems: The locations are fixed and known, meaning our distance measurements between manure storages and study wells had minimal error. This may have contributed to our finding that the “distance to manure storage” risk factor was relevant in five multivariable models.

Because manure application records were incomplete (only large farms are required to report applications), we assumed all agricultural fields near wells were potential sources of manure at the time of sampling, which was likely true for only some fields, resulting in misclassification. However, when the model was restricted to only bovine-positive samples, this restriction removed any chance of misclassification (i.e., positivity indubitably showed manure must be near the well), which likely explains why we were able to link agricultural field area to bovine marker concentration. The impact of misclassification of manured sites may have been lessened for contaminant detection models constructed with more positive samples (i.e., greater statistical power). These models (coliforms, nitrate-N, and any fecal marker) did indeed identify agricultural risk factors.

Risk Factors for Well Contamination with Markers for Any Fecal Microbe

The any fecal marker category included the 82 samples (79 wells) positive for any of the 24 microbial markers found in the fecal material of humans, bovines and ruminants, or other vertebrate hosts (Table 3). Multivariable modeling showed detection of any marker in this category was associated with well proximity to locations of both human and bovine fecal material, namely septic drainfields and manure storages. The model included two other risk factors: rainfall and bedrock depth (Table 5). Similar findings were reported by O'Dwyer et al. (2018), who showed septic system density, cattle density, rainfall, and karst bedrock in Ireland were associated with private well contamination with *E. coli*.

Any fecal marker detection probability increased by a factor of three when septic drainfields increased from zero to two within 229m of wells; additional drainfields did not further increase the detection probability (Figure 5B). Manure storage distance from wells was associated with fecal contamination after accounting for its interaction with bedrock depth; for wells closer to manure storage, the probability of detecting any fecal marker increased more steeply at shallow bedrock depth (Figure 5D).

To model the concentration outcome of any fecal marker, only positive samples were included, reducing statistical power compared to the detection outcome model. Nonetheless, bedrock depth was strongly associated with fecal marker concentration after adjusting for manure storage distance and the area of agricultural fields within 229m of wells (Table 5).

The multivariable models for any fecal marker encapsulate the key study finding: Fecal contamination in the county's private wells stems from both septic systems and manure, and contamination is exacerbated by shallow bedrock depth and elevated rainfall. Both fecal sources release untreated wastes to the landscape at noteworthy volumes. Septic system drainfields in the county are estimated to release into the subsurface 6.79×108 L of household wastewater per year, and the county's cattle population produces approximately 1.74×109 L manure (fecal and urine combined) per year (see Supplemental Material, "Septic System Effluent Volume Released Annually in Kewaunee County, Cattle Manure Volume Produced Annually in Kewaunee County").

Precipitation as a Risk Factor for Private Well Contamination

There is ample evidence showing precipitation favors microbial contamination of private wells. Precipitation quantity in the period preceding sampling was positively associated with the occurrence in private wells of indicator bacteria (Hynds et al. 2012; O'Dwyer et al. 2014; Procopio et al. 2017; Invik 2019) human enteric viruses (Allen et al. 2017) and the human-specific *Bacteroides* marker HF183 (Murphy et al. 2020). The antecedent precipitation periods associated with contamination varied between 30 (Invik et al. 2019) and 5 d (Hynds et al. 2012), and even shorter periods of rainfall (24 h) may be associated with contamination of vulnerable aquifers (Morrissey et al. 2015). In our study 2-d antecedent cumulative rainfall was more strongly associated than 7- or 14-d periods with detection of any fecal marker and markers specific to humans (see Table S10). However, when rainfall was included in multivariable models it was not as strongly associated to contamination as the other risk factors (Table 5).

Well Construction Risk Factors Related to Contamination

Well construction risk factor modeling did not identify a single overriding factor. Of 14 possible multivariable models (combinations of contaminant type, recharge, and outcome measurement) only six had any variables that met the univariable screening criteria (Table 6; and see Tables S11, S12, and S13). Four of the six models involved nitrate, suggesting well construction was more related to nitrate than microbial contamination. Statistical power may have been an issue, particularly for human and bovine markers, as construction data on file with the state government were not available for 35% of study wells. Nevertheless, the quality of the well construction data was good. Our data were derived from bona fide construction records instead of relying on well-owner recall. Summary statistics for all well construction data are reported in Tables S14–S16.

Table 6

Multivariable modeling of well construction risk factors as related to detection probabilities and concentrations of coliforms, any fecal-associated marker, and nitrate in private wells.

			Multivariable model			
Contaminant and outcome measurement (n)[a]	**Risk factor**	**Univariable model p-value**	**Risk factor median[b]**	**Risk factor range[b]**	**Coefficient or trend[c,d]**	**p-value[e]**
Any fecal marker[f] detection (83)	Casing depth	0.15	17.7	12.2–48.2	Negative	0.31
	Open interval length	0.13	29.0	2.1–79.6	Positive	0.24
	Bedrock depth	0.027	4.6	0–46.6	−0.02	0.26
Coliforms concentration, recharge (47)	Well depth	0.047	48.8	18.3–100.6	Negative	0.59
	Casing depth	0.057	18.9	12.2–80.2	None	0.91
	Groundwater depth at construction	0.0004	12.2	1.8–36.6	Negative	0.0038
	Well age	0.0042	24	5–49	0.04	0.016
NO_3^--N>10mg/L detection, recharge (201)	Casing length below water table	0.040	8.5	–36–58.8	−0.02	0.13
	Bedrock depth	0.0028	6.4	0–55.2	Negative	0.28

			Multivariable model			
Contaminant and outcome measurement (n)[a]	**Risk factor**	**Univariable model p-value**	**Risk factor median[b]**	**Risk factor range[b]**	**Coefficient or trend[c,d]**	**p-value[e]**
NO^-_3-N concentration, recharge (124)	Well age	0.15	22	2–80	Positive	0.16
	Bedrock depth	0.0063	4.7	0–31.4	Negative	0.11
NO^-_3-N>10mg/L detection, no-recharge (251)	Casing depth	0.12	18.9	6.1–126.5	0.01	0.65
	Casing length below water table	0.02	8.8	–36–117.3	−0.02	0.33
	Bedrock depth	<0.0001	10.1	0.3–54.3	Negative	0.07
NO^-_3-N concentration, no-recharge (127)	Casing depth	0.043	18.0	6.1–126.5	−0.008	0.57
	Casing length below water table	0.054	5.5	–19.8–117.3	Negative	0.74
	Bedrock depth	0.0019	6.7	0.3–49.4	Negative	0.0088

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Note: Univariable model p-values used for selecting risk factors are included for reference; complete univariable statistics are provided in Tables S11, S12, and S13. Risk factor eligibility for inclusion in multivariable models is described in statistical methods.

[a]n=number of samples in multivariable model.

[b]Units for length and depth are meters; age is in years.

[c]In lieu of reporting multiple coefficients for spline-represented variables we report the overall trend (positive or negative).

[d]Interpretation of coefficient linear terms: change in ln(detection probability) or change in ln(concentration) for a unit change in the risk factor.

[e]The composite p-value is reported for spline-represented variables.

[f]"Any fecal marker" includes all microorganisms regardless of host specificity.

Casing depth was included in more multivariable well construction models than any other variable; minimum depths specified in well construction codes are believed to prevent contamination. However, its independent effect in the presence of other risk factors in the well construction models was equivocal; associations were weak, and trends were inconsistent (positive, negative, and none)

(Table 6). Casing length below water table was the second most frequently included risk factor, and its trends were consistent; longer casing into the aquifer reduced NO_3^--N contamination. For example, increasing casing length from 36m above to 59m below the water table decreased the probability of NO_3^--N contamination >10mg/L during recharge by 90% (Figure 5E). Placing the casing bottom deeper into the aquifer likely results in nitrate that is infiltrating from the land surface to be further diluted before it enters the well. Of 453 study wells that had data on casing length below water table, 77 wells (17%) had casings that ended above the water table, providing no dilution benefit.

Older wells tend to have greater nitrate and bacterial contamination (Yessis et al. 1996; Goss et al. 1998), but in our study, of the 14 possible multivariable models, well age was associated only with coliforms concentration during recharge (Table 6). Changes in State code in 1988 improved well construction reporting, so our construction data skewed toward newer wells (median age approximately 20 y) that comply with recent construction regulations (e.g., only one well had casing depth less than the State minimum of 12.2m.)

Well depth is frequently identified in groundwater studies as an important factor affecting nitrate and microbial contamination. Deeper wells have less nitrate (Glanville et al. 1997; Lichtenberg and Shapiro 1997; Goss et al. 1998; Allevi et al. 2013; Swistock et al. 2013; Lockhart et al. 2013; Warner and Arnold 2010), coliforms (Gonzales 2008; Goss et al. 1998; Allevi et al. 2013), *E. coli* (O'Dwyer et al. 2018), and human viruses (Allen et al. 2017). Warner and Arnold (2010) found that nitrate concentrations among 378 private wells in the glacial aquifer system in the United States (of which Kewaunee County is part) had less spatial and temporal variation than the variation contributed by well depth. They suggest deeper wells have older groundwater with lower dissolved oxygen favoring denitrification. Well depth was not associated with nitrate contamination in our study wells, likely because the aquifer is oxic at least to 70m (Bradbury and Muldoon 1992).

Hynds et al. (2012) showed that well design and construction were more important than septic systems, geological setting, or precipitation in explaining the variability of thermotolerant coliform contamination in private wells in Ireland. Our findings differ. Overall, well construction was not strongly associated with nitrate and microbial contamination of private wells in the Silurian dolomite aquifer of northeastern Wisconsin. Nor are our findings unique. In a study of 180 randomly selected private wells in northeastern Ohio, well age and well depth determined from construction records were not associated with coliform contamination (Won et al. 2013). Many studies that have investigated the link between well construction and contamination included dug wells and sand points (Yessis et al. 1996; Goss et al. 1998) or wells that lacked adequate sealing between the casing and well annulus, a condition that would allow direct ingress of surface contaminants (Hynds et al. 2012; Fennell 2017). In contrast, for our study wells that have construction data, all were drilled, none were dug, and all were sealed with grout. For wells such as these, in this hydrogeological setting, it appears differences in construction have less impact on contamination than other factors.

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Utility and Generalizability of Findings

We have shown private household wells open to the Silurian dolomite aquifer in Kewaunee County, Wisconsin, were contaminated with nitrate, coliform bacteria, and diverse taxa of fecal-associated microbes, some of which were pathogenic. Contamination rates depended on bedrock depth, land use, groundwater recharge, rainfall, and to a lesser extent factors related to well construction. Our examination of risk factors was comprehensive, and multivariable modeling allowed each risk factor to be evaluated for its independent effects in the presence of other factors. In addition, risk factors were analyzed as continuous-scaled variables, which aids interpretation and is amenable for policymaking, for example, establishing setback distances between private wells and agricultural fields, allowable septic system densities, or minimum bedrock depths for manure applications.

Our findings likely apply to other regions that depend on the Silurian dolomite aquifer and where agricultural and exurban land uses affect groundwater quality. The aquifer is regionally extensive and an important water supply for public, domestic, and commercial uses in six U.S. states: Wisconsin, Illinois, Iowa, Michigan, Indiana, and Ohio (USGS 2016). The Silurian dolomite aquifer in Canada extends from Lake Huron to Niagara Falls and supplies water to nearly 800,000 people in southern Ontario (Allen et al. 2017). In northeast Wisconsin the aquifer is emblematic of an open-access resource and the “tragedies” that can result when the resource becomes degraded by competing interests. Understanding how the aquifer is contaminated—the sources, extent, and factors involved—may contribute to the broader appreciation that this essential resource is shared among all who depend on it.

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Acknowledgments

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References

- Alhajjar BJ, Stramer SL, Cliver DO, Harkin JM. 1988. Transport modelling of biological tracers from septic systems. Water Res 22(7):907–915, 10.1016/0043-1354(88)90028-0. [CrossRef] [Google Scholar]
- Allen AS, Borchardt MA, Kieke BA Jr., Dunfield KE, Parker BL. 2017. Virus occurrence in private and public wells in a fractured dolostone aquifer in Canada. Hydrogeol J 25(4):1117–1136, 10.1007/s10040-017-1557-5. [CrossRef] [Google Scholar]
- Allevi RP, Krometis L-AH, Hagedorn C, Benham B, Lawrence AH, Ling EJ, et al.. 2013. Quantitative analysis of microbial contamination in private drinking water supply systems. J Water Health 11(2):244–255, PMID: 23708572, 10.2166/wh.2013.152. [PubMed] [CrossRef] [Google Scholar]
- American Public Health Association. 1995. Standard Methods for the Examination of Water and Wastewater, 19th ed. Washington, DC: American Public Health Association. [Google Scholar]
- Atherholt TB, Korn LR, Louis JB, Procopio NA. 2015. Repeat sampling and coliform bacteria detection rates in New Jersey domestic wells. Groundwater Monit R 35(2):70–80. 10.1111/j.1745-6584.2012.00997.x, 10.1111/gwmr.12094. [CrossRef] [CrossRef] [Google Scholar]
- Bay Lake Regional Planning Commission. 2016. Kewaunee County 20-Year Comprehensive Plan Update. http://media.baylakerpc.org/media/51229/kewaunee%20county%20comp%20plan_farm%20preservation%20plan%20full%20document-%2001182017.pdf [accessed 10 September 2019].
- Blaschke AP, Derx J, Zessner M, Kirnbauer R, Kavka G, Strelec H, et al.. 2016. Setback distances between small biological wastewater treatment systems and drinking water wells against virus contamination in alluvial aquifers. Sci Total Environ 573:278–289, PMID: 27570196, 10.1016/j.scitotenv.2016.08.075. [PubMed] [CrossRef] [Google Scholar]
- Blaustein RA, Pachepsky YA, Hill RL, Shelton DR. 2015. Solid manure as a source of fecal indicator microorganisms: release under simulated rainfall. Environ Sci Technol 49(13):7860–7869, PMID: 26011817, 10.1021/acs.est.5b01095. [PubMed] [CrossRef] [Google Scholar]
- Borchardt MA, Bradbury KR, Alexander EC, Archer J, Braatz L, Forest B, et al.. 2011. Norovirus outbreak caused by a new septic system in a dolomite aquifer. Ground Water 49(1):85–97, PMID: 20199588, 10.1111/j.1745-6584.2010.00686.x. [PubMed] [CrossRef] [Google Scholar]
- Borchardt MA, Muldoon MA, Hunt RJ, Bonness DE, Firnstahl AD, Kieke BA, et al.. 2019. Assessing Groundwater Quality in Kewaunee County, Wisconsin and Characterizing the Timing and Variability of Enteric Pathogen Contamination Within the Dolomite Aquifer in Northeastern Wisconsin. DNR Project Number 227, Final Report. Wisconsin Geology and Natural History Survey, Open-File Report 2019-05, 2019.
- Bradbury KR, Muldoon MA. 1992. Hydrogeology and groundwater monitoring of fractured dolomite in the Upper Door Priority Watershed, Door County, Wisconsin. Wisconsin Geological and Natural History Survey Open File Report, WOFR 1992-2, https://wgnhs.wisc.edu/catalog/publication/000776/resource/wofr199202 [accessed 22 June 2019].

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Clean Water Organizations Comments Exhibit 28

- Bradbury KR, Rayne TW, Muldoon MA. 2001. Field verification of capture zones for municipal wells at Sturgeon Bay, Wisconsin. Final Report to the Wisconsin Department of Natural Resources. https://wgnhs.uwex.edu/pubs/000823/ [accessed 22 June 2019].
- Bromley DW, Cernea MM. 1989. The Management of Common Property Natural Resources: Some Conceptual and Operational Fallacies (English). World Bank Discussion Papers; No. WDP 57. Washington, DC: World Bank Group, http://documents.worldbank.org/curated/en/548811468740174575/The-management-of-common-property-natural-resources-some-conceptual-and-operational-fallacies [accessed 15 March 2018]. [Google Scholar]
- Center for Watershed Science and Education Wisconsin. 2018. Well Water Viewer: Private Well Data for Wisconsin. University of Wisconsin – Stevens Point. https://www.uwsp.edu/cnr-ap/watershed/Pages/WellWaterViewer.aspx [accessed 29 March 2018].
- DiSimone LA. 2009. Quality of Water from Domestic Wells in Principal Aquifers of the United States, 1991-2004. U.S. Geological Survey Scientific Investigations Report 2008–5227. http://pubs.usgs.gov/sir/2008/5227 [accessed 21 November 2019].
- Diston D, Sinreich M, Zimmermann S, Baumgartner A, Felleisen R. 2015. Evaluation of molecular- and culture-dependent MST markers to detect fecal contamination and indicate viral presence in good quality groundwater. Environ Sci Technol 49(12):7142–7151, PMID: 25871525, 10.1021/acs.est.5b00515. [PubMed] [CrossRef] [Google Scholar]
- Eckhardt DAV, Stackelberg PE. 1995. Relation of ground-water quality to land use on Long Island, New York. Groundwater 33(6):1019–1033, 10.1111/j.1745-6584.1995.tb00047.x. [CrossRef] [Google Scholar]
- Erb K, Ronk E, Koundinya V, Luczaj J. 2015. Groundwater quality changes in a karst aquifer of northeastern Wisconsin, USA: reductions of brown water incidence and bacterial contamination resulting from implementation of regional task force recommendations. Resources 4(3):655–672, 10.3390/resources4030655. [CrossRef] [Google Scholar]
- Final Report of the Northeast Wisconsin Karst Task Force. 2007. Erb K, Steiglitz R, eds. https://cdn.shopify.com/s/files/1/0145/8808/4272/files/G3836.pdf [accessed 12 February 2020].
- Felleiter S, McDermott K, Hall G, Sheth P, Majury A. 2020. Exploring private water wells for fecal sources and evidence of pathogen presence in the context of current testing practices for potability in Ontario. Water Qual Res J Can 55(1):93–105, 10.2166/wqrj.2019.035. [CrossRef] [Google Scholar]
- Fennell C. 2017. The impact of domestic wastewater treatment system effluent on private water wells: an evaluation of contamination fingerprinting techniques. Thesis. University of Dublin, Trinity College, Dublin. [Google Scholar]
- Gardner KK, Vogel RM. 2005. Predicting ground water nitrate concentration from land use. Ground Water 43(3):343–352, PMID: 15882326, 10.1111/j.1745-6584.2005.0031.x. [PubMed] [CrossRef] [Google Scholar]
- Gardner TED, Geary P, Gordon IAN. 1997. Ecological sustainability and on-site effluent treatment systems. Australas J Environ Manag 4(2):144–156, 10.1080/14486563.1997.10648378. [CrossRef] [Google Scholar]
- Garson GD. 2013. Generalized Linear Models/Generalized Estimating Equations, 2013 Edition. Asheboro, NC: Statistical Associates Publishers. [Google Scholar]

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Clean Water Organizations Comments Exhibit 28

- Gibson KE, Schwab KJ, Spencer SK, Borchardt MA. 2012. Measuring and mitigating inhibition during quantitative real time PCR analysis of viral nucleic acid extracts from large-volume environmental samples. Water Res 46(13):4281–4291, PMID: 22673345, 10.1016/j.watres.2012.04.030. [PubMed] [CrossRef] [Google Scholar]
- Glanville TD, Baker JL, Newman JK. 1997. Statistical analysis of rural well contamination and effects of well construction. Trans ASAE 40(2):363–370, 10.13031/2013.21281. [CrossRef] [Google Scholar]
- Goss MJ, Barry DAJ, Rudolph DL. 1998. Contamination in Ontario farmstead domestic wells and its association with agriculture: 1. Results from drinking water wells. J Contam Hydrol 32(3–4):267–293, 10.1016/S0169-7722(98)00054-0. [CrossRef] [Google Scholar]
- Hagedorn C, Mc Coy EL, Rahe TM. 1981. The potential for ground water contamination from septic effluents. J Environ Qual 10(1):1–8, 10.2134/jeq1981.00472425001000010001x. [CrossRef] [Google Scholar]
- Hastie TJ, Tibshirani RJ, Friedman JH. 2001. The Elements of Statistical Learning: Data Mining, Inference, and Prediction. New York: Springer-Verlag. [Google Scholar]
- Healy RW, Cook PG. 2002. Using groundwater levels to estimate recharge. Hydrogeol J 10(1):91–109, 10.1007/s10040-001-0178-0. [CrossRef] [Google Scholar]
- Hynds PD, Misstear BD, Gill LW. 2012. Development of a microbial contamination susceptibility model for private domestic groundwater sources. Water Resour Res 48:W12504, 10.1029/2012WR012492. [CrossRef] [Google Scholar]
- Hynds P, Misstear BD, Gill LW, Murphy HM. 2014b. Groundwater source contamination mechanisms: physicochemical profile clustering, risk factor analysis and multivariate modeling. J Contam Hydrol 159:47–56, PMID: 24583518, 10.1016/j.jconhyd.2014.02.001. [PubMed] [CrossRef] [Google Scholar]
- Invik J, Barkema HW, Massolo A, Neumann NF, Cey E, Checkley S. 2019. Escherichia coli contamination of rural well water in Alberta, Canada is associated with soil properties, density of livestock and precipitation. Can Water Resour J 44(3):248–262, 10.1080/07011784.2019.1595157. [CrossRef] [Google Scholar]
- Iturriza-Gómara M, Kang G, Gray J. 2004. Rotavirus genotyping: keeping up with an evolving population of human rotaviruses. J Clin Virol 31(4):259–265, PMID: 15494266, 10.1016/j.jcv.2004.04.009. [PubMed] [CrossRef] [Google Scholar]
- Jiang B, Dennehy PH, Spangenberger S, Gentsch JR, Glass RI. 1995. First detection of group C rotavirus in fecal specimens of children with diarrhea in the United States. J Infect Dis 172(1):45–50, PMID: 7797945, 10.1093/infdis/172.1.45. [PubMed] [CrossRef] [Google Scholar]
- Katz BG, Griffin DW, McMahon PB, Harden HS, Wade E, Hicks RW, et al.. 2010. Fate of effluent-borne contaminants beneath septic tank drainfields overlying a karst aquifer. J Environ Qual 39(4):1181–1195, PMID: 20830905, 10.2134/jeq2009.0244. [PubMed] [CrossRef] [Google Scholar]
- Krolik J, Evans G, Belanger P, Maier A, Hall G, Joyce A, et al.. 2014. Microbial source tracking and spatial analysis of *E. coli* contaminated private well waters in southeastern Ontario. J Water Health 12(2):348–356, PMID: 24937229, 10.2166/wh.2013.192. [PubMed] [CrossRef] [Google Scholar]

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Clean Water Organizations Comments Exhibit 28

- Li X, Atwill ER, Antaki E, Applegate O, Bergamaschi B, Bond RF, et al.. 2015. Fecal indicator and pathogenic bacteria and their antibiotic resistance in alluvial groundwater of an irrigated agricultural region with dairies. J Environ Qual 44(5):1435–1447, PMID: 26436261, 10.2134/jeq2015.03.0139. [PubMed] [CrossRef] [Google Scholar]
- Lichtenberg E, Shapiro LK. 1997. Agriculture and nitrate concentrations in Maryland community water system wells. J Environ Qual 26(1):145–153, 10.2134/jeq1997.00472425002600010022x. [CrossRef] [Google Scholar]
- Lockhart KM, King AM, Harter T. 2013. Identifying sources of groundwater nitrate contamination in a large alluvial groundwater basin with highly diversified intensive agricultural production. J Contam Hydrol 151:140–154, PMID: 23800783, 10.1016/j.jconhyd.2013.05.008. [PubMed] [CrossRef] [Google Scholar]
- Lohr SL. 2010. Sampling: Design and Analysis. 2nd ed. Boston, MA: Brooks/Cole. [Google Scholar]
- Lusk MG, Toor GS, Yang Y-Y, Mechtensimer S, De M, Obreza TA. 2017. A review of the fate and transport of nitrogen, phosphorus, pathogens, and trace organic chemicals in septic systems. Crit Rev Environ Sci Technol 47(7):455–541, 10.1080/10643389.2017.1327787. [CrossRef] [Google Scholar]
- Madadgar O, Nazaktabar A, Keivanfar H, Zahraei Salehi T, Lotfollah Zadeh S. 2015. Genotyping and determining the distribution of prevalent G and P types of group a bovine rotaviruses between 2010 and 2012 in Iran. Vet Microbiol 179(3–4):190–196, PMID: 26072368, 10.1016/j.vetmic.2015.04.024. [PubMed] [CrossRef] [Google Scholar]
- Masciopinto C, La Mantia R, Chrysikopoulos CV. 2008. Fate and transport of pathogens in a fractured aquifer in the Salento area, Italy. Water Resour Res 44:W01404, 10.1029/2006WR005643. [CrossRef] [Google Scholar]
- Matthijnssens J, Joelsson DB, Warakomski DJ, Zhou T, Mathis PK, van Maanen MH, et al.. 2010. Molecular and biological characterization of the 5 human-bovine rotavirus (WC3)-based reassortant strains of the pentavalent rotavirus vaccine, RotaTeq. Virology 403(2):111–127, PMID: 20451234, 10.1016/j.virol.2010.04.004. [PubMed] [CrossRef] [Google Scholar]
- McNutt LA, Wu C, Xue X, Hafner JP. 2003. Estimating the relative risk in cohort studies and clinical trials of common outcomes. Am J Epidemiol 157(10):940–943, PMID: 12746247, 10.1093/aje/kwg074. [PubMed] [CrossRef] [Google Scholar]
- Mieszkin S, Yala JF, Joubrel R, Gourmelon M. 2010. Phylogenetic analysis of *Bacteroidales* 16S rRNA gene sequences from human and animal effluents and assessment of ruminant faecal pollution by real-time PCR. J Appl Microbiol 108(3):974–984, PMID: 19735325, 10.1111/j.1365-2672.2009.04499.x. [PubMed] [CrossRef] [Google Scholar]
- Morrissey PJ, Johnston PM, Gill LW. 2015. The impact of on-site wastewater from high density cluster developments on groundwater quality. J Contam Hydrol 182:36–50, PMID: 26331764, 10.1016/j.jconhyd.2015.07.008. [PubMed] [CrossRef] [Google Scholar]
- Muldoon MA, Bradbury KR. 2010. Assessing seasonal variations in recharge and water quality in the silurian aquifer in areas with thicker soil cover. Wisconsin groundwater management practice monitoring project, DNR-198. http://digital.library.wisc.edu/1711.dl/EcoNatRes.MuldoonAssess [accessed 22 June 2019].

- Muldoon MA, Simo JA, Bradbury KR. 2001. Correlation of high-permeability zones with stratigraphy in a fractured-dolomite aquifer, Door County, Wisconsin. Hydrogeol J 9(6):570–583, 10.1007/s10040-001-0165-5. [CrossRef] [Google Scholar]
- Murphy HM, McGinnis S, Blunt R, Stokdyk J, Wu J, Cagle A, et al.. 2020. Septic systems and rainfall influence human fecal marker and indicator organism occurrence in private wells in southeastern Pennsylvania. Environ Sci Technol 54(6):3159–3168, PMID: 32073835, 10.1021/acs.est.9b05405. [PubMed] [CrossRef] [Google Scholar]
- Nennich TD, Harrison JH, VanWieringen LM, Meyer D, Heinrichs AJ, Weiss WP, et al.. 2005. Prediction of manure and nutrient excretion from dairy cattle. J Dairy Sci 88(10):3721–3733, PMID: 16162547, 10.3168/jds.S0022-0302(05)73058-7. [PubMed] [CrossRef] [Google Scholar]
- NGWA (National Groundwater Association). 2020. Groundwater Use in the United States of America. NGWA USA Groundwater Use Factsheet 01-13-2020. https://www.ngwa.org/docs/default-source/default-document-library/groundwater/usa-groundwater-use-fact-sheet.pdf?sfvrsn=5c7a0db8_4 [accessed 1July 2020].
- Nicosia LA, Rose JB, Stark L, Stewart MT. 2001. A field study of virus removal in septic tank drainfields. J Environ Qual 30(6):1933–1939, PMID: 11789999, 10.2134/jeq2001.1933. [PubMed] [CrossRef] [Google Scholar]
- NOAA (National Oceanic and Atmospheric Administration/National Centers for Environmental Information). n.d.. Climate at a Glance: Global Mapping. https://www.ncdc.noaa.gov/cag/ [accessed 18 March 2021].
- Nolan BT, Hitt KJ. 2006. Vulnerability of shallow groundwater and drinking-water wells to nitrate in the United States. Environ Sci Technol 40(24):7834–7840, PMID: 17256535, 10.1021/es060911u. [PubMed] [CrossRef] [Google Scholar]
- Nolan BT. 2001. Relating nitrogen sources and aquifer susceptibility to nitrate in shallow ground waters of the United States. Groundwater 39(2):290–299, 10.1111/j.1745-6584.2001.tb02311.x. [PubMed] [CrossRef] [Google Scholar]
- NRCS 313 (Natural Resources Conservation Service Conservation Practice Standard 313). Waste Storage Facility, Wisconsin Natural Resources Conservation Service, Madison, WI, January 2014.
- O'Dwyer J, Dowling A, Adley CC. 2014. Microbiological assessment of private groundwater-derived potable water supplies in the Mid-West Region of Ireland. J Water Health 12(2):310–317, PMID: 24937225, 10.2166/wh.2014.178. [PubMed] [CrossRef] [Google Scholar]
- O'Dwyer J, Hynds PD, Byrne KA, Ryan MP, Adley CC. 2018. Development of a hierarchical model for predicting microbiological contamination of private groundwater supplies in a geologically heterogeneous region. Environ Pollut 237:329–338, PMID: 29499576, 10.1016/j.envpol.2018.02.052. [PubMed] [CrossRef] [Google Scholar]
- Procopio NA, Atherholt TB, Goodrow SM, Lester LA. 2017. The likelihood of coliform bacteria in NJ domestic wells based on precipitation and other factors. Ground Water 55(5):722–735, PMID: 28369797, 10.1111/gwat.12518. [PubMed] [CrossRef] [Google Scholar]

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Clean Water Organizations Comments Exhibit 28

- Rasmuson A, Erickson B, Borchardt M, Muldoon M, Johnson WP. 2020. Pathogen prevalence in fractured versus granular aquifers and the role of forward flow stagnation zones on pore-scale delivery to surfaces. Environ Sci Technol 54(1):137–145, PMID: 31770489, 10.1021/acs.est.9b03274. [PubMed] [CrossRef] [Google Scholar]
- Rayne TW, Bradbury KR, Krause JJ. 2019. Impacts of a rural subdivision on groundwater quality: results of long-term monitoring. Ground Water 57(2):279–291, PMID: 29603208, 10.1111/gwat.12666. [PubMed] [CrossRef] [Google Scholar]
- Reneau RB Jr. 1979. Changes in concentrations of selected chemical pollutants in wet, tile-drained soil systems as influenced by disposal of septic tank effluents. J Environ Qual 8(2):189–196, 10.2134/jeq1979.00472425000800020011x. [CrossRef] [Google Scholar]
- Shaver RH, Ault CH, Ausich WI, Droste JB, Horowitz AS, James WC, et al.. 1978. The Search for a Silurian Reef Model, Great Lakes Area: Indiana Department of Natural Resources Geological Survey Special Report 15. https://igws.indiana.edu/bookstore/details.cfm?Pub_Num=SR15 [accessed 29 June 2019].
- Sherrill MG. 1979. Contamination Potential in the Silurian Dolomite Aquifer, Eastern Wisconsin. USGS Water-Resources Investigations Open-File Report, 78–108. Reston, VA: USGS, 10.3133/wri78108 [accessed 1 October 2018]. [CrossRef] [Google Scholar]
- Sherrill MG. 1978. Geology and ground Water in Door County, Wisconsin, with Emphasis on Contamination Potential in the Silurian Dolomite. U.S. Geological Survey Water-Supply Paper 2047. Reston, VA: USGS. [Google Scholar]
- Stokdyk J, Spencer SK, Walsh J, de Lambert J, Firnstahl AD, Anderson A, et al.. 2019. *Cryptosporidium* incidence and surface water influence of groundwater supplying public water systems in Minnesota, USA. Environ Sci Technol 53(7):3391–3398, PMID: 30895775, 10.1021/acs.est.8b05446. [PubMed] [CrossRef] [Google Scholar]
- Stokdyk JP, Firnstahl AD, Walsh JF, Spencer SK, de Lambert JR, Anderson AC, et al.. 2020. Viral, bacterial, and protozoan pathogens and fecal markers in wells supplying groundwater to public water systems in Minnesota, USA. Water Res 178:115814, PMID: 32325219, 10.1016/j.watres.2020.115814. [PubMed] [CrossRef] [Google Scholar]
- Toetz D. 2006. Nitrate in ground and surface waters in the vicinity of a concentrated animal feeding operation. Arch Hydrobiol 166(1):67–77, 10.1127/0003-9136/2006/0166-0067. [CrossRef] [Google Scholar]
- U.S. EPA. (United States Environmental Protection Agency). 1977. The Report to Congress–Waste Disposal Practices and Their Effects on Ground Water. CgD-78-120: B-166506. Washington, DC: U.S. Environmental Protection Agency. [Google Scholar]
- U.S. EPA. 2020. National Primary Drinking Water Regulations. 40 CFR Part 141 https://www.ecfr.gov/cgi-bin/text-idx?tpl=/ecfrbrowse/Title40/40cfr141_main_02.tpl [accessed 16 April 2020].
- U.S. General Accounting Office. 1997. Information on the Quality of Water Found at Community Water Systems and Private Wells. United States GAO/RCED-97-123.. Washington, DC: U.S. Government Accounting Office. [Google Scholar]
- USDA NASS (U.S. Department of Agriculture National Agricultural Statistics Service). 2002. Census of Agriculture. http://agcensus.mannlib.cornell.edu/AgCensus/getVolumeOnePart.do?year=2002&part_id=1015&number=49&title=Wisconsin [accessed 2 November 2018].

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Clean Water Organizations Comments Exhibit 28

- USDA NASS. 2017. Census of Agriculture. www.nass.usda.gov/AgCensus [accessed 8 December 2020].
- USGS (U.S. Geological Survey). 2016. U.S. Geological Survey Ground Water Atlas of the United States, https://pubs.usgs.gov/ha/ha730/ Page last modified 30-Nov-2016 [accessed 27 May 2020].
- USGS (U.S. Geological Survey). 2020. USGS Water Data for the Nation: U.S. Geological Survey National Water Information System Database. 10.5066/F7P55KJN [accessed 15 September 2018]. [CrossRef]
- Warner KL, Arnold TL. 2010. Relations that Affect the Probability and Prediction of Nitrate Concentration in Private Wells in the Glacial Aquifer System in the United States. U.S. Geological Survey Scientific Investigations Report 2010–5100, https://pubs.usgs.gov/sir/2010/5100/ [accessed 1 April 2020].
- Wisconsin Department of Health Services. n.d. Drinking Water: Manure in Private Wells. https://www.dhs.wisconsin.gov/water/manure.htm [accessed 10 May 2021].
- Wisconsin Department of Natural Resources. 2018. Deer Abundance and Densities in Wisconsin Deer Management Units. https://dnr.wi.gov/topic/hunt/maps.html/falldeerperdr.pdf [accessed 12 May 2021].
- Won G, Gill A, LeJeune JT. 2013. Microbial quality and bacteria pathogens in private wells used for drinking water in northeastern Ohio. J Water Health 11(3):555–562, PMID: 23981882, 10.2166/wh.2013.247. [PubMed] [CrossRef] [Google Scholar]
- Yates MV. 1985. Septic tank density and ground-water contamination. Groundwater 23(5):586–591, 10.1111/j.1745-6584.1985.tb01506.x. [CrossRef] [Google Scholar]
- Yessis J, McColl RS, Seliske P. 1996. Methodological aspects of monitoring for microbial contamination of drinking water from private wells: the water quality program of the region of waterloo. Can Water Resour J 21(3):221–228, 10.4296/cwrj2103221. [CrossRef] [Google Scholar]
- Zhang Y, Kelly W, Panno SV, Liu W-T. 2014. Tracing fecal pollution sources in karst groundwater by Bacteriodales genetic biomarkers, bacterial indicators, and environmental variables. Sci Total Environ 490:1082–1090, PMID: 24922611, 10.1016/j.scitotenv.2014.05.086. [PubMed] [CrossRef] [Google Scholar]

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Bacteria | Minnesota Pollution Control Agency

pca.state.mn.us/pollutants-and-contaminants/bacteria

Countless bacteria can be found in land, water, humans, and animals. Most bacteria are beneficial, serving as food for larger organisms and playing critical roles in natural processes such as organic matter decomposition and food digestion. But about 10% of bacteria, such as *E. coli,* are harmful and, if ingested by humans, can cause sickness or even death.

Sources

Bacteria in Minnesota lakes and streams mainly come from sources such as failing septic systems, wastewater treatment plant releases, livestock, and urban stormwater. Waste from pets and wildlife is another, lesser source of bacteria.

Human health and environmental concerns

In addition to bacteria, human and animal waste may contain pathogens such as viruses and protozoa that could be harmful to humans and other animals. The behavior of bacteria and pathogens in the environment is complex. Levels of bacteria and pathogens in a body of water depend not only on their source, but also on weather, current, and water temperature. As these factors fluctuate, the level of bacteria and pathogens in the water may increase or decrease. Some bacteria can survive and grow in the environment while many pathogens tend to die off with time.

Monitoring, reporting, and regulations

Testing for specific disease-producing bacteria or other pathogens is difficult, expensive, and time-consuming. The MPCA tests for fecal coliform and *E. coli* bacteria, which are commonly found in fecal waste and are easy to measure. They are often used as “indicator organisms” to denote the potential presence of fecal waste. Although using indicator bacteria to assess the presence of pathogens in not a perfect process, it is the best available option at this time. Lakes and streams in Minnesota meet water quality standards if they have a monthly geometric mean less than 126 colony-forming units of *E. coli* per 100 milliliters of water, between April and October.

Most lakes and streams in Minnesota meet water quality standards for bacteria. MPCA uses the *E. coli* water quality standard to identify water bodies that may be contaminated with fecal waste. Higher levels of *E. coli* in the water may or may not be accompanied by higher levels of pathogens and an increased risk of harm; varying survival rates of bacteria make is impossible to definitively state when pathogens are present. See the Minnesota Department of Health Waterborne Illness web page for more information on how to reduce your risk for waterborne illnesses when swimming, boating, or wading.

Is my lake or stream safe for swimming?

Minnesota does not have a list of “safe” bodies of water for recreation. Sometimes a city or county health department will close a swimming beach due to bacterial contamination. Conditions can change over time, and state water-testing efforts are not frequent enough to be time current, particularly in streams and rivers. If you have questions about a specific beach, check with the proper beach authority for their current information and recommendations.

Check with your city or county environmental services to see if your local lake is tested on a regular basis. Two examples of local testing programs:

- Minnesota Lake Superior Beach Monitoring Program
- Hennepin County public swimming beaches

Addressing bacterial contamination

Some bacteria and pathogens will always be present in surface waters. While most of the bacteria and pathogens from fecal waste in the water will die off over time, some may survive. Pathogens from fecal waste generally die off in the environment much faster than bacteria. While there is not a way to rid water bodies of all pathogens, we can reduce bacteria in surface waters by combining the efforts of many individuals and groups. The best methods include:

- Controlling runoff on feedlot properties and where manure is spread on farmland
- Repairing or replacing failing septic systems
- Improving wastewater treatment processes at some facilities
- Controlling erosion with practices such as conservation tillage and riparian buffers
- Rotational livestock grazing, which reduces both sedimentation and fecal coliform concentrations
- Urban stormwater management – runoff detention, infiltration, and street sweeping

Many government entities and groups across Minnesota are working to better understand sources of bacteria in water and mitigate them. Some examples include:

- Pollutant reduction studies that lead to limits on bacteria discharged by wastewater treatment facilities to lakes and streams
- Feedlot runoff controls and other conservation practices installed by farmers because of permit requirements or a statewide water quality certification program
- County and state programs to bring failing sewer systems into compliance

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The Animal Feed Industry's Impact on the Planet

independentmediainstitute.org/2024/01/29/the-animal-feed-industrys-impact-on-the-planet

January 30, 2024

January 29, 2024

> *Click here to read the article on the Observatory.*

The diet of factory-farmed animals is linked to environmental destruction around the globe.

By *Vicky Bond*

In some parts of the continental United States, you might drive through a nearly unchanging landscape for hours. Stretching for miles and miles, vast swaths of soil are dedicated to growing crops—corn, grains, fruits, and vegetables that make up the foundation of our food system.

The process seems highly efficient, producing enormous quantities of food every year. But only a small percentage of these crops will go toward feeding humans. According to a 2013 study conducted by researchers at the Institute on the Environment at the University of

Minnesota and published in the journal Environmental Research Letters, a mere 27 percent of crop calorie production in the United States actually feeds humans. So what happens to the rest?

Some crops are used for the production of ethanol and other biofuels. But the vast majority—more than 67 percent of crop calories grown in the U.S.—are used to feed animals raised for human consumption.

Rather than feeding people, these crops feed the billions of chickens, cows, pigs, and other animals who live and die on factory farms. And that’s a problem.

The issue is that feeding humans indirectly—essentially, making animals the caloric middlemen—is a highly inefficient use of food. “For every 100 calories of grain we feed animals, we get only about 40 new calories of milk, 22 calories of eggs, 12 of chicken, 10 of pork, or 3 of beef,” writes Jonathan Foley, PhD, executive director of the nonprofit Project Drawdown, for National Geographic. “Finding more efficient ways to grow meat and shifting to less meat-intensive diets… could free up substantial amounts of food across the world.”

This shift in growing and consuming food more sustainably has become especially important, with up to 783 million people facing hunger in 2022, according to the United Nations. Research indicates that if we grew crops exclusively for humans to consume directly we could feed an additional 4 billion people worldwide.

Farming has always loomed large in American politics, history, and identity. But the idyllic farming we may imagine—rich piles of compost, seedlings poking through the soil, and flourishing gardens of diverse fruits and vegetables—has transformed into factory farming, a highly industrialized system far removed from earth and soil. Animal feed is essential for the sustenance of this industry—supplying the cattle feedlots, broiler chicken sheds, and egg factories that increasingly make up the foundation of our food system.

What Factory-Farmed Animals Eat

Take a moment to picture a farm animal enjoying dinner. Are you imagining a cow grazing on grass or perhaps a chicken pecking at the ground, foraging for seeds and insects? In today’s factory farming system, the “feed” these animals eat is far removed from their natural diets. Rather than munching on grass or insects, most animals on factory farms eat some type of animal feed—a cost-effective mixture of grains, proteins, and often the addition of antibiotics designed to make them grow as quickly as possible.

The ingredients in animal feed don’t just matter to the animals’ health. They also impact human health—especially since the average American consumes 25 land animals yearly. Researchers have noted that animal feed ingredients are “fundamentally important” to human health impacts. As author and journalist Michael Pollan puts it: "We are what we eat, it is often said, but of course that's only part of the story. We are what what we eat eats too."

So, what are the main ingredients used in animal feed today?

Corn and Other Grains

In 2019, farmers planted 91.7 million acres of corn in the U.S. This equals 69 million football fields of corn. How can so much land be devoted to a single crop—especially something many people only eat on occasion?

The answer is that corn is in almost everything Americans eat today. It's just there indirectly—in the form of animal feed, corn-based sweeteners, or starches. The U.S. is the world's largest producer, consumer, and exporter of corn. And a large percentage of all that corn is used for animal feed, supplying factory farms across the country.

While "cereal grains"—such as barley, sorghum, and oats—are also used for animal feed, corn is by far the number one feed grain used in the U.S., accounting for more than 96 percent of total feed grain production. Corn supplies the carbohydrates in animal feed, offering a rich energy source to increase animals' growth.

Unfortunately, what this system offers in efficiency it lacks in resilience. Numerous researchers have expressed concern about the vulnerability of the food supply that is so reliant on a single crop. "Under these conditions, a single disaster, disease, pest, or economic downturn could cause a major disturbance in the corn system," notes Jonathan Foley in another article for Scientific American. "The monolithic nature of corn production presents a systemic risk to America's agriculture."

Soybeans

When you think about soybeans, you might imagine plant-based foods like tofu and tempeh. However, the vast majority of soybeans are used for animal feed. Animal agriculture uses 97 percent of all soybean meal produced in the United States.

While corn is rich in carbohydrates, soybeans are the world's largest source of animal protein feed. Similar to corn, Americans might not eat a lot of soybeans in the form of tofu, tempeh, and soy milk—in fact, 77 percent of soy grown globally is used to feed livestock, and only 7 percent of it is used directly for human consumption, states a 2021 Our World in Data article—but they do consume soy indirectly through animal products like meat and dairy.

Soy production comes at a high cost to the environment. It is heavily linked to deforestation, driving the destruction of forests, savannahs, and grasslands—as these natural ecosystems are converted to unnatural farmland—and "putting traditional, local livelihoods at risk."

Critical habitats, like the Cerrado savannah in Brazil, are being razed to clear space for soybean production to meet the global demand for animal feed. More than half of the Cerrado's 100 million hectares of native landscape has already been lost, with livestock and soybean farming being major contributors to this destruction.

"Most soybean-driven land conversions in Brazil have happened in the Cerrado," said Karla Canavan, vice president for commodity trade and finance at World Wildlife Fund, in 2022. "The corridor [Cerrado] is like an inverted forest that has enormous roots and is a very important carbon sink. … Unfortunately, more than 50 percent of the Cerrado has been already converted into soybean farmlands."

It's a common misconception that plant-based soy products like tofu drive global deforestation. In reality, the vast majority of soy is used for animal feed. To fight this tragic habitat destruction, it's far more effective to replace meat with soy-based alternatives.

Animal Protein and Waste

Editor's note: The following section contains graphic descriptions that may disturb some readers.

It's not just plants like corn and soybeans that go into animal feed. The factory farming industry has a long history of feeding animals waste and proteins from other animals. In 2014, outrage ensued when an investigation by the Humane Society of the United States revealed that pig farmers were feeding animals the intestines of their own piglets. At a huge factory farm in Kentucky, workers were filmed eviscerating dead piglets and turning their intestines into a puree that was being fed back to mother pigs.

This wasn't even an isolated atrocity. The executive director of the American Association of Swine Veterinarians in 2014 commented that the practice was "legal and safe" and was meant to immunize the mother pigs against a virus called porcine epidemic diarrhea, according to the New York Times. Pigs aren't the only animals who are effectively turned into cannibals by the factory farming industry.

Farmers were only prohibited from feeding cow meat to other cows following concerns about bovine spongiform encephalopathy (BSE), more commonly known as mad cow disease. The U.S. Department of Agriculture notes on its website that BSE may have been caused by feeding cattle protein from other cows. The practice was banned in 1997—but, notably, only because of the risks to human health and not out of concern for the cows.

Antibiotics

Another key ingredient in animal feed likely doesn't come to mind when you think about animal nutrition. This ingredient is antibiotics, commonly used in the food given to animals across the country.

On factory farms, animals are confined in extremely crowded, filthy facilities—the perfect conditions for spreading illness and disease. Not only do antibiotics allow animals to survive the conditions in these facilities but they also encourage animals to grow unnaturally large and fast. Drugs are administered through food and water, starting when the animals are just a few days old.

The meat industry's excessive antibiotic use has directly been linked to antimicrobial resistance (AMR), a massive threat to human health. As bacteria are killed off, the surviving that remain gradually learn how to survive the attacks, becoming resistant to antibiotics over time.

AMR means that conditions that should be easy and affordable to treat—like ear infections—can become life-threatening. It's "one of today's biggest threats to global health, food security, and development," according to the World Health Organization, states a News-Medical article, and it's projected to kill four times as many people per year as COVID-19 did in 2020, according to the British Society for Antimicrobial Chemotherapy.

Additives and Preservatives

Along with the mixture of corn, soybeans, and a cocktail of antibiotics, animal feed may also contain a plethora of additives and preservatives. The Code of Federal Regulations provides a long list of additives legally permitted in animals' food and drinking water. These include "condensed animal protein hydrolysate" (produced from meat byproducts of cattle slaughtered for human consumption), formaldehyde, and petrolatum—to name a few.

Unfortunately, many of these additives and preservatives have been linked to adverse human health impacts. For example, formaldehyde, which is classified as a known human carcinogen by the National Toxicology Program, is commonly used in animal feed to reduce salmonella contamination. In 2017, following concerns about farmworkers being exposed to the harmful substance, the European Commission voted to ban feed producers from using formaldehyde as an additive in animal feed.

Animal Feeding Operations

To understand the true impact of animal feed, we must look at animal feeding operations. Of all the animals in our food system today, 99 percent live on factory farms—enormous, vertically integrated operations designed to make as much profit as possible (at the expense of animals, people, and the environment). The transition to using animal feed has been closely intertwined with the transition to this type of large-scale factory farming.

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The official term for a factory farm is concentrated animal feeding operation or CAFO. As the name implies, these operations are laser-focused on feeding large numbers of animals until they reach "slaughter weight," after which they are killed and turned into products.

The faster an animal reaches slaughter weight, the more quickly the industry profits. So factory farms have dialed in on the most efficient way to feed animals in the shortest amount of time. Rather than grazing on pasture, animals are confined in stationary cages or crowded sheds and given feed that will increase their growth rates—even while it hurts their health.

Take cows, for example. Along with sheep and other grazing animals, they are known as "ruminants"—because they have a rumen, an organ perfectly designed to transform grass into protein. But the industry feeds cows corn instead of grass because it brings them to "slaughter weight" much faster than grazing. Sadly, this high-starch diet can disturb a cow's rumen, causing pain with severe bloat, acidosis (or heartburn), and other types of stomach upset.

When it comes to feeding animals on factory farms these are some key industry terms to know:

- **Growth rates:** This is the rate at which an animal grows or how quickly the animal reaches "slaughter weight." Sadly, most factory farm animals are bred to grow so quickly that their health suffers. Chickens raised for meat frequently develop bone deformities, muscle diseases like white striping, and heart problems. Many chickens have difficulty walking, or even just standing due to painful lameness as a consequence of their fast growth rate.
- **Feed conversion ratio:** This is the ratio between the amount of feed an animal eats and the amount of body weight that an animal gains. In other words, a feed conversion ratio is the industry's effort to feed animals as little as possible to make them grow as quickly as possible.
- **Selective breeding:** This is the practice of breeding two animals to produce offspring with a desired trait. For example, the poultry industry breeds birds who quickly develop outsized breast muscles. In the meat industry, selective breeding is generally used to optimize both feed conversion ratio and growth rates.

Animal Feed Industry Impacts

Overall, factory farming is incredibly resource-intensive and harmful to the environment. From agricultural runoff to water waste and pollution, CAFOs are responsible for some of humanity's worst climate impacts.

"Livestock farms generate about 70 percent of the nation's [United States] ammonia emissions, plus gases that cause global warming, particularly methane," according to the Public Broadcasting Service. The practice of growing crops for animal feed is one of the

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worst drivers of environmental destruction—leaving biodiversity loss, deforestation, and greenhouse gas emissions in its wake.

Deforestation

Growing crops necessary to feed huge numbers of animals to support human meat consumption requires vast amounts of land, which results in massive deforestation. Forests worldwide are systematically being cleared and replanted with monocrops (such as the corn and soybeans mentioned earlier) to meet the demand for animal products—and therefore, animal feed.

Brazil, for example, is the world's biggest beef exporter. In the Amazon rainforest—nearly two-thirds of which is part of Brazil—crops for animal feed are one of the primary drivers of deforestation, damaging an essential habitat for countless species. Deforestation rates have averaged nearly 2 million hectares yearly since 1995 in the Amazon, or about seven football fields every minute.

Meanwhile, farmland expansion accounts for 90 percent of deforestation worldwide, "including crops grown for both human and animal consumption, as well as the clearing of forests for animal grazing," according to a July 2022 article in Sentient Media.

Deforestation eliminates one of our best defenses against climate change as healthy, intact forests provide a crucial ecosystem service: carbon sequestration. Forests safely store more carbon than they emit, making them powerful "carbon sinks" critical to maintaining a stable climate. When we destroy forests for farmland and other uses, we remove that carbon sink and release all the carbon into the atmosphere that had been stored there.

Biodiversity Loss and Extinction Threat

Naturally, deforestation goes hand in hand with biodiversity loss—of which animal agriculture is also a key driver. A 2021 study found that land use conversions to support the "global food system" are a primary driver of biodiversity loss. Tragically, researchers project that more than 1,000 species will lose at least a quarter of their habitats by 2050 if meat consumption continues at the same rate.

At the UN Biodiversity Conference (COP15) in Montreal in December 2022, delegates warned that if our land-intensive eating habits don't change, more and more critical species will go extinct. As author and journalist Michael Grunwald points out in the New York Times: "[W]hen we eat cows, chickens, and other livestock, we might as well be eating macaws, jaguars, and other endangered species."

Water Use

Along with vast amounts of land, growing crops for animal feed requires enormous quantities of water. In the U.S. alone, more than 60 percent of freshwater was used to grow crops in 2012, and around 2.5 trillion gallons per year of water was used for animal feed in the same year. Corn, soybeans, and the other grains used in animal feed require about 43 times more water than grass or roughage, which animals could access if they were allowed to graze.

Soil Degradation

The intensive farming practices required to grow vast amounts of crops—like corn and soybeans—even take a toll on the soil.

Healthy soil contains millions of living organisms, which naturally replenish and recycle organic material and nutrients. Soil filters water, stores carbon, and allows for carbon, nitrogen, and phosphorus cycles that are critical for life on Earth.

But intensive farming practices, like growing "monocultures" (huge amounts of one crop like corn or soybeans), can degrade soil and deplete critical nutrients. Not only do these farming practices prevent soil's natural processes but they can also reduce the amount of carbon stored in soil—a huge problem in the face of climate change. Intensive agriculture, closely intertwined with factory farming, damages the soil beyond repair.

Change Is Possible

The impacts of our animal-based food production system are far-reaching and complex. The intensive farming practices that supply animal feed for factory farms are destroying our water, air, and soil—and harming countless animals raised in food supply chains. But there is hope. It's not too late to build a better food system from the ground up.

The movement to build a healthier food system is growing every day. Around the world, people are advocating for systemic change—from plant-based food options to better treatment of farmed animals. In fact, according to a March 2022 article in Phys.org, "switching to a plant-based diet in high-income nations would save an area the size of the EU worldwide." Moreover, if just one person follows a vegan diet, an average of 95 animals will be spared each year, according to the book, *Ninety-Five: Meeting America's Farmed Animals in Stories and Photographs*.

Concerned citizens and consumers can also hold corporations accountable for animal abuse and environmental degradation—by pressuring companies to adopt more sustainable practices. Already, several large meat producers and fast food and supermarket chains have stopped keeping pigs in gestation crates after people expressed "disgust" at the practice. According to the New York Times, "[T]he tide is turning because consumers are making their preferences known."

> *Click here to read the article on the Observatory.*

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Photo Credit: Albert Bridge / Wikimedia Commons

Understanding Global Warming Potentials

epa.gov/ghgemissions/understanding-global-warming-potentials

January 12, 2016

Greenhouse gases (GHGs) warm the Earth by absorbing energy and slowing the rate at which the energy escapes to space; they act like a blanket insulating the Earth. Different GHGs can have different effects on the Earth's warming. Two key ways in which these gases differ from each other are their ability to absorb energy (their "radiative efficiency"), and how long they stay in the atmosphere (also known as their "lifetime").

Starting in 1990, the Intergovernmental Panel on Climate Change (IPCC) used the Global Warming Potential (GWP) to allow comparisons of the global warming impacts of different gases. Specifically, it is a measure of how much energy the emission of 1 ton of a gas will absorb over a given period of time, relative to the emission of 1 ton of carbon dioxide (CO_2). The larger the GWP, the more that a given gas warms the Earth compared to CO_2 over that time period. The time period usually used for GWPs is 100 years. GWPs provide a common unit of measure, which allows analysts to add up emissions estimates of different gases (e.g., to compile a national GHG inventory), and allows policymakers to compare emissions reduction opportunities across sectors and gases.

- CO_2, by definition, has a GWP of 1 regardless of the time period used, because it is the gas being used as the reference. CO_2 remains in the climate system for a very long time: CO_2 emissions cause increases in atmospheric concentrations of CO_2 that will last thousands of years.

- Methane (CH_4) is estimated to have a GWP of 27-30 over 100 years. CH_4 emitted today lasts about a decade on average, which is much less time than CO_2. But CH_4 also absorbs much more energy than CO_2. The net effect of the shorter lifetime and higher energy absorption is reflected in the GWP. The CH_4 GWP also accounts for some indirect effects, such as the fact that CH_4 is a precursor to ozone, and ozone is itself a GHG.
- Nitrous Oxide (N_2O) has a GWP 273 times that of CO_2 for a 100-year timescale. N_2O emitted today remains in the atmosphere for more than 100 years, on average. (Learn why EPA's U.S. Inventory of Greenhouse Gas Emissions and Sinks uses a different value.)
- Chlorofluorocarbons (CFCs), hydrofluorocarbons (HFCs), hydrochlorofluorocarbons (HCFCs), perfluorocarbons (PFCs), and sulfur hexafluoride (SF_6) are sometimes called high-GWP gases because, for a given amount of mass, they trap substantially more heat than CO_2. (The GWPs for these gases can be in the thousands or tens of thousands.)

Explore the questions and answers below to learn more about global warming potentials (GWPs).

Frequently Asked Questions

- Why does the IPCC definition of GWP differ from the definitions used in ISO (e.g., 14044 and 21930:2017) and related Environmental Product Declarations and Product Category Rules?
- Why do GWPs change over time?
- Why are GWPs presented as ranges?
- What GWP estimates does EPA use for GHG emissions accounting, such as the *Inventory of U.S. Greenhouse Gas Emissions and Sinks* (Inventory) and the Greenhouse Gas Reporting Program?
- Are there alternatives to the 100-year GWP for comparing GHGs?

Why does the IPCC definition of GWP differ from the definitions used in ISO (e.g., 14044 and 21930:2017) and related Environmental Product Declarations and Product Category Rules?

The International Organization for Standardization (ISO) community differs in its definition and use of the term Global Warming Potential (GWP) from that used by IPCC. This ISO approach is applied in Environmental Production Declaration (EPD), Product Category Rules (PCR), Buy Clean Policies, and related programs. This definition and use are inconsistent with how GWP is defined by the IPCC and used in many international GHG accounting efforts, including national reporting by Parties to the UNFCCC and Paris Agreement.

The ISO and relevant communities use the term "GWP" as an impact category to refer to the embodied greenhouse gases of a specific product or product-level GHG emission intensities (see, e.g., ISO 21930:2017). This specific use of GWP by the EPD community refers to the total greenhouse gas emissions directly associated with the production of a product, including the upstream activities of extraction and transport of raw materials. This type of calculation can also be described with terms such as "embodied GHG equivalent" or "GHG footprint." The product GWP measure is reported in CO_2-equivalents per functional unit in EPDs, PCRs, etc. However, the ISO calculation of CO_2-equivalents requires the use of the original GWP as defined by IPCC, thereby making the EPD/ISO GWP inherently confusing as it uses both meanings of the term GWP simultaneously.

To reduce confusion, the use of the term "Global Warming Potential" or "GWP" that fall outside the IPCC definition or use—i.e., a measure of the relative climate impact of a given greenhouse gas relative to the impact of carbon dioxide (as defined on this page)—should include a definition of the non-IPCC usage of the term to distinguish it from the original established IPCC definition. In the case of how ISO and relevant communities use the term GWP, it should be clearly explained that the specific meaning in that context refers to "embodied GHG equivalent," "embodied GHG emissions," or "carbon equivalent footprint," as applicable. This context is especially important if the document uses both different meanings of the term "GWP" such as in the ISO/EPD context.

Why do GWPs change over time?

EPA and other organizations will update the GWP values they use occasionally. This change can be due to updated scientific estimates of the energy absorption or lifetime of the gases or to changing atmospheric concentrations of GHGs that result in a change in the energy absorption of 1 additional ton of a gas relative to another.

Why are GWPs presented as ranges?

> In the most recent report by the Intergovernmental Panel on Climate Change (IPCC), multiple methods of calculating GWPs were presented based on how to account for the influence of future warming on the carbon cycle. For this Web page, we are presenting the range of the lowest to the highest values listed by the IPCC.

What GWP estimates does EPA use for GHG emissions accounting, such as the *Inventory of U.S. Greenhouse Gas Emissions and Sinks* (Inventory) and the Greenhouse Gas Reporting Program?

> The EPA considers the GWP estimates presented in the most recent IPCC scientific assessment to reflect the state of the science. In science communications, the EPA will refer to the most recent GWPs. The GWPs listed above are from the IPCC's Sixth Assessment Report, published in 2021.
>
> The EPA's *Inventory of U.S. Greenhouse Gas Emissions and Sinks* (Inventory) complies with international GHG reporting standards under the United Nations Framework Convention on Climate Change (UNFCCC). UNFCCC guidelines now require the use of the GWP values from the IPCC's Fifth Assessment Report (AR5), published in 2013. The Inventory also presents emissions by mass, so that CO_2 equivalents can be calculated using any GWPs, and emission totals using more recent IPCC values are presented in the annexes of the Inventory report for informational purposes.
>
> The data collected by EPA's Greenhouse Gas Reporting Program is generally reported in mass units of greenhouse gas and is used in the Inventory. The Reporting Program, generally uses GWP values from the AR4 to determine whether facilities exceed reporting thresholds and to publish data in CO_2 equivalent values. The Reporting Program collects data about some industrial gases that do not have GWPs listed in the AR4; for these gases, the Reporting Program uses GWP values from other sources, such as the AR5.
>
> EPA's CH_4 reduction voluntary programs also use CH_4 GWPs from the AR5 report for calculating CH_4 emissions reductions through energy recovery projects, for consistency with the national emissions presented in the Inventory.

Are there alternatives to the 100-year GWP for comparing GHGs?

The United States primarily uses the 100-year GWP as a measure of the relative impact of different GHGs. However, the scientific community has developed a number of other metrics that could be used for comparing one GHG to another. These metrics may differ based on timeframe, the climate endpoint measured, or the method of calculation.

For example, the 20-year GWP is sometimes used as an alternative to the 100-year GWP. Just like the 100-year GWP is based on the energy absorbed by a gas over 100 years, the 20-year GWP is based on the energy absorbed over 20 years. This 20-year GWP prioritizes gases with shorter lifetimes, because it does not consider impacts that happen more than 20 years after the emissions occur. Because all GWPs are calculated relative to CO_2, GWPs based on a shorter timeframe will be larger for gases with lifetimes shorter than that of CO_2, and smaller for gases with lifetimes longer than CO_2. For example, for CH_4, which has a short lifetime, the 100-year GWP of 27–30 is much less than the 20-year GWP of 81–83. For CF_4, with a lifetime of 50,000 years, the 100-year GWP of 7380 is larger than the 20-year GWP of 5300.

Another alternate metric is the Global Temperature Potential (GTP). While the GWP is a measure of the heat absorbed over a given time period due to emissions of a gas, the GTP is a measure of the temperature change at the end of that time period (again, relative to CO_2).The calculation of the GTP is more complicated than that for the GWP, as it requires modeling how much the climate system responds to increased concentrations of GHGs (the climate sensitivity) and how quickly the system responds (based in part on how the ocean absorbs heat).

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Nitrate contamination of Minnesota waters shows little sign of going away, despite years of effort

www2.startribune.com/nitrate-pollution-minnesota-groundwater-farm-fertilizer-mpca-wells-epa/600310942

Jeff Hargarten, Jennifer Bjorhus, Star Tribune

Farm pollution persists despite hundreds of millions spent to clean it up.

By Jeff Hargarten and Jennifer Bjorhus Star Tribune
November 28, 2023 — 6:20pm

Brian Peterson, Star Tribune file

Utica, Minn., a farm town of about 200 people surrounded by fields in Winona County, is preparing to dig a new, deeper well to find clean water because the city's water is contaminated with nitrate. It's one example of the state's stubborn problem with reducing nitrate contamination from farm pollution.

Minnesota has spent hundreds of millions of dollars and decades of effort to reduce nitrate that's contaminating drinking water and rivers. The progress so far: negligible.

The main source of the nitrate is nitrogen fertilizer, a pillar of production agriculture that includes animal manure and synthetic chemicals. Farmers apply tens of thousands of tons of fertilizers to their fields every year, and what isn't absorbed by crops can seep into aquifers and any runoff can end up in rivers.

Despite numerous programs designed to encourage farmers to change their ways, purchases of fertilizer keep growing. In many parts of Minnesota farm country, drinking water wells and streams carry that legacy: A decades-old state law limits how much nitrate is allowed in drinking water, although some researchers now say that level needs to be much stricter to protect people.

The three agencies tasked with keeping Minnesota waters clear of harmful levels of nitrate acknowledge that the situation isn't improving, particularly for private wells in the vulnerable topography of the state's hilly southeastern corner. In that region, frustrated residents have called for the federal government to intervene on what environmental groups call a public health emergency — and the EPA recently responded with a directive that Minnesota clean up its act.

A lack of progress

Nitrate levels of 10 milligrams per liter of water or higher have violated federal health standards since the 1960s, since those concentrations are known to cause the potentially life-threatening condition methemoglobinemia, or blue baby syndrome, that starves infants of oxygen.

But there's a push to reduce the state and federal nitrate standard from the 10 mg/l limit, given growing research around links to cancer and other damaging health impacts from drinking water with nitrate at half the legal maximum concentration, or even lower.

Community drinking water supplies, which serve cities, towns and mobile home parks, are regularly tested to assure nitrate levels are below the state and federal health limit.

While those with the highest nitrate concentrations have taken action to reduce it, about 177,000 Minnesotans still lived in communities with average readings above 3 milligrams of nitrate per liter of water as of 2022, levels considered by health authorities to be caused by human activity, not nature.

At least 400,000 Minnesotans in more than 100 communities live in areas where water has tested at least once for elevated nitrate levels since 2013. They're mostly spread across central and southern parts of the state.

Separately, there are some 980,000 private wells in Minnesota, according to the Minnesota Well Owners Organization. And people who rely on them for drinking water are on their own to have them tested and, if necessary, find remedies.

Far more Minnesotans could be affected by elevated nitrate levels in their water, but a lack of one central testing agency means it is difficult to gather and compare data.

The volunteer private well tests the Department of Agriculture has helped run show the problem is widespread. In southeast Minnesota from 2008 through 2018, about 8% to 15% of the hundreds of private wells tested each year showed nitrate pollution above the 10 mg/L health limit. In 2021, about 30% of those private wells showed results above 3 milligrams.

In the 14-county Central Sands Region from 2011-2018, about 3% to 5% of the hundreds of private wells tested each year were polluted with nitrate above the 10 mg/L limit.

Public drinking water systems — not private wells — that violate federal nitrate contamination standards must report them to the EPA. Those violations in Minnesota totaled 34 last year in the EPA's Safe Drinking Water Information System and included gas stations, bars and churches.

Impaired rivers and streams

Nitrate also endangers fish and other aquatic life when it leaches into lakes, streams and rivers.

The nitrate entering the Mississippi River contributes to the huge oxygen-starved dead zone in the Gulf of Mexico. As part of the Hypoxia Task Force of states up and down the river, Minnesota has pledged to cut the nitrate in the Mississippi by 20% by 2025. But nitrate has actually risen in spots, as it has in most of the state's major rivers.

Lawmakers directed the Minnesota Pollution Control Agency in 2010 to set limits on nitrate to protect fish and aquatic life. It hasn't happened. It would be too expensive for small wastewater treatment plants, and wouldn't effectively reduce the nitrate from the farms it has no power to regulate, the agency told the Star Tribune.

About 5% — or 165 miles — of Minnesota's rivers and streams used for drinking water are impaired by nitrogen and/or phosphorus as of 2022, meaning they don't meet federal quality standards. In all, the EPA lists more than 300 bodies of water across the state including parts of the Minnesota, Mississippi and St. Croix rivers, as well as other streams and rivers, as threatened or impaired by nitrogen and phosphorus and in need of a restoration plan.

Spending with little impact

Hundreds of millions in federal and state funding has paid for nitrate research, efforts to change farming and other practices and nitrate filtration systems for water supplies in Hastings, Cold Spring, Adrian and four other cities.

That's paid for Nitrogen Smart farmer training in the past, water research, conservation programs, source water protection work and guidance for farmers on adopting best management practices — and that's just a few examples. The state covers this list in its five year progress reports on the state's 2014 Nutrient Reduction Strategy to cut nitrogen and phosphorus in waters.

The state's Clean Water Fund, part of the sales-tax funded Legacy Amendment, has directed at least $148 million to the nitrate problem since 2010, according to a Star Tribune analysis, and is just one of several spending sources.

None of it appears to have made a dent in the overall demand for nitrogen fertilizer. As cropland has expanded, farmers bought a record high 824,000 tons of nitrogen fertilizer in 2020, the most recent year for which data is available, according to sales tracked by the state Department of Agriculture.

Agency response

The responsibility for reducing nitrate lies mostly with three state agencies: Minnesota Department of Health, the Minnesota Department of Agriculture and the Minnesota Pollution Control Agency (MPCA). All said their efforts will pay off eventually.

The MPCA blamed climate change's effect on precipitation for the failure to show progress on nitrate reduction.

"It will take time to see the benefit of this work, especially as more frequent and extreme weather events caused by climate change are both masking our progress and worsening the nitrate problem by forcing nitrate pollution off lands, into groundwater, rivers, and downstream," said MPCA spokeswoman Andrea Cournoyer.

The Health Department said 30 years of data doesn't show increasing nitrate violations in the public water supplies it watches, but that it's a "different story" for private well owners in certain highly vulnerable parts of the state.

The Agriculture Department agrees that in parts of southeast Minnesota, the nitrate in private water wells "has been going up slowly for decades."

"Nowhere in the U.S. is a state tackling nitrate issues like Minnesota," the agriculture department said.

Some in southeast Minnesota, a land of heavy agriculture and a porous karst geography, say they can't wait any longer for help. A group from Dodge, Goodhue, Fillmore, Houston, Mower, Olmstead, Wabasha and Winona counties asked the EPA to declare a public health emergency because state and local authorities haven't controlled nitrate pollution of groundwater.

About 80,000 residents in those counties rely on private wells for their drinking water and about 300,000 use public water systems, according to the request for help, filed in April by the Minnesota Center for Environmental Advocacy, the Minnesota Well Owners Association and others.

The EPA responded with a letter this month, warning Minnesota's three responsible agencies of possible enforcement actions if they don't enact measures to better warn residents of nitrate dangers, provide bottled water and develop plans to reduce nitrate pollution in the region.

Further reading

Sources: Environmental Protection Agency, EPA Safe Drinking Water Information System, Minnesota Pollution Control Agency, Minnesota Department of Health, Minnesota Department of Agriculture, Environmental Working Group, Star Tribune reporting and analysis

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Commentary | Open Access

Confronting our Agricultural Nonpoint Source Control Policy Problem

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Discussions are open until six months from issue publication: .

Research Impact Statement: Reform of agricultural nonpoint source pollution policies is necessary to make progress in achieving water quality goals.

Abstract

Federal and state agricultural and environmental agencies have spent enormous sums since the 1990s to reduce nonpoint source (NPS) water pollution from agriculture. Yet, water quality problems are pervasive, and agriculture is a major cause. The lack of progress is often attributed to insufficient funding for pollution control practices relative to the scale of the problem. However, we attribute the lack of progress to shortcomings in agricultural NPS pollution control policy. We illustrate our argument after considering nearly four decades of federal, state, and local efforts to reduce agricultural NPS pollution to the Chesapeake Bay. Additional funding for current programs, absent fundamental program reform, is unlikely to produce reductions from agriculture needed to achieve desired water quality outcomes.

INTRODUCTION

The 1972 Federal Clean Water Act ushered in a new era of state and federal regulation, supported by enormous public and private spending directed at restoring, in the words of the Act "the physical, biological and chemical integrity of the nation's waters." Now, 50 years later, States (U.S.) rivers and streams are in poor biological condition, 25% are in fair condition, and only 28% are in good condition (USEPA 2017). Agricultural nonpoint source (NPS) pollution is often a principal cause of water quality impairments. The 2017 USEPA National Water Quality Inventory lists agricultural NPS pollution as the leading cause of water quality impairments in rivers and streams, the third-largest cause for lakes, the second largest for wetlands, and a major contributor to contamination of estuaries and groundwater (USEPA 2017). Agriculture is the largest source of nutrients contributing to the eutrophication of the Gulf of Mexico, the Chesapeake Bay, and the Great Lakes (Goolsby et al. 1999; Howarth 2008).

Policies and programs to reduce agricultural NPS pollution rely primarily on agricultural producers voluntarily implementing pollution control practices, encouraged by technical and financial assistance from federal and state programs. These programs have achieved only limited successes in reducing agricultural NPS loads (Sprague et al. 2011; Shortle et al. 2012; Ator et al. 2020). This widely acknowledged gap between NPS reductions achieved and the amount needed to meet water quality goals often is attributed to insufficient funding for existing technical and financial assistance programs (DeGood 2020).

We argue that increased funding is not enough. The limited success of NPS programs is embedded in the structure of the programs, and how these programs guide and direct choices; choices made by agricultural producers, technical assistance providers who advise producers, and water quality program managers. We illustrate our argument with the Chesapeake Bay Program (CBP) and conclude that fundamental policy reforms will be needed for achieving substantial reductions in agricultural NPS loads.

EXISTING APPROACHES TO ADDRESS AGRICULTURAL NPS POLLUTION

Programs to encourage agricultural NPS load reductions can take a variety of forms (Segerson 2013; OECD 2017; Shortle 2017; Pannell and Classen 2020; Shortle et al. 2021). With some exceptions, [1] conventional agricultural NPS policy in the U.S. rests on the premise that agricultural producers voluntarily decide how to manage their operations and whether or how to reduce to NPS pollution. To encourage producers to implement NPS pollution control practices, information programs inform them of the best management practices (BMPs) intended to improve water quality, and points them to government funding and sometimes private funding available for implementing the practices. Because BMPs can be costly, and in many cases reduce producers' net income, programs typically encourage implementation by sharing implementation costs (Shortle et al. 2021). Federal and state technical assistance

Environmental Quality Incentives Program and there are state programs that also cost-share BMP implementation. Cost sharing is typically for a portion of the cost of BMP installation and in limited circumstances some annual operation and maintenance costs (Ribaudo and Shortle 2019; Ribaudo 2001).

The Limited Success of NPS Programs: Illustration from the Chesapeake Bay

The CBP illustrates the current agricultural NPS pollution policy conundrum. Since the 1980s, nitrogen and phosphorus were identified as the primary pollutants limiting attainment of desired Bay water quality outcomes and agricultural NPS was identified early on as a major contributor of nutrient loads. In 1990, nutrient reduction targets for meeting water quality goals were set, these targets were revised in the 2000s, and brought under federally mandated nutrient limits in 2010.[2] Through all these years, policymakers understood that without agricultural NPS load reductions nutrient reduction targets and desired water quality outcomes would be unattainable.

For over three decades, federal and state governments have been committed to funding the types of conventional technical and financial cost share programs described above, hoping to encourage BMP implementation and meet agricultural NPS reduction targets. In fact, the CBP has been successful in increasing federal and state funding to support these programs, including securing a special federal appropriation of $256 million for the NRCS Chesapeake Bay Watershed Initiative (Natural Resource Conservation Service 2021). Recently, there have been renewed efforts to increase NPS program funding, arguing that more funding for these conventional programs will finally secure Bay water quality goals (Northey 2021).

Also of note is that the CBP has invested substantial resources to build a state-of-the-art model to evaluate and inform water quality managers decision-making (Hood et al. 2021). With respect to NPS pollution, the CBP watershed model is the basis for prioritizing BMP implementation and for crediting progress toward meeting NPS load reduction targets. As BMP implementation is reported, the CBP model credits NPS reductions by multiplying model-based estimates of nutrient runoff (pounds per acre) by an assigned BMP removal efficiency and the number of acres treated by the BMP. The model calculates nutrient runoff as an average over a relatively large area (~20,000 acres) for different land use types (crop, hay, etc.). The BMP pollutant removal efficiencies are generally a single number (e.g., 30% N removal for a riparian buffer) applied across the watershed. In the CBP model, these removal efficiencies are usually generated by expert judgment from a group of subject matter authorities (Stephenson et al. 2018).

the CBP model estimates, all pollution controls (implemented since 1985) have reduced nitrogen (N) loads by nearly 100 million pounds and phosphorus loads 14 million pounds per year. Over three-quarters of N reductions have come from wastewater treatment plants and from reductions in atmospheric deposition (CBP 2021). Point sources have reduced P loadings about 80% since 1985, which represents about 70% of the estimated P reductions achieved since 1985. The CBP identifies a need for another 50 million pounds of N reductions by 2025 to meet water quality standards, noting that these reductions must come primarily from agricultural NPS.

Meanwhile, statistical analyses of monitoring data suggest that the CBP model may be overestimating the nutrient reductions achieved by the cumulative impact of agricultural BMPs. Ator et al. (2019) found little evidence that agricultural NPS loads declined between 1992 and 2012. Another statistical analysis of monitoring data found that while P loads are declining in some regions of the Bay watershed, those improvements were offset by increases in agricultural P sources in other areas (Fanelli et al. 2019; Kleinman et al. 2019; Ator et al. 2020). While the limited response in observed pollutant reductions could be due the time that is required for NPS reductions to produce ambient water quality outcomes, the so-called "lag times," evidence suggests that another cause is at play: our agricultural NPS programs are not as effective as expected. The CBP is not alone in confronting this NPS challenge. Reductions from BMP implementation predicted by models routinely over estimate measured reductions (Osmond et al. 2012; Lintern et al. 2020). The challenge of measuring reductions in NPS loads in response to BMP adoption is one of the most fundamental and common challenges confronting large-scale water quality programs (Osmond et al. 2012; Boesch 2019; Lintern et al. 2020).

CHALLENGES WITH AGRICULTURAL NPS INCENTIVES

The continued failure to meet agricultural NPS reduction goals is not simply due to a lack of funding or a lack of effort. To a significant degree, the problem lies with the incentives inherent in conventional program design. These incentives influence choices made by producers and technical service providers that often limit the implementation of cost-effective BMPs in the locations that produce the greatest NPS loads. The following illustrations of NPS incentive challenges are drawn from the CBP, but these challenges are common across most large-scale water quality programs.

Agricultural Producers Face Limited Financial Incentives to Address NPS Pollution

sharing for practices is unlikely to result in producers and technical service providers seeking to identify water quality problem areas, and then implementing the most effective BMPs. Consider a BMP that produces little agronomic benefit to a producer's operation, promises significant low-cost nutrient reductions but requires substantial upfront capital investment and ongoing operation and maintenance expenditures. BMPs such as stream buffers, denitrifying bioreactors, stream fencing, and manure storage/treatment can generate substantial nutrient reductions at relatively low costs (Price et al. 2021; Stephenson et al. 2021). From a strictly financial perspective, agricultural producers will not install and operate a technology with few on-farm benefits and that costs them money (even if cost-shared). The structure of our cost-share programs does not directly pay producers for what is needed: pollutant reductions.

Program Managers Have Limited Ability and Incentives to Target NPS Hotspots

Many studies demonstrate that relatively small portions of the agricultural landscape produce most of the agricultural load. The way NPS loads are counted and reductions are credited is a disincentive for program managers to identify and treat these high loss areas. Suppose that 80% of nutrient losses on a 250-acre farm is coming from only 25 acres. The CBP crediting system and technical assistance programs provide few incentives for technical service providers and producers to focus on those 25 acres. If the 250 acres is in the same land use (say corn), CBP crediting gives the same reduction credit whether the BMP is placed on any of the 225 low loss acres, or the 25 high loss acres. Furthermore, conventional programs typically require that agricultural producers develop conservation plans for the entire farm operation to be eligible for program benefits. A producer willing to aggressively treat only the 25 high loss acres might not want or need a whole farm plan and, under current program guidelines, the producer would be ineligible for financial assistance without a plan that covers the entire farm.

Technical Service Providers Are Not Rewarded for Loads Reduced

Technical service providers serve as the conduit between the entity funding BMP implementation and producers, providing engineering, installation, and maintenance assistance to producers, and facilitating financial assistance. This structure, the technical service provider as a liaison, provides no direct incentive for a service provider to prioritize reductions from difficult and often high loading areas. Suppose a service provider can work with two neighboring producers. One producer has low nutrient losses and willingly adopts conservation practices. The other producer has high nutrient losses and is reluctant to participate in government programs. Such diversity of producer behavior is real and can be substantial (Ribaudo 2015). One recent study in a portion of the Chesapeake Bay watershed as measured by contracts processed. When programs, as in the CBP, credit nutrient reductions by BMPs installed, the same NPS reduction credit applies to both producers. Spending time with a reluctant, but high nutrient loss producer is a poor investment of the service providers time when the measure of success is participants enrolled and BMPs installed.

Technical Service Providers and Water Quality Managers cannot "Go Big"

Cost-share programs typically cap the amount of assistance that can be received by an individual agricultural producer. While distributing funding over more participants helps engage more producers in the conservation program, such funding limitations restrict what water quality managers and technical service providers can do to address larger scale NPS issues. For example, at a regional level, nutrient losses tend to be highest in areas with nutrient mass imbalances, where nutrient imports, in the form of fertilizers and animal feed, exceed the ability of the local cropping system to utilize the nutrients. The use of conventional BMPs, most of which do not address excessive nutrient mass imbalances, offers limited potential to reduce NPS loads. Regional animal waste management systems (manure conversion, waste to energy projects, transport) offer opportunities to address regional nutrient mass imbalances, but given the large upfront and ongoing maintenance and operation cost, and lack of on farm benefits associated with such systems limit their uptake.

Barriers to Innovation Exist in Current Program Structure

Incentives for innovation in NPS technologies and management are weak. Under conventional cost-share programs, entrepreneurs face limited profit opportunities to develop innovative NPS control practices because conventional agricultural cost-share programs create no buyers for such products. Producers have no incentive to pay for these technologies (unless there are on-farm benefits) and water quality managers have no means to pay for them given the requirement that costs must be shared.

Water quality managers, agricultural producers, and technical service providers have few incentives to invest in actions that produce more certain load reductions. Consider a producer who wants to implement a BMP where pollutant removal can be more readily measured or observed, for example in situ nutrient extraction (measurement of aquatic biomass harvest), direct treatment of runoff or water (influent and effluent from bioreactors), or manure conversion technologies, among others (Rose et al. 2015; Stephenson and Shabman 2017; Stephenson et al. 2018). Consider another example of a producer who is willing to demonstrate intermediate outcomes from conservation activities, such as changes in soil nutrient levels or

POLICY REFORM IS NEEDED TO MAKE PROGRESS IN ADDRESSING NPS POLLUTION

Conventional NPS program designs create limited incentives for program managers, technical service providers, or producers to care about whether BMPs provide the expected NPS load reductions. As a result, it is unlikely that significant progress will be made on NPS load reduction without fundamental policy and programmatic change (Shortle et al. 2012, 2021; Ribaudo and Shortle 2019). The most fundamental change would replace the current program premise that producers decide both whether and how to control their pollution, with a new premise that a producer or group of producers is obligated to limit their pollution but has discretion and flexibility in deciding how that limit is met.

Whatever the program premise, first, reform must shift the focus from practices to outcomes. Incentive systems that reward quantifiable nutrient reductions or observable water quality outcomes, such as "pay-for-performance" ("pay-for-success") systems, may better motivate agricultural producers to seek out and implement practices that result in the largest NPS reductions. Payment for performance programs can be designed in a variety of ways, but all should require that technical service providers also be able and willing to evaluate all NPS reduction options and develop plans for reducing pollutants. [3]

Second, the focus on outcomes through a "pay-for-performance" ("pay-for-success") system will require establishing acceptable practices for quantifying either pollutant reduction or changes in water quality conditions. Outcomes can be documented by direct measurement, by indirect, but observable, indicators of pollutant loss potential (e.g. soil nutrient levels), or by using more sophisticated field-scale models to predict site-specific reductions from implemented BMPs. Measured outcomes can be used for determining when the producers would be paid under the pay for performance system or for determining if the limits are being met. Measured outcomes allow technical service providers to be rewarded for working with high loss producers and for targeting high loss areas, and measured outcomes mean water quality managers' report progress as quantified load reductions, or improvement in ambient water quality conditions.

A shift toward outcome-based program design should involve experimentation with innovative combinations of incentive systems and outcome-based measurement (Shabman et al. 2011). As one example, producer-led watershed cooperatives could be created with the assistance of technical service providers to achieve measurable water quality. Such organizations would be incentivized to achieve specific quantifiable, independently verified, water quality outcomes, for instance, at the outlet of small watersheds by offering reward or bonus payments made to the producers to identify and direct cost-share funds received from the NPS programs to the investments that yield the most effective, more certain pollutant reductions (Maille et al. 2009).

Third, as noted above, reform may require shifting away from the premise of conventional programs that producers decide based on financial or personal adoption benefits whether to limit NPS pollution, to program designs that obligate producers to limit their NPS pollution. Such mandatory limits must be structured to recognize the diversity in agriculture across scales and across production systems. Consider large regional nutrient mass imbalances from high concentrations of intensive livestock operations. In vertically integrated production systems, such as poultry and swine, manure ownership and management requirements could be assigned to the integrator, rather than individual producers working under contract with the integrator. The integrator would be responsible for meeting manure disposal requirements but would be allowed the flexibility and technical expertise to find cost-effective solutions for the treatment, transport, and use of the manure.

Reform may mean that some agricultural producers accept more responsibilities for delivering pollutant reductions. Reform can mean more funding to existing programs given that funding requests often exceed available program funds, but new funding must be dedicated to paying for outcomes. Reform must mean that water quality managers rely more on measured outcomes, rather than tallying BMPs installed when determining progress. Reform must mean that agencies invest in training technical service providers in new skills needed to execute new program designs and embrace changes to familiar program and reward systems.

The challenges to making this transition are many and transition will not come easily. Reform will meet resistance. Acknowledging the need for change is the first step, and that will require accepting that we cannot simply buy our way out of the problem by spending more money on conventional, voluntary programs.

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AUTHOR CONTRIBUTIONS

Kurt Stephenson: Conceptualization; writing – original draft. Leonard Shabman: Conceptualization; writing – original draft. James Shortle: Conceptualization; writing – review and editing. Zachary Easton: Conceptualization; writing – original draft.

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DATA AVAILABILITY STATEMENT

Data sharing is not applicable to this article as no new data were created or analyzed in this study.

LITERATURE CITED

Ator, S.W., J.D. Blomquist, J.S. Webber, and J.G. Chanat. 2020. "Factors Driving Nutrient Trends in Streams of the Chesapeake Bay Watershed." *Journal of Environmental Quality*. https://doi.org/10.1002/jeq2.20101.

PubMed | Web of Science® | Google Scholar

Ator, S.W., A.M. Garcia, G.E. Schwarz, J.D. Blomquist, and A.J. Sekellick. 2019. "Toward Explaining Nitrogen and Phosphorus Trends in Chesapeake Bay Tributaries, 1992–2012." *Journal of the American Water Resources Association* **55** (5): 1149–68.

CAS | Web of Science® | Google Scholar

Boesch, D. 2019. "Barriers and Bridges in Abating Coastal Eutrophication." *Frontiers in Marine Science* **6**. https://doi.org/10.3389/fmars.2019.00123.

Web of Science® | Google Scholar

CBP (Chesapeake Bay Program). 2021. " Chesapeake Progress: Modeled Nitrogen and Phosphorus Loads to the Chesapeake Bay." https://www.chesapeakeprogress.com/clean-water/watershed-implementation-plans.

Google Scholar

DeGood, K. 2020. *A Call to Action on Combating Nonpoint Source and Stormwater Pollution*. Center for American Progress. https://www.americanprogress.org/issues/economy/reports/2020/10/27/492149/call-action-combating-nonpoint-source-stormwater-pollution/
.

Google Scholar

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Back

Fanelli, R.M., J.D. Blomquist, and R.M. Hirsch. 2019. "Point Sources and Agricultural Practices Control Spatial–Temporal Patterns of Orthophosphate in Tributaries to Chesapeake Bay." *Science of the Total Environment* **652**: 422–33.

PubMed | Web of Science® | Google Scholar

Goolsby, D.A., W.A. Battaglin, G.B. Lawrence, R.S. Artz, B.T. Aulenbach, R.R. Hooper, D.R. Keeney, and G.J. Stensland. 1999. " Flux and Sources of Nutrients in the Mississippi Atchafalaya River Basin Topic 3 Report for the Integrated Assessment on Hypoxia in the Gulf of Mexico: Silver Spring, MD, NOAA Coastal Ocean Office, NOAA Coastal Ocean Program Decision Analysis Series No. 17." 130 pp.

Google Scholar

Hood, R.R., G.W. Shenk, R.L. Dixon, S.M.C. Smith, W.P. Ball, J.O. Bash, R. Batiuk, et al. 2021. "The Chesapeake Bay Program Modeling System: Overview and Recommendations for Future Development." *Ecological Modeling* **456**: 109635.

Web of Science® | Google Scholar

Howarth, R.W. 2008. "Coastal Nitrogen Pollution: A Review of Sources and Trends Globally and Regionally." *Harmful Algae* **8** (1): 14–20.

CAS | Web of Science® | Google Scholar

Keiser, D.A., and J.S. Shapiro. 2019. "Consequences of the Clean Water Act and the Demand for Water Quality." *Quarterly Journal of Economics* **134** (1): 349–96.

Web of Science® | Google Scholar

Kleinman, P., R. Fanelli, B. Hirsch, A.R. Buda, Z.M. Easton, L. Wainger, C. Brosch, et al. 2019. "Phosphorus and the Chesapeake Bay — Lingering Issues and Emerging Concerns for Agriculture." *Journal of Environmental Quality* **48**: 1191–203.

CAS | PubMed | Web of Science® | Google Scholar

Kling, C.L. 2013. "State Level Efforts to Regulate Agricultural Nonpoint Sources of Water Quality Impairment." *Choices* **28** (3): 1–4.

Google Scholar

Diffuse Nutrient Pollution: Wicked Problems across Urban and Agricultural Watershed." *Environmental Science & Technology*. https://doi.org/10.1021/acs.est.9b07511.

PubMed | Web of Science® | Google Scholar

Maille, P., A.R. Collins, and N. Gillies. 2009. "Performance-Based Payments for Water Quality: Experiences from a Field Experiment." *Journal of Soil and Water Conservation* **64** (3): 85A–87A.

Web of Science® | Google Scholar

Natural Resource Conservation Service. 2021. " Chesapeake Bay Watershed Initiative." https://www.nrcs.usda.gov/Internet/NRCS_RCA/reports/fb08_cp_cbwi.html https://www.nrcs.usda.gov/Internet/NRCS_RCA/reports/cp_nat.html.

Google Scholar

Northey, H. 2021. " Chesapeake Bay Farmers Facing Cleanup Deadline Seek USDA Boost." *E&E News*, September 20.

Google Scholar

OECD. 2017. *Diffuse Pollution, Degraded Waters: Emerging Policy Solutions*. Paris: OECD Studies on Water, OECD Publishing. https://doi.org/10.1787/9789264269064-en.

Google Scholar

Osmond, D., D. Meals, D. Hoag, M. Arabi, A. Luloff, G. Jennings, M. McFarland, J. Spooner, A. Sharpley, and D. Line. 2012. "Improving Conservation Practices Programming to Protect Water Quality in Agricultural Watersheds: Lessons Learned from the National Institute of Food and Agriculture–Conservation Effects Assessment Project." *Journal of Soil and Water Conservation* **67** (5): 122A–27A.

Web of Science® | Google Scholar

Pannell, D.J., and R. Classen. 2020. "The Roles of Adoption and Behavior Change in Agricultural Policy." *Applied Economic Perspectives and Policy* **42** (1): 31–41.

Web of Science® | Google Scholar

September 3, 2024
Clean Water Organizations Comments Exhibit 33

Back

Web of Science® Google Scholar

Price, E., T. H. Fleming, and L. Wainger. 2021. " Cost Analysis of Stormwater and Agricultural Practices for Reducing Nitrogen and Phosphorus Runoff in Maryland." Maryland Center for Environmental Science, Report number: TS-772-21. https://doi.org/10.13140/RG.2.2.28896.74246/1.

Google Scholar

Ribaudo, M. 2001. " Non-Point Source Pollution Control Policy in the USA." In *Environmental Policies for Agricultural Pollution Control*, edited by J.S. Shortle and D. Abler, 123–50. New York: CABI Publishing.

Google Scholar

Ribaudo, M. 2015. "The Limits to Voluntary Conservation Programs." *Choices* **30** (2): 1–5.

Google Scholar

Ribaudo, M., and J. Shortle. 2019. "Reflections on 40 Years of Applied Economics Research on Agriculture and Water Quality." *Agricultural and Resource Economics Review* **48** (3): 519–30.

Web of Science® Google Scholar

Rose, J., S. Bricker, S. Deonarine, J.G. Ferreira, T. Getchis, J. Grant, J.K. Kim, et al. 2015. *Nutrient Bioextraction*. New York: Encyclopedia of Sustainability Science and Technology, Springer.

Google Scholar

Segerson, K. 2013. "When is Reliance on Voluntary Approaches in Agriculture Likely to Be Effective?" *Applied Economic Perspectives and Policy* **35** (4): 565–92.

Web of Science® Google Scholar

Shabman, L., B. Rose, and K. Stephenson. 2011. "Environmental Services Programs for the Chesapeake Bay." *Choices* **26** (3).

Google Scholar

Back

Web of Science® | Google Scholar

Shortle, J.S., M. Ollikainen, and A. Iho. 2021. *Water Quality and Agriculture: Economics and Policy for Agricultural Nonpoint Source Water Pollution*. Cham: Springer Nature.

Google Scholar

Shortle, J.S., M. Ribaudo, R.D. Horan, and D. Blandford. 2012. "Reforming Agricultural Nonpoint Pollution Policy in an Increasingly Budget-Constrained Environment." *Environmental Science & Technology* **46** (3): 1316–25.

CAS | PubMed | Web of Science® | Google Scholar

Sprague, L.A., R.M. Hirsch, and B.T. Aulenbach. 2011. "Nitrate in the Mississippi River and its Tributaries, 1980 to 2008: Are we Making Progress?" *Environmental Science and Technology* **45** (17): 7209–16.

CAS | PubMed | Web of Science® | Google Scholar

Stephenson, K., W. Ferris, E. Bock, and Z. Easton. 2021. "Treatment of Legacy Nitrogen as a Compliance Option to Meet Chesapeake Bay TMDL Requirements." *Environmental Science and Technology* **55** (20): 13593–601.

CAS | PubMed | Web of Science® | Google Scholar

Stephenson, K., C. Hershner, B. Benham, Z.M. Easton, J. Hanson, S. Julius, and E. Hinrichs. 2018. " Consideration of BMP Performance Uncertainty in Chesapeake bay Program Implementation." STAC Publication Number 18-003, Edgewater, MD, 33 pp.

Google Scholar

Stephenson, K., and L. Shabman. 2017. "Nutrient Assimilation Services for Water Quality Credit Trading Programs: A Comparative Analysis with Nonpoint Source Credits." *Coastal Management* **45** (1): 24–43.

Web of Science® | Google Scholar

USEPA (U.S. Environmental Protection Agency). 2017. " National Water Quality Inventory: Report to Congress." EPA 841-R-16-011.

Citing Literature

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Groundwater quality

pca.state.mn.us/air-water-land-climate/groundwater-quality

1. Air, Water, Land, Climate
2. Water
3. Water quality

Image

Groundwater is the source of drinking water for about 75% of all Minnesotans and provides almost all of the water used to irrigate crops. Groundwater in parts of the central and southwestern regions of the state is contaminated with high nitrate concentrations from agriculture and, to a lesser extent, failing septic systems. Nitrate levels are higher in groundwater under agricultural land than water below urban areas. Groundwater availability in Minnesota varies by region. It is more difficult to access in the northeast, when it's available at all, and is scarce in some areas of the southwest.

Overall conditions

- The quality of groundwater varies around the state. Even within an aquifer, the quality can change at different depths. Near-surface groundwater in areas of high urban density or intensive agriculture is more likely to be contaminated by chloride or nitrate.
- The overuse of groundwater threatens surface water quality, and draws contaminated near-surface water into our drinking water aquifers.

Current regulations and voluntary best management practices will not be sufficient to maintain healthy groundwater and shield contaminated wells and aquifers from additional pollution. Even if all existing laws were followed to the letter, groundwater would still be subject to unacceptable levels of nutrients and other contaminants. Targeted action will be required to cut off unregulated sources of pollution.

Northeast Minnesota

Availability issues. Higher volume supplies of groundwater can be difficult to obtain in the northeast, compared to the central part of the state.

Central region

- **Availability good.** Groundwater is available throughout this region in volumes sufficient to satisfy residential use.
- **Nitrate pollution.** About 40 percent of the shallow wells (less than 30 feet deep) in the central region have higher nitrate concentrations than the EPA allows for drinking water.

Metro area and the southeast

- **Availability issues.** Though this region has multiple aquifers, groundwater availability is threatened by high consumption in the Twin Cities metro area.
- **Chloride pollution.** Groundwater in the Twin Cities metro area shows high concentrations of chloride.
- **Nitrate pollution.** Most of the sand and gravel aquifers in southern Minnesota have nitrate concentrations that exceed EPA guidelines for human health.

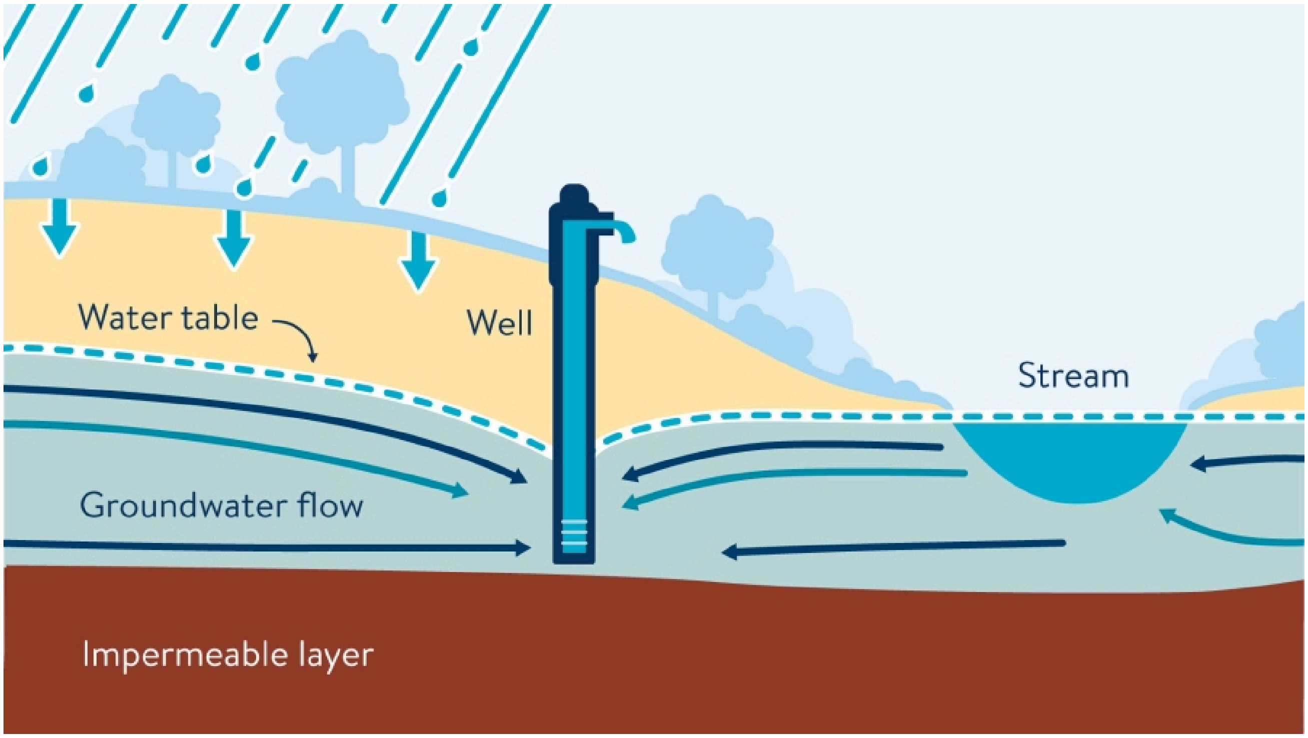
Western and southwestern Minnesota

Nitrate pollution. About 20 percent of the monitored shallow wells in the southwestern region have nitrate concentrations higher than the EPA allows for drinking water.

How groundwater affects surface water

Groundwater contamination and diminishing water levels in the ground can affect bodies of water on the surface. Groundwater feeds surface waters and helps maintain water levels during droughts. If groundwater is being used up and the water level in a stream goes down as a result, the pollutants in the stream will be concentrated, doing greater environmental damage.

The low water levels in Little Rock Creek north of St. Cloud illustrate how groundwater interacts with surface water. Heavy groundwater pumping in the area contributes to low stream flows in the summer, killing off fish. Downstream at Little Rock Lake, low water and excess nutrients cause massive summer algae blooms. The local soil and water conservation district is working with farmers on irrigation management strategies that will use less groundwater.



BEFORE THE
UNITED STATES ENVIRONMENTAL PROTECTION AGENCY

Petition for Emergency Action Pursuant to the Safe Drinking Water Act, 42 U.S.C. § 300i, to Protect the Citizens of the Karst Region of Minnesota from Imminent and Substantial Endangerment to Public Health Caused By Nitrate Contamination of Underground Sources of Drinking Water.	EPA Docket No. ____________ April 24, 2023

Submitted on Behalf of Petitioners
Minnesota Center for Environmental Advocacy,
Environmental Working Group,
Minnesota Well Owners Organization,
Center for Food Safety,
Clean Up the River Environment,
Food & Water Watch,
Friends of the Mississippi River,
Izaak Walton League Minnesota Division
Land Stewardship Project,
Minnesota Trout Unlimited,
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I. Introduction

Petitioners respectfully petition the U.S. Environmental Protection Agency (EPA) to exercise its emergency powers established in Section 1431 of the Safe Drinking Water Act (SDWA), 42 U.S.C. § 300i, to address groundwater contamination that presents an imminent and substantial endangerment to the health of residents in southeastern Minnesota. Like many other parts of the Nation plagued by pollution from industrial agriculture, the residents in southeastern Minnesota are suffering from drinking water contamination. As detailed in this Petition, this region has an extensive and well-documented history of nitrate contamination in its underground sources of drinking water, which continues to put the health of residents at risk. The EPA must act now to address this too-long ignored health crisis and ensure clean drinking water for Minnesotans.

Southeastern Minnesota is particularly vulnerable to groundwater pollution due to its karst geography. According to the Minnesota Pollution Control Agency (MPCA):

> Southeastern Minnesota is characterized by an unusual type of geography called karst. It features rolling hills, hollows, caves, sinkholes, and dramatic bluffs and valleys. In karst landscapes, the distinction between groundwater and surface water is blurry. . . . [C]ontaminated surface water can easily become groundwater pollution, and pose a health risk to those using it for drinking.[1]

The "karst region" of southeastern Minnesota is depicted in Figure 1 below.[2]

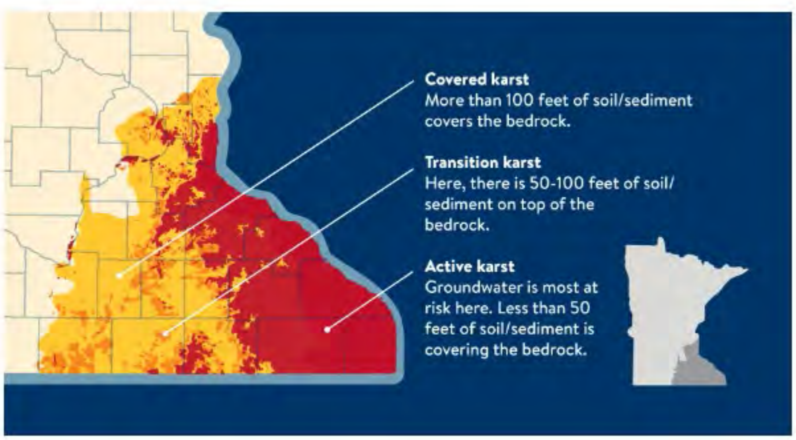

Figure 1: Minnesota's Karst Region
Based on a map created by E. Calvin Alexander, Jr., Yongli Gao, and Jeff Green

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[1] *Protecting water in karst regions*, MINN. POLLUTION CONTROL AGENCY, https://www.pca.state.mn.us/air-water-land-climate/protecting-water-in-karst-regions (last visited Apr. 13, 2023).
[2] *Id.*

The karst region[3] is a predominantly rural area of the State where many people rely on private wells, rather than public water supplies, for their drinking water.[4] All drinking water in this region—public and private—comes from groundwater aquifers. The population of the eight counties comprising this region is 380,513.[5] About 300,000 people in this area rely on community water systems while the remaining 80,000 use wells.[6] It is important to note that the populations more likely to be affected by nitrate contamination are people living in small towns, who are dependent on community water systems and private wells and who are also more likely to be of lower income.[7] The karst region of Minnesota is a community overburdened by pollution. The Administrator has called on EPA to strengthen the enforcement of cornerstone environmental statutes in these communities.[8]

This Petition is based on data that have been compiled by the Minnesota Department of Agriculture (MDA), the Minnesota Department of Health (MDH), the Minnesota Pollution Control Agency (MPCA), the Minnesota Department of Natural Resources (MDNR), Petitioner Minnesota Well Owners Organization, and Petitioner Environmental Working Group. The data demonstrate that nitrate concentrations in

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[3] The karst region does not follow county lines, but for purposes of data analysis, this Petition uses the eight counties of Dodge, Fillmore, Goodhue, Houston, Mower, Olmsted, Wabasha, and Winona as a substitute. These counties are all fully within what is considered the karst region.

[4] For information on community water systems in Minnesota that rely on groundwater *see Interactive Map: Community Water Systems*, MINN. DEP'T OF HEALTH, https://mndatamaps.web.health.state.mn.us/interactive/cwss.html (last visited Apr. 13, 2023). For further data on private wells in Minnesota, *see Minnesota Well Index*, MINN. DEP'T OF HEALTH, https://mnwellindex.web.health.state.mn.us/# (last visited Apr. 13, 2023).

[5] *See Minnesota Demographics*, CUBIT PLANNING, https://www.minnesota-demographics.com/counties_by_population (last visited Apr. 13, 2023).

[6] The population served by each community water system in the eight-county region system can be determined by clicking on MDH's water system map, *see Interactive Map: Community Water Systems*, MINN. DEP'T OF HEALTH, https://mndatamaps.web.health.state.mn.us/interactive/cwss.html (last visited Apr. 13, 2023).

[7] *Tap Water for 500,000 Minnesotans Contaminated With Elevated Levels of Nitrate*, ENV'T WORKING GRP. (Jan. 14, 2020), https://www.ewg.org/interactive-maps/2020_nitrate_in_minnesota_drinking_water_from_groundwater_sources/ [hereinafter EWG Tap Water Report]; *see also Interactive Maps: Poverty in Minnesota counties*, MINN. DEP'T OF HEALTH, https://mndatamaps.web.health.state.mn.us/interactive/poverty.html (last visited Apr. 14, 2023).

[8] Memorandum from Lawrence E. Starfield, Acting Assistant Adm'r of U.S. EPA, on Strengthening Enf't in Communities with Env't Just. Concerns to Office of Enf't and Compliance Assurance (Apr. 30, 2021), https://www.epa.gov/sites/default/files/2021-04/documents/strengtheningenforcementincommunitieswithejconcerns.pdf.

public water systems and underground sources of drinking water routinely exceed federal and state drinking water standards, putting the health of area residents at serious risk.

As explained in this Petition, the well-documented nitrate contamination of drinking water in the karst region necessitates prompt and decisive EPA emergency action under the SDWA. Elevated levels of nitrate in drinking water are known to increase the risk of a wide range of very serious health problems, including birth defects, blue-baby syndrome, various cancers, thyroid disease, and other maladies. This contamination poses an imminent and substantial threat to human health, and the problem is not getting any better.

Despite Minnesota applying for and being granted "primacy" under the SDWA, state and local officials have failed to do what is needed to correct the pervasive threat to human health. The data confirm that past voluntary measures employed by the State have been unsuccessful at reducing nitrate concentrations in crucial drinking water sources to below federal and state standards. EPA is fully empowered under the SDWA to take emergency action to protect human health in the karst region of Minnesota given present circumstances.

Because of its landscape features, groundwater quality in the karst region is largely driven by land use practices, and land use in this region is dominated by industrial row crop agriculture and feedlots. Petitioners request that EPA act to protect human health and effectuate the goals of the SDWA in the karst region of Minnesota through an investigation focused on the agricultural land uses that are most likely driving the contamination of drinking water resources. Specifically, Petitioners request that EPA issue orders, as necessary, to protect the health of people who use the drinking water, including, at a minimum, orders that require responsible contaminators to provide a free and safe alternative source of drinking water for impacted communities; orders that prohibit concentrated animal feeding operations (CAFOs) from expanding or constructing new operations until nitrate concentrations fall below unsafe levels; public notice of potential contamination events, such as manure land applications; an investigation to determine the specific entities and land use practices causing the contamination; a survey to identify public water systems, private supply wells, or ground water monitoring wells near potentially contaminated areas; monitoring of contaminants; control of the source of contaminants; and cleanup of contaminated soils endangering underground sources of drinking water. Petitioners further request that EPA seek injunctions through civil actions, as needed, to return the area's underground aquifers to a safe and drinkable condition.

II. Interests of Petitioners

Minnesota Center for Environmental Advocacy (MCEA) is a nonprofit environmental advocacy organization with offices in St. Paul and Duluth, Minnesota.

Since 1974, MCEA has defended Minnesota's natural resources, water, air and climate, and the health and welfare of Minnesotans. MCEA is driven by the principle that everyone has a right to a clean and healthy environment, and that decisions must be based on fact, science, and the law.

Environmental Working Group (EWG) is a nonprofit, nonpartisan organization that empowers people to live healthier lives in a healthier environment. For 30 years, EWG has harnessed its signature blend of research, advocacy, and unique educational tools to drive consumer choice and inspire civic action.

Minnesota Well Owners Organization (MNWOO) is a statewide nonprofit with a mission to help ensure safe drinking for Minnesota private well users who depend on groundwater for their private water systems and wells. MNWOO works with well users and partners with other non-governmental organizations, and local and state government units to build individual and community values for the protection, enhancement, and restoration of Minnesota groundwater through outreach, education, and advocacy. MNWOO's goal is to conduct free water quality screening clinics and provide professional help to connect and activate the community of well owners, land managers, water managers, and policy makers who steward Minnesota's groundwater. MNWOO seeks to remove the threats to safe drinking water on a foundation of accurate, up-to-date, and practical information that addresses the personal, community, economic, technical, legal, and policy barriers faced by private well owners seeking safe drinking water. MNWOO works to motivate private well owners and decision makers to take the individual and collective steps necessary to assure safe drinking water from all private wells for future generations.

Center for Food Safety (CFS) is a nonprofit environmental advocacy organization that aims to empower people and protect the environment from the harmful effects of industrial agriculture, including groundwater contamination from the concentration of industrial animal operations and their waste. CFS represents over a million members and supporters across the country, including over 9,000 members in Minnesota. CFS uses education, science-based advocacy, and litigation to address the negative environmental and public health effects of industrial agriculture.

Clean Up the River Environment (CURE) is a rural Minnesota nonprofit organization headquartered in the Minnesota River valley. CURE's mission is to protect and restore resilient rural landscapes and build vibrant, just, and equitable rural communities. CURE embodies three core practices: (1) awakening people's bonds with the natural world around them; (2) inclusively, strategically, and dialectically exploring issues and actions; and (3) systematically building communities of change at critical intersections of ecological and social wellbeing. Among CURE's values and guiding principles are that the capacity of communities to flourish is directly connected to the condition of the landscapes that embrace them; a moral responsibility to future generations to be good stewards of the ecosystems in which they live; and the human use of natural resources can be regenerative and a sustainable force. CURE, with its rural roots, is aware that the Dakota and Ojibwe Nations and other rural communities, already culturally, socially, and politically marginalized, are often most impacted by climate change, clean water scarcity, and environmental degradation. While local control is important to CURE, it is equally important that there is accountability to all Minnesotans and to future generations. Because rural communities are frontline communities when it comes to pollution from industrial agriculture, CURE requests that EPA exercise its broad emergency powers, per the SDWA, to address groundwater contamination in southeastern Minnesota. Too often industrial agriculture is given a pass on protections for our land and water, putting profits over people. CURE asks EPA to step in and be a voice for those communities impacted by groundwater contamination.

Food & Water Watch (FWW) is a national, nonprofit membership organization that mobilizes regular people to build political power to move bold and uncompromised solutions to the most pressing food, water, and climate problems of our time. FWW uses grassroots organizing, media outreach, public education, research, policy analysis, and litigation to protect people's health, communities, and democracy from the growing destructive power of the most powerful economic interests. FWW has long advocated for stronger regulation of factory farm pollution and industrial agribusiness to protect farmers, rural communities, and the environment.

Friends of the Mississippi River (FMR) engages people to protect, restore and enhance the Mississippi River and its watershed in the Twin Cities region. FMR's water quality and drinking water protection work focuses on addressing agricultural contamination of surface water and groundwater with a goal of ensuring all Minnesotans have access to clean, safe, and healthy waters.

For over 100 years, the Izaak Walton League has fought for clean air and water, healthy fish and wildlife habitat, and conserving special places for future generations. It was the first conservation organization with a mass membership. Today, the League plays a unique role in supporting citizens locally and shaping conservation policy nationwide. The League is a grass roots member organization that has led efforts for clean water legislation achieving initial success with the passage of federal water pollution acts in 1948, 1956 and finally the Clean Water Act of 1972. The League continues to advocate for preserving wetlands, protecting wilderness, and promoting soil and water conservation. Its Save Our Streams (SOS) program involves activists in all fifty states in monitoring water quality. The Minnesota Division of the Izaak Walton League of America is composed of 16 chapters located throughout the state of Minnesota. The League's broader mission is to conserve, restore, and promote the sustainable use and enjoyment of our natural resources, including soil, air, woods, waters, and wildlife. More specifically in regard to groundwater, by a resolution passed at the 1988 Annual Meeting, the Division went on record pointing out the need for better protection and management of the state's groundwater. While some protections have been put in place at the state level, it is clear that these have been inadequate. Greater federal protections are urgently needed.

Land Stewardship Project (LSP) is a private, nonprofit organization founded in 1982 to foster an ethic of stewardship for farmland, to promote sustainable agriculture, and to develop healthy communities. LSP is dedicated to creating transformational change in our food and farming system. LSP's work has a broad and deep impact, from new farmer training and local organizing to federal policy and community-based food systems development. At the core of all of LSP's work are the values of stewardship, justice, and democracy.

Minnesota Trout Unlimited (MNTU) is a nonprofit, nonpartisan conservation organization working to protect, restore, and sustain the watersheds and groundwater sources that support coldwater fisheries. For more than 60 years our members have advocated for clean water, both for recreational benefits and drinking. Minnesota trout streams are protected as Class 1 drinking water sources due to their close connection to groundwater. Nitrate contamination of southeast Minnesota groundwater and trout streams not only harms humans, but also the aquatic organisms on which these ecosystems depend. MNTU's several thousand Minnesota members regularly fish southeast streams and drink the water drawn from area aquifers.

Public Health Law Center (PHLC) is a nonprofit law and policy organization working to advance equitable public health policies through the power of law. For over 20 years, PHLC has fought to regulate and eliminate commercial tobacco, promote healthy food, support physical activity, and improve environmental health as a means of reducing chronic disease. PHLC partners with Tribal health leaders, federal agencies, health advocacy organizations, state and local governments, and many others to combat systems of institutional racism and create healthier communities across the country.

III. Legal Background

A. Safe Drinking Water Act

Congress enacted the SDWA as a powerful tool for protecting drinking water resources throughout the United States. Under the Act, EPA may delegate duties to state authorities to develop policies, regulations, and programs to ensure access to safe drinking water. On the federal level, the SDWA "requires EPA to protect the public from . . . drinking water contaminants."[9]

[9] *City of Portland v. Env't Prot. Agency*, 507 F.3d 706, 709 (D.C. Cir. 2007).

States may apply for, and EPA may delegate, "primacy" to states, which shifts significant authority and responsibility to state officials to implement the SDWA.[10] To assume primacy, the state is supposed to adopt regulations at least as stringent as EPA's national requirements, develop adequate procedures for enforcement and levying penalties, conduct inventories of water systems, maintain records and compliance data, and develop a plan for providing safe drinking water under emergency conditions.[11] While a state granted primacy has responsibility to implement the SDWA's provisions in that state, EPA retains emergency powers under Section 1431 of the SDWA to take actions necessary to abate imminent and substantial endangerment to the health of persons caused by drinking water contamination when state officials have failed to effectively do so on their own.

B. EPA's Emergency Powers

For EPA to exercise its Section 1431 authority, two conditions must be met. First, EPA must have received "information that a contaminant which is present in or likely to enter a public water system or an underground source of drinking water . . . may present an imminent and substantial endangerment to the health of persons."[12] Second, EPA must have received information that "appropriate State and local authorities have not acted to protect the health of such persons" in a timely and effective manner.[13]

1. Contaminant

The SDWA defines a contaminant as "any physical, chemical, biological, or radiological substance or matter in water."[14] While this broad definition does not require a substance to be regulated under the Act in order to be classified as a "contaminant," nitrate is listed as a contaminant with an established maximum contaminate level (MCL) of 10 mg/L.[15] An MCL is the "maximum permissible level of a contaminant in water which is delivered to any user of a public water system."[16] MCLs are promulgated after a determination by EPA based on the best available, peer-reviewed science and data that the regulation of the contaminant will reduce a threat to public health.[17] Establishing

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[10] 42 U.S.C. § 300g-2; 40 C.F.R. §§ 142.10–142.19 (primacy enforcement responsibility).
[11] ELENA H. HUMPHREYS & MARY TIEMANN, CONG. RES. SERV., RL31243, SAFE DRINKING WATER ACT (SDWA): A SUMMARY OF THE ACT & ITS MAJOR REQUIREMENTS 7 (2021), https://sgp.fas.org/crs/misc/RL31243.pdf.
[12] 42 U.S.C. § 300i; *see also* U.S. ENV'T PROT. AGENCY, UPDATED GUIDANCE ON EMERGENCY AUTHORITY UNDER SECTION 1431 OF THE SDWA 8 (2018) [hereinafter EMERGENCY AUTHORITY GUIDANCE].
[13] 42 U.S.C. § 300i; *see also* EMERGENCY AUTHORITY GUIDANCE, *supra* note 12, at 12-13.
[14] 42 U.S.C. § 300f(6).
[15] 40 C.F.R. § 141.62(b).
[16] 42 U.S.C. § 300f(3).
[17] 42 U.S.C. §§ 300g-l(b)(1)(A), (b)(3)(A).

nationwide, health-based MCLs is central to EPA's role in protecting drinking water under the SDWA.[18]

The MCL for nitrate was set at 10 mg/L to protect against blue-baby syndrome; however, recent studies have shown that even lower levels of nitrate can cause other health effects, including cancer and reproductive harm.[19] For example, recent studies have found statistically significant increased risks of colorectal cancer at drinking water levels far below the current MCL of 10 mg/L.[20]

2. Imminent & Substantial Endangerment

An endangerment from a contaminant is "imminent" if conditions that give rise to it are present, even if the actual harm may not be realized for years.[21] Courts have established that an "imminent hazard" may be declared at any point in a chain of events that may ultimately result in harm to the public.[22] Information presented to EPA need not demonstrate that residents are actually drinking contaminated water and becoming ill to warrant EPA exercising its Section 1431 emergency authority.[23] In other words, an actual injury need not have occurred for EPA to act, and to wait for such actual injury to befall the public would be counter to the precautionary intent behind the SDWA. Thus, while the threat or risk of harm must be "imminent" for EPA to act, actual and documented harm itself need not be.[24] While endangerments are readily determined to be imminent where MCL violations expose sensitive populations to a contaminant, contaminants that lead to chronic health effects may also cause "imminent endangerment."[25] In such cases, it is appropriate to consider the length of time a population has been or could be exposed to a contaminant.[26]

An endangerment is "substantial" "if there is a reasonable cause for concern that someone may be exposed to a risk of harm."[27] For instance, Congress has deemed an

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[18] 42 U.S.C. § 300g-1(b)(4)(B).

[19] *See, e.g.,* Mary. H. Ward et al., *Drinking Water Nitrate and Human Health: An Updated Review*, 15 INT'L J. ENV'T RSCH. & PUB. HEALTH 1557 (2018); Alexis Temkin et al., *Exposure-Based Assessment and Economic Valuation of Adverse Birth Outcomes and Cancer Risk Due to Nitrate in United States Drinking Water*, 176 ENV'T RSCH. 108442 (2019).

[20] *See, e.g.,* Jorg Schullehner et al., *Nitrate in Drinking Water and Colorectal Cancer Risk: A Nationwide Population-Based Cohort Study*, 143 INT'L J. CANCER 73 (2018).

[21] EMERGENCY AUTHORITY GUIDANCE, *supra* note 12, at 8 (citing *United States v. Conservation Chem. Co.*, 619 F. Supp. 162, 193-94 (W.D. Mo. 1985)).

[22] *Id.* n.15 (citing cases).

[23] *See Trinity Am. Corp. v. Env't Prot. Agency*, 150 F.3d 389, 399 (4th Cir. 1998).

[24] EMERGENCY AUTHORITY GUIDANCE, *supra* note 12, at 8.

[25] *Id.*

[26] *Id.*

[27] *Id.* at 11.

endangerment sufficiently substantial where a substantial likelihood exists that contaminants capable of causing adverse health effects will be ingested by consumers if preventative action is not taken.[28] As with imminence, EPA has made clear that actual reports of human illness resulting from contaminated drinking water are not necessary to establish substantial endangerment.[29]

C. Minnesota's Authority

Minnesota has several state agencies with jurisdiction over the quality of underground sources of drinking water: MDH, MDA, and MPCA are the primary ones. The graphic below shows the differing roles of these agencies.[30]

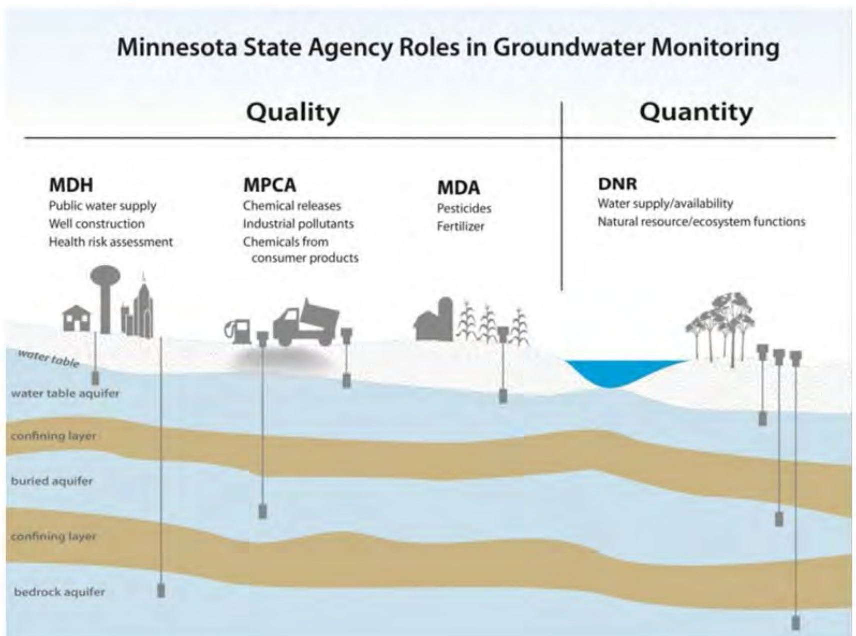

Figure 2: Agency Roles in Groundwater

[28] *See* H.R. REP. NO. 93-1185, at 35-36 (1974).

[29] *See* EMERGENCY AUTHORITY GUIDANCE, *supra* note 12, at 11 (citing *United States v. North Adams*, 777 F. Supp. 61, 84 (D. Mass. 1991)).

[30] SHARON KROENING & SOPHIA VAUGHAN, MINN. POLLUTION CONTROL AGENCY, CONDITIONS OF MINNESOTA'S GROUNDWATER QUALITY 2013-2017, 4 (2019), https://www.pca.state.mn.us/sites/default/files/wq-am1-10.pdf [hereinafter MPCA GROUNDWATER QUALITY 2013-2017]. The graphic also depicts the MDNR, which controls water appropriation and has a role in agricultural drainage projects that affect public waters. MDNR also conducts some groundwater monitoring as part of is County Geologic Atlas program.

The MDH administers the Minnesota Well Code for the construction of new wells and borings[31] and Minnesota's SDWA.[32] EPA granted Minnesota primacy under the federal SDWA in 1976.[33] Although the SDWA allows states to set higher standards than the federal minimum, Minnesota state law sets the drinking water quality standard for nitrate at the same level as the federal standard: 10 mg/L.[34] Public water systems with nitrate levels over 10 mg/L must notify people who receive water from them.[35]

The MPCA's authority extends to discharges from point sources under its water pollution control laws.[36] Point sources include animal feeding operations, which, as discussed below, are a significant contributor of nitrate pollution to groundwater in the karst region. The MPCA regulates animal feeding operations with more than 1,000 animal units through the issuance of National Pollution Discharge Elimination System (NPDES) permits,[37] but smaller farms are unregulated. Finally, the MDA has statutory authority under the Minnesota Groundwater Protection Rule to regulate the use of pesticides and commercial fertilizer.[38]

D. EPA's Authority in Minnesota

Despite Minnesota's primacy under the SDWA, EPA retains emergency powers to abate present or likely contamination of public water systems (PWS) or underground sources of drinking water (USDW) when such contamination poses an imminent and substantial threat to human health and the state "ha[s] not acted to protect the health of [endangered] persons."[39]

EPA's Section 1431 authority extends to contaminated USDW and PWS that pose a threat to human health,[40] including sources that supply private wells.[41] EPA defines USDW as an aquifer or part of an aquifer "(1) [w]hich supplies any public water systems; or (2) which contains a sufficient quantity of ground water to supply a public water system; and (i) currently supplies drinking water for human consumption."[42] PWS are

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31 MINN. R. 4725.0500–4725.7605.
32 MINN. STAT. §§ 144.381–144.387.
33 MINN. DEP'T OF HEALTH, MINNESOTA DRINKING WATER ANNUAL REPORT FOR 2021 2 (2022), https://www.health.state.mn.us/communities/environment/water/docs/report21.pdf.
34 MINN. R. 4720.0350 (adopting national standards by reference).
35 MINN. STAT. § 144.385.
36 MINN. STAT. § 115.03.
37 MINN. R. 7020.2003, subp. 2(B).
38 MINN. STAT. § 103H.275; MINN. R. 1573.0010–1573.0090.
39 42 U.S.C. § 300i(a).
40 *Id.*
41 EMERGENCY AUTHORITY GUIDANCE, *supra* note 12, at 7-8.
42 40 C.F.R. § 144.3.

aquifers that provide water for human consumption and "ha[ve] at least fifteen service connections or regularly serve[] at least twenty-five individuals."[43] The drinking water for the hundreds of thousands of residents of the karst region of Minnesota comes from either private or community wells that rely on groundwater. The underground aquifers that supply these wells therefore qualify as USDW and PWS within the purview of the SDWA.

To abate endangerment to human health that arises despite a state's efforts to curtail it, Congress authorized EPA to, among other things, issue "such orders as may be necessary to protect the health of persons who are or may be users of" the affected drinking water supplies and to commence civil enforcement actions against entities causing threats to public health by contaminating drinking water supplies.[44] Petitioners ask EPA to use that authority here.

IV. Drinking Water Contamination in the Karst Region Constitutes an Endangerment under the SDWA and Necessitates Emergency Action by EPA

Nitrate contamination in Minnesota's karst region is a widespread issue that has stubbornly persisted through decades as state officials continuously fail to effectively address the problem. "Nitrate contamination of surface water and groundwater is a long-standing issue in the region. Impacts to municipal and private drinking water supplies by nitrate are widespread and well-documented."[45] According to MPCA, "[t]rends from the past 10, 20, and 40 years show that statewide . . . nitrate concentrations have generally been increasing."[46] Figure 3 is a MPCA graphic which shows that there are no areas of the state where nitrate trends in surface water have decreased between 2008 and 2017.[47] The main contributors to this problem are large-scale animal agriculture facilities and industrial row-crop agriculture which dominate land use within the area and that are not effectively addressed by existing regulations and policies promoting voluntary actions.

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[43] 42 U.S.C. § 300f(4)(A).
[44] EMERGENCY AUTHORITY GUIDANCE, *supra* note 12, at Attach. 2.
[45] ANTHONY C. RUNKEL ET AL., GEOLOGIC CONTROLS ON GROUNDWATER AND SURFACE WATER FLOW IN SOUTHEASTERN MINNESOTA AND ITS IMPACT ON NITRATE CONCENTRATIONS IN STREAMS, MINN. GEOLOGIC SURV., 4 (2013) [hereinafter RUNKEL 2013].
[46] DAVE WALL ET AL., MINN. POLLUTION CONTROL AGENCY, 5-YEAR PROGRESS REPORT ON MINNESOTA'S NUTRIENT REDUCTION STRATEGY 17 (2020), https://www.lrl.mn.gov/docs/2021/other/210420.pdf [hereinafter 5-YEAR PROGRESS REPORT].
[47] *Id.*

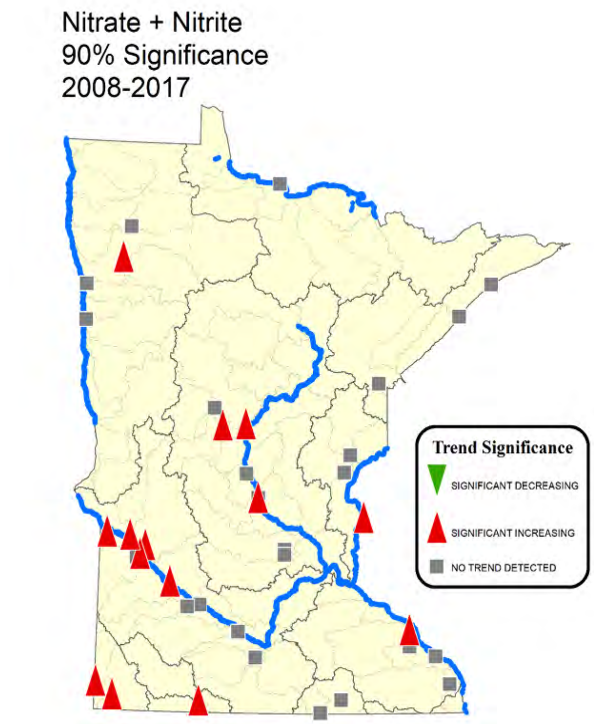

Figure 3: 5-year Progress on Nitrate

Emergency action by EPA is necessary to address the dangerous levels of nitrate in the karst region because the contamination poses an imminent and substantial risk to the health of more than 380,000 residents who rely on groundwater, and because Minnesota officials have failed to improve drinking water quality, despite knowing about the problem, for over 40 years.[48]

A. The Karst Region is Particularly Susceptible to Nitrate Pollution

Groundwater in the karst region is vulnerable to contamination because of the fluid interaction between groundwater and surface water. The rapid movement of water in and out of the ground in this region leaves a blurry distinction between groundwater and surface water that is compounded by Minnesota's multi-agency approach to drinking water policies, regulation, and funding. Specific karst features such as stream sinks and sinkholes that inject water into the ground and the springs that discharge groundwater to the surface are depicted in Figure 4.[49] "[N]ot only does karst aquifer groundwater flow rapidly (flows have been measured in miles per day versus the inches, or feet, per year common to sandstones), but contaminants in the groundwater are not

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[48] 5-YEAR PROGRESS REPORT, *supra* note 46, at 17.

[49] RUNKEL 2013, *supra* note 45, at Fig. 3.

readily filtered out. As a result, contaminants can reach domestic wells located miles from the source of contamination."[50]

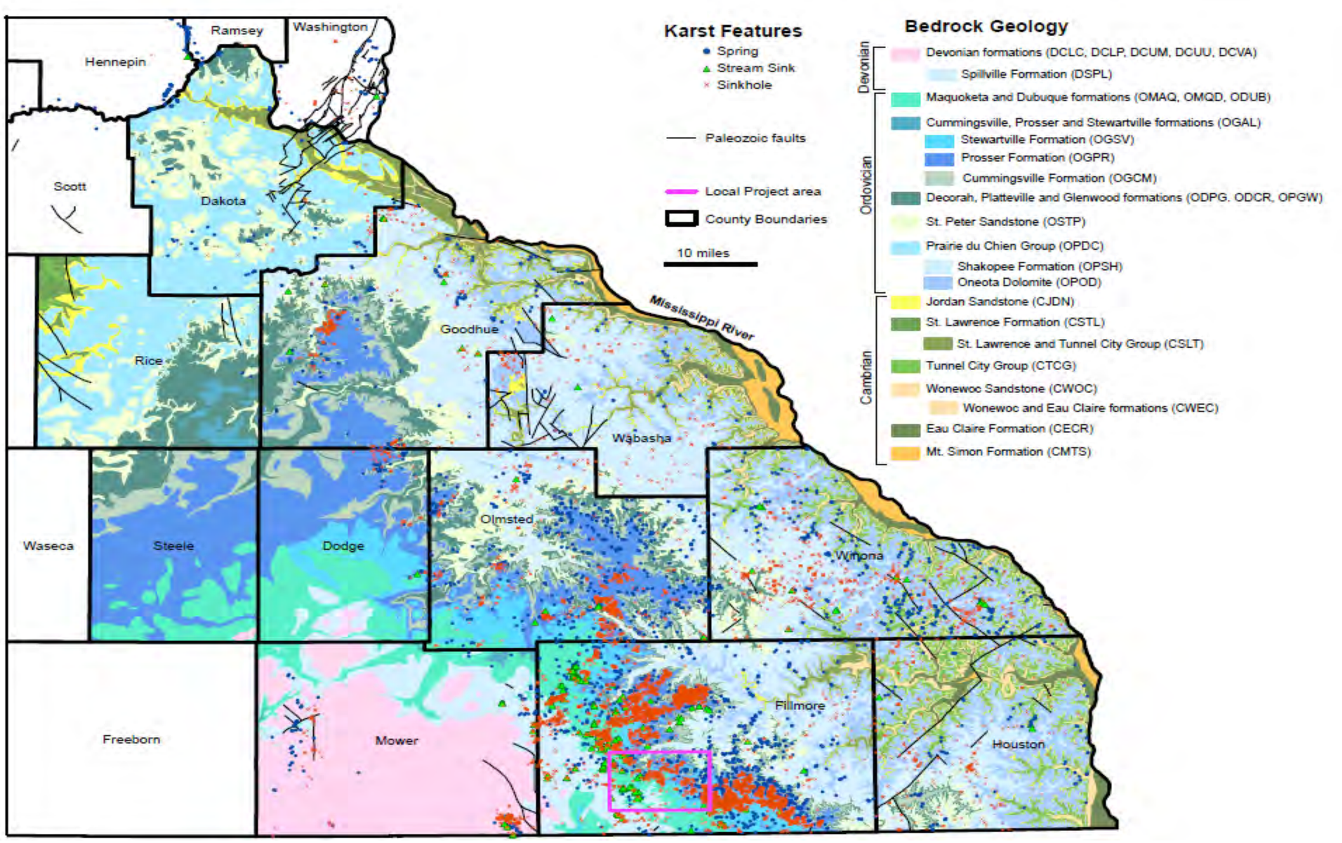

Figure 4: Karst Features

Nitrate pollution is particularly troublesome because nitrate is mobile in groundwater.[51] Nitrate mobility in karst regions can be largely determined by rainfall frequency and intensity.

Recent research indicates that up to 80% of nitrate loading in karst regions can be traced to fertilizers that are quickly flushed from soils into the karst and groundwater

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[50] JEFFREY ST. ORES ET AL., GROUNDWATER POLLUTION PREVENTION IN SOUTHEAST MINNESOTA'S KARST REGION, 465 UNIV. OF MINN. EXTENSION BULL. 6 (1982), https://conservancy.umn.edu/bitstream/handle/11299/169069/mn_2000_eb_465.pdf?sequence=1 [hereinafter ORES 1982].

[51] MINN. POLLUTION CONTROL AGENCY, EFFECTS OF LIQUID MANURE STORAGE SYSTEM ON GROUNDWATER QUALITY 3 (2001), https://www.pca.state.mn.us/sites/default/files/rpt-liquidmanurestorage.pdf.

systems during rain events.[52] Water carries the excess nitrogen from fertilizers on the surface through the soil column and into the fractured karst bedrock, where oxygenated conditions facilitate conversion of nitrogen to nitrate.[53] Combining nitrogen intensive land uses with the karst region's heightened vulnerability to nitrate contamination is a major hazard.

As a result, "[g]roundwater in uppermost bedrock units, especially on the karstic plateaus that dominate the landscape of southeastern Minnesota, is typically nitrate-enriched, with concentrations commonly between 5-15 ppm."[54] Rural communities are particularly at risk since private wells are more likely to draw from shallow aquifers than public water systems, which can pull water from deeper wells and multiple sources.[55]

Minnesota officials have been aware of the vulnerability of this region for at least 80 years. "S.P. Kingston, a former Minnesota health official, noted in 1943 that the regional groundwater system in southeast Minnesota is particularly vulnerable to contamination from many sources."[56] And nitrate was identified as one of the contaminants of concern as early as 1982: "Many shallow wells in southeast Minnesota contain coliform bacteria and high nitrate levels—both indicators of possible contamination."[57] The evidence of nitrate contamination in the groundwater of this region is robust.

B. The Karst Region Has a Documented History of Nitrate Contamination

The karst region has an extensive history with nitrate contamination in groundwater aquifers. Although nitrate is a naturally occurring substance, the presence of nitrate in groundwater at concentrations above 3 parts per million or milligrams per liter is not natural and indicates an anthropogenic source of the nitrate.[58]

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[52] Fu-Jun Yue et al., *Rainfall and Conduit Drainage Combine to Accelerate Nitrate Loss from a Karst Agroecosystem: Insights from a Stable Isotope Tracing and High-Frequency Nitrate Sensing*, 186 WATER RSCH. 116388 (2020), https://doi.org/10.1016/j.watres.2020.116388.
[53] PHILIP MONSON, MINN. POLLUTION CONTROL AGENCY, AQUATIC LIFE WATER QUALITY STANDARDS DRAFT TECHNICAL SUPPORT DOCUMENT FOR NITRATE 1 (2022), https://www.pca.state.mn.us/sites/default/files/wq-s6-13.pdf.
[54] RUNKEL 2013, *supra* note 45, at 59.
[55] *Learn About Private Water Wells*, ENV'T PROT. AGENCY (Mar. 1, 2023), https://www.epa.gov/privatewells/learn-about-private-water-wells.
[56] ORES 1982, *supra* note 50, at 3.
[57] *Id.*
[58] *Nitrate in Drinking Water*, MINN. DEP'T OF HEALTH (DEC. 8, 2022), https://www.health.state.mn.us/communities/environment/water/contaminants/nitrate.html.

Regular sampling of wells to detect nitrate began over 30 years ago. Fifty-five wells in Winona County were first sampled in 1990 and 1991.[59] Twenty-five of the well samples were taken from the shallower Prairie du Chien aquifer and 30 were from the deeper Jordan aquifer. "Nitrate concentrations exceeded the 10 mg/l drinking water standard in 48 percent of Prairie du Chien wells and 3.2 percent of Jordan wells."[60] Fifteen to thirty years later, nothing had improved: testing data from wells sampled between 2005 to 2017 revealed that 49% of wells in agricultural areas of the state, installed near the water table, exceeded the MCL for nitrate.[61]

Petitioners present a compilation of data in this Petition that shows nitrate contamination in private wells in the karst region. The data were compiled by Petitioners EWG and MNWOO. In 2020, EWG used data from the Township Testing Program[62] conducted by MDA, a Volunteer Nitrate Monitoring Network,[63] and new well tests required by MDH since the Well Code was adopted in 1975.[64] EWG used the data to create an interactive map showing nitrate contamination by township.[65] The Township Testing Program sampled and analyzed over 32,000 private wells between 2017 and 2020. The Volunteer Nitrate Monitoring Network in the karst region began in 2008 with a network of 675 private drinking water wells. "Between February 2008 and August 2018, 13 sampling events occurred representing 5,421 samples."[66] And MDH provided EWG with location data and test results for each of the 45,598 wells sampled between 2009 and 2018.[67] Finally, MNWOO hosts well testing clinics that allow homeowners to test their

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[59] David B. Wall & Charles P. Regan, *Water Quality and Sensitivity of the Prairie du Chien-Jordan Aquifer in West-Central Winona County*, MINN. POLLUTION CONTROL AGENCY, ES1 (1991).
[60] *Id*.
[61] MPCA GROUNDWATER QUALITY 2013-2017, *supra* note 30, at 2, 15.
[62] MINN. DEP'T AGRIC., TOWNSHIP TESTING PROGRAM UPDATE - MAY 2022 (2022), https://www.mda.state.mn.us/sites/default/files/docs/2022-05/ttpupdate2022_05.pdf (hereinafter TOWNSHIP TESTING UPDATE 2022).
[63] MINN. DEP'T OF HEALTH, VOLUNTEER NITRATE MONITORING NETWORK: METHODS AND RESULTS (2012), https://www.health.state.mn.us/communities/environment/water/docs/swp/no3methods.pdf.
[64] MINN. R. 4725.0500–4725.7605.
[65] *Interactive Map: Nitrate in Minnesota Private Drinking Water from Groundwater Sources (2009-2018)*, ENV'T WORKING GRP., https://www.ewg.org/interactive-maps/2020_nitrate_in_minnesota_private_drinking_water_from_groundwater_sources/map/ (last visited Apr. 17, 2023).
[66] KIM KAISER ET AL., MINN. DEP'T OF AGRIC., NITRATE RESULTS AND TRENDS IN PRIVATE WELL MONITORING NETWORKS 2008-2018 2 (2019), https://wrl.mnpals.net/islandora/object/WRLrepository%3A3395/datastream/PDF/view.
[67] EWG Tap Water Report, *supra* note 7, at Methodology.

well water for nitrates and chlorides at no cost. MNWOO provided data from 119 different wells, from at least 24 townships from five counties in the karst region. To date, these data points do not appear in any other public record. The karst-region-specific data from these combined sources are depicted in Figure 5.

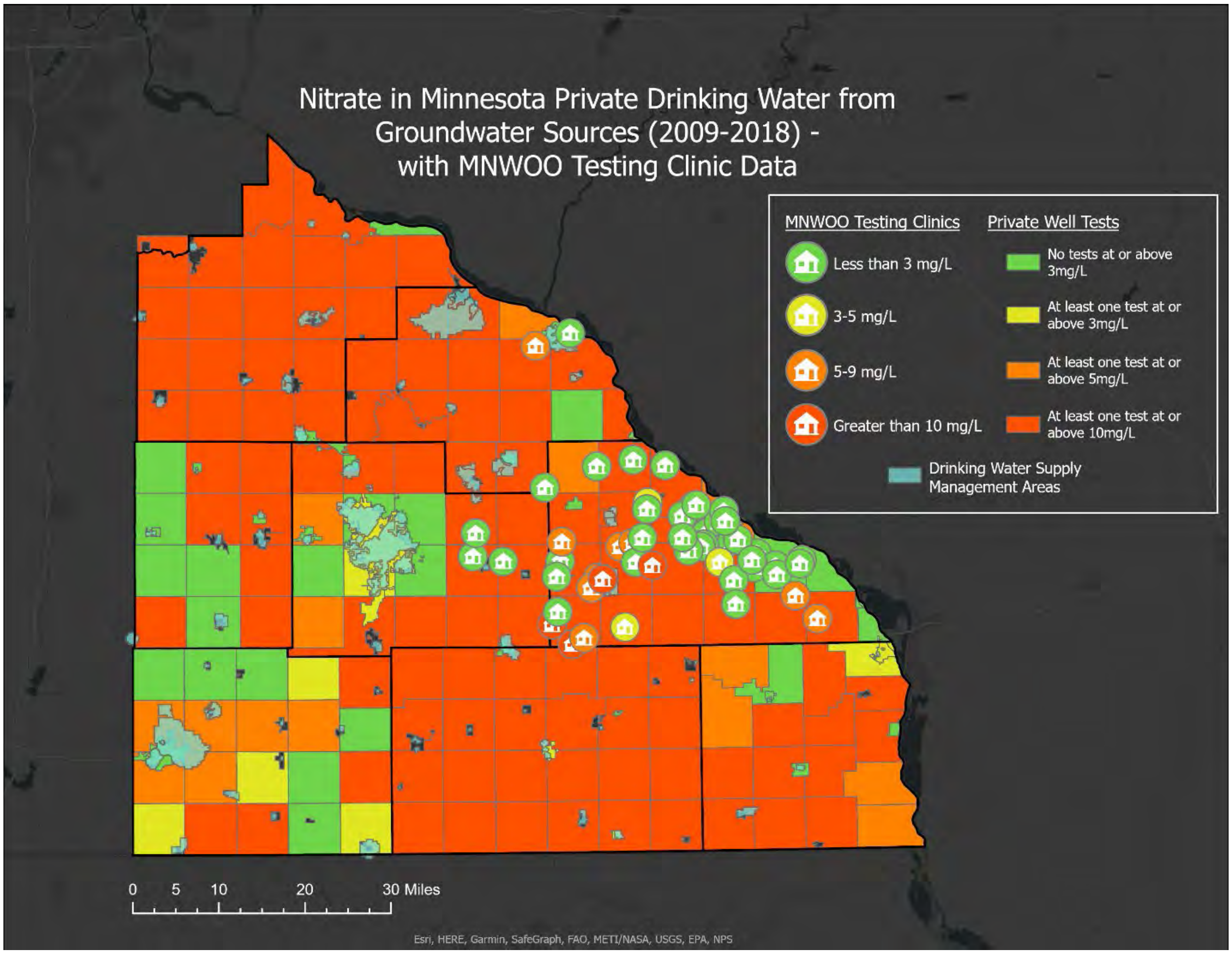

Figure 5: Private Well Contamination
Data from Township Testing Program, Southeast Volunteer Monitoring Network, MDH Well Index, and MNWOO clinic

Approximately 9% of the wells tested during the initial round of the Township Testing Program were found to have samples that exceeded the MCL for nitrate of 10mg/l. The multiple rounds of sampling and analysis also found a maximum nitrate concentration of 69.8 mg/L. The percentage of wells tested between 2008 and 2018 in the Volunteer Nitrate Monitoring Network (VNMN) above 10 mg/l ranged from a low of 7.5% in 2012 to a high of 14.6% in 2008. More recent data from the VNMN show that (among continuing participants) nitrate contamination continues: In 2019, 9% of wells tested above 10 mg/l, in 2020 it was 9.4% and in 2021 it was 8.5%.[68] The MNWOO clinic conducted in the karst region in February 2023 showed a 6% rate of nitrate contamination above 10 mg/L.

Figure 5 also depicts the location of the wells in comparison to the Drinking Water Supply Management Areas (DWSMAs). DWSMAs are defined geographic areas around public water supply wells that represent a 10-year travel time for water to reach the well. These areas are used by MDH and local communities in developing Well Head Protection Areas and are the geographic limitation for MDA's ability to protect groundwater under the Groundwater Protection Rule from commercial fertilizers and pesticides. As figure 5 demonstrates, many of the private wells in this region fall outside of a protected DWSMA. EPA needs to step in to afford private well owners protection against nitrate contamination.

It is also important to note that despite the additional protection available to protect PWS, many community water supplies with 25 or more connections to a well and many transient community water supplies like churches, campgrounds, and businesses in the area, are also affected by nitrate contamination. Petitioner EWG has also compiled Minnesota well testing data into an interactive map for public water systems,[69] and presents a karst-specific version of that map in Figure 6.

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[68] *Southeast Minnesota Volunteer Monitoring Network*, MINN. DEP'T OF AGRIC., https://www.mda.state.mn.us/southeast-minnesota-volunteer-nitrate-monitoring-network (last visited Apr. 17, 2023).

[69] *Interactive Map: Nitrate in Minnesota Public Drinking Water from Groundwater Sources (2009-2018)*, ENV'T WORKING GRP., https://www.ewg.org/interactive-maps/2020_nitrate_in_minnesota_public_drinking_water_from_groundwater_sources/map/ (last visited Apr. 17, 2023).

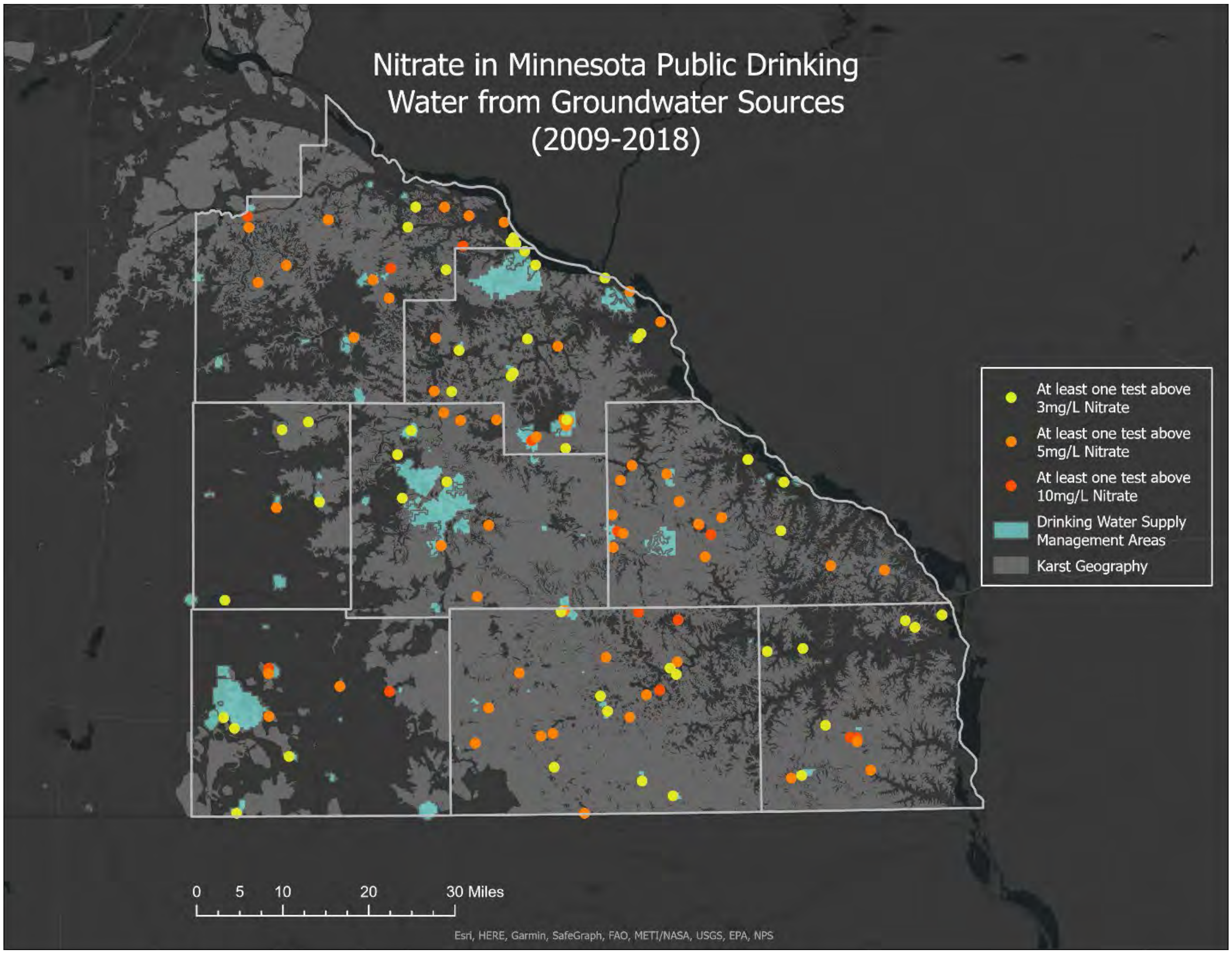

Figure 6: Public Drinking Water Contamination

In its 2020 analysis, EWG determined that groundwater-derived drinking water for an estimated 150,000 Minnesotans is contaminated with nitrate at levels over the legal limit. For 4,178 Minnesotans, the level is more than double the legal limit.[70] Cities in the karst region have long struggled with high nitrate concentrations in their drinking water. For example, the city of Lewiston has dug multiple deeper wells to try to eradicate nitrate from the city's water at a cost of approximately $1 million per well.[71] Had the city pursued a treatment system, the cost would have risen to $3.1 million, and doubled water rates for residents.[72]

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70 EWG Tap Water Report, *supra* note 7.

71 Elizabeth Baier, *Even in Region with Abundant Water, Residents Turn to Bottles and Try to Conserve*, MPR NEWS (Mar. 20, 2014), https://www.mprnews.org/story/2014/03/20/ground-level-beneath-the-surface-southeast-minnesota.

72 *Id.*

As another example, the city of Utica has two city wells, but as shown in the graph below, one well has been exceeding the 10 mg/L MCL since 2003 and is now for emergency use only. The other well, drilled in the late 1970s, began with a nitrate concentration of 3.9 mg/L, but that concentration has been steadily increasing and was as high as 8.6 mg/l in 2019.

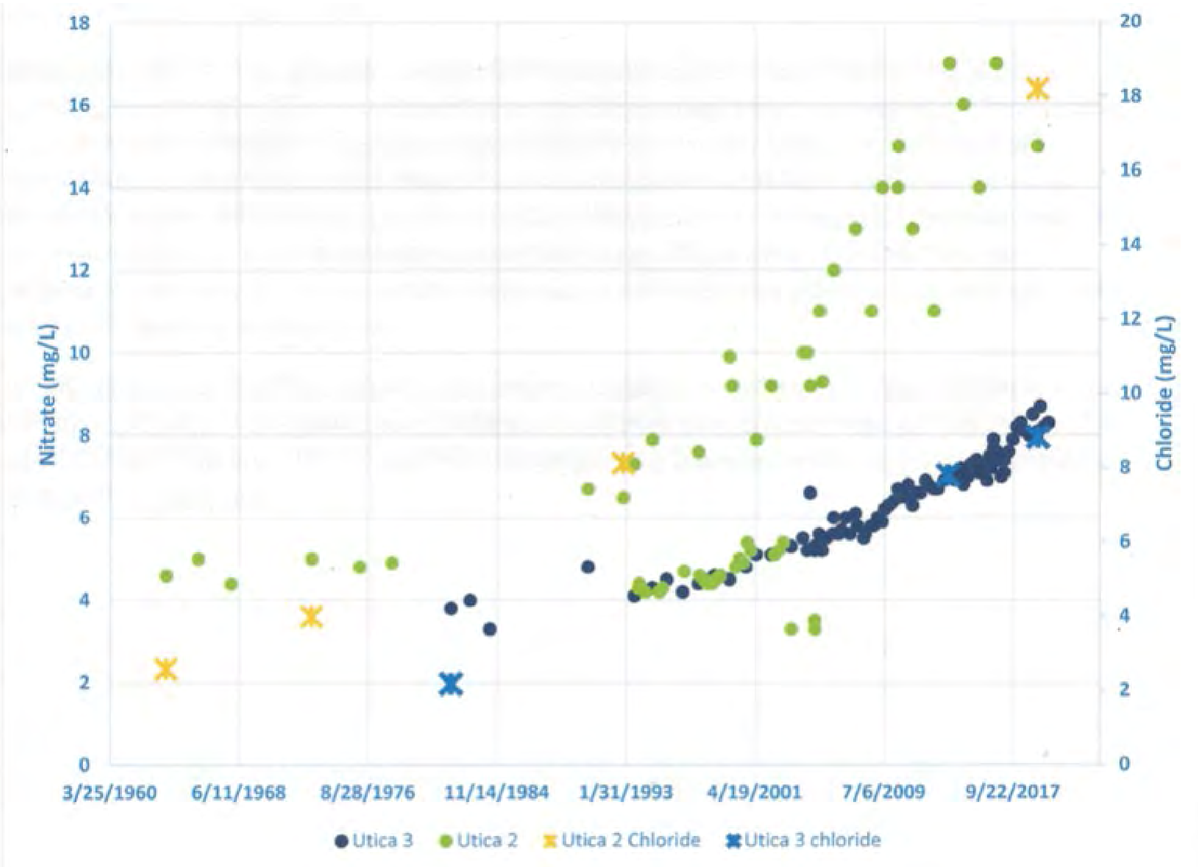

Figure 7: Utica City Well Contamination
Data from Minnesota Geological Survey

C. Under-Regulated Animal Feeding Operations and Industrial Row Crop Agriculture Are Dominant Land Use Activities and the Predominant Causes of Nitrate Contamination in the Karst Region

Most nitrate contamination in the karst region is caused by harmful agricultural practices on groundwater recharge areas that are not sufficiently addressed by Minnesota regulators. Despite evidence of adverse impacts on groundwater and public health caused by manure storage, the excessive or poorly timed application of manure, and animal feeding operations under MPCA, industrial row-crop agriculture under MDA, or the wellhead protections under MDH, Minnesota has had inadequate state and local regulation for decades, resulting in a public health crisis that requires emergency action from EPA. The root cause of this pollution is public policy that makes polluting actions cheaper and easier than sustainable practices. The vast majority of farmers care deeply about stewardship of the land, but our policies do not reflect that same stewardship.

1. Animal Agriculture

Within the boundaries of Houston, Fillmore, Mower, Dodge, Olmsted, Wabasha, Winona, and Goodhue counties, there are currently approximately 3,170 animal feedlot operations that are required to register with MPCA's Feedlot program, with more added every year.[73] In addition, as depicted in the map below, many more feedlots are located in this area that fall below the number of animal units that require a permit or registration.

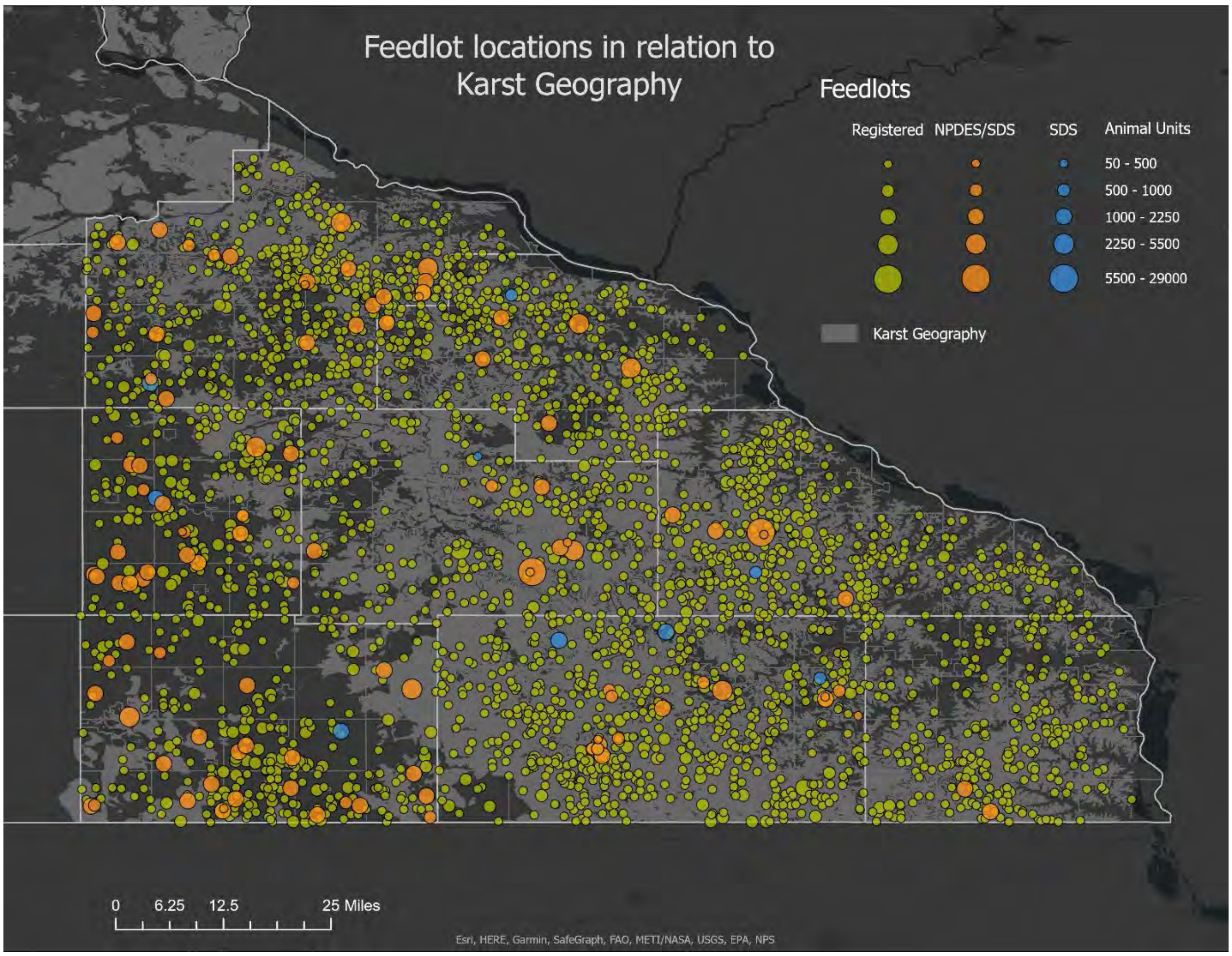

Figure 8: Karst Region Feedlots
Data from MPCA's Feedlots in Minnesota Database

[73] *Counties Delegated to Administer the MPCA Feedlot Program,* MINN. POLLUTION CONTROL AGENCY (Apr. 2022), https://www.pca.state.mn.us/sites/default/files/wq-f1-12.pdf.

The counties that are subject to this Petition house approximately 500,000 dairy cow and cattle animal units and another 260,000 swine units.[74] And the number of feeding operations statewide is on the rise.[75] Current feeding operations also continue to grow: in February 2023, the Fillmore County Board of Commissioners voted unanimously to increase the county's animal unit cap from 2,000 to 4,000 animal units per feedlot.[76] Moreover, almost 65% of the cattle units and over 37% of the swine units are located within landscapes designated as prone to surface karst feature development by MDNR. Those numbers jump to 96% and 69% respectively if we look at facilities within one mile of areas prone to the development of surface karst features.[77]

The storage structures designed to contain millions of gallons of liquid manure, manure piles, and feedlot runoff, can also be significant sources of nitrogen to groundwater in this area.[78] Manure storage structures that are constructed in compliance with National Resource Conservation Service (NRCS) standards are actually designed to leak. According to the NRCS handbook, "properly" constructed lagoons can leak up to 5,000 gallons of manure wastewater per acre per day.[79] In one study conducted by MPCA, "[t]here was evidence of shallow ground water contamination down-gradient of manure storage areas at each [feedlot operation]."[80]

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[74] *Feedlots in Minnesota*, MINN. GEOSPATIAL COMMONS, https://gisdata.mn.gov/dataset/env-feedlots (last visited Apr. 17, 2023).
[75] Sarah Porter & Craig Cox, *Manure Overload: Manure Plus Fertilizer Overwhelms Minnesota's Land and Water*, ENV'T WORKING GRP. (May 28, 2020), https://www.ewg.org/interactive-maps/2020-manure-overload/ [hereinafter *Manure Overload*].
[76] Brian Todd, *Fillmore County doubles its animal unit cap for feedlots*, AGWEEK (Mar. 1, 2023), https://www.agweek.com/news/policy/fillmore-county-doubles-its-animal-unit-cap-for-feedlots.
[77] *Minnesota Regions Prone to Surface Karst Feature Development*, MINN. GEOSPATIAL COMMONS, https://gisdata.mn.gov/dataset/geos-surface-karst-feature-devel (last visited Apr. 17, 2023).
[78] MINN. POLLUTION CONTROL AGENCY, EFFECTS OF LIQUID MANURE STORAGE SYSTEMS ON GROUND WATER QUALITY–SUMMARY REPORT (2001), https://www.pca.state.mn.us/sites/default/files/rpt-liquidmanurestorage-summary.pdf.
[79] U.S. DEP'T OF AGRIC. NAT. RES. CONSERVATION SERV., AGRICULTURAL WASTE MANAGEMENT FIELD HANDBOOK, CHAPTER 10: AGRICULTURAL WASTE MANAGEMENT SYSTEM COMPONENT DESIGN App. 10D-16 (2009), https://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=31529.wba ("NRCS guidance considers an acceptable initial seepage rate to be 5,000 gallons per acre per day.").
[80] MINN. POLLUTION CONTROL AGENCY, EFFECTS OF LIQUID MANURE STORAGE SYSTEMS ON GROUND WATER QUALITY–SUMMARY REPORT 2 (2001), https://www.pca.state.mn.us/sites/default/files/rpt-liquidmanurestorage-summary.pdf.

In addition to the manure storage structures themselves, manure from livestock operations in the karst region is commonly used as fertilizer for row crops in the area. When liquified manure storage systems reach capacity, operators must empty them, often by disposing of the liquified manure and process wastewater onto nearby agricultural fields, regardless of the season. These land applications of manure are one of the largest sources of nitrogen from animal feeding operations.[81]

The karst region includes a number of townships, such as Utica and Fremont, that have sandy soils derived from sandstone bedrock. Applications of manure to sandy soils at high agronomic rates leave nitrogen in the soil after the growing season, which then leaches into the groundwater as nitrate, endangering public health.[82] The townships with the highest percentages of private wells exceeding 10 mg/L nitrate concentration have sandy soils or thin soils over karst.

2. Industrial Agriculture

Another major contributor to the nitrate contamination is widespread industrial agriculture in the region. In the eight-county area, 73% of land cover is devoted to agriculture—60% is cropland and 13% is hay or pastureland.[83] This is a high concentration of agriculture for a sensitive karst landscape with a high sensitivity to groundwater contamination. In comparison, only 51% of Minnesota's land cover is devoted to agriculture statewide.[84] A significant portion of this southeastern Minnesota land is related to the animal agriculture in the region: it is used to grow feed crops for

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[81] *Estimated Animal Agriculture Nitrogen and Phosphorus from Manure*, ENV'T PROT. AGENCY (Jan. 11, 2023), https://www.epa.gov/nutrient-policy-data/estimated-animal-agriculture-nitrogen-and-phosphorus-manure.

[82] Michael J. Goss et al., *Chapter Five–A Review of the Use of Organic Amendments and the Risk to Human Health*, 120 ADVANCES IN AGRONOMY 275 (2013), https://doi.org/10.1016/B978-0-12-407686-0.00005-1 ("Spreading manure on the land in fall or winter results in smaller recovery of applied nitrogen by the crops, while the risk of surface runoff, leaching and denitrification is greater.") ("Leaching losses of labeled N from the manure application were considerably greater than those from the original fertilizer application in all years.").

[83] These percentages were calculated using the Multi-Resolution Land Characteristics National Land Cover Database Enhanced Visualization Analysis Tool, *see MRLC NLCD EVA Tool*, MRLC, https://www.mrlc.gov/eva/ (last visited Apr. 17, 2023).

[84] *Agricultural Lands*, MINN. BOARD OF WATER AND SOIL RES., https://bwsr.state.mn.us/agricultural-lands (last visited Apr. 17, 2023).

animals[85] and/or receives the application of manure and waste from the nearby CAFOs as fertilizer.

But much of this fertilizer is over-applied. EWG's modeling found that in 69 of Minnesota's 72 agricultural counties, nitrogen from manure combined with nitrogen in fertilizer exceeded the recommended agronomic rates of MPCA and the University of Minnesota.[86] EWG identified 13 counties in Minnesota where the percent of Nitrogen, from fertilizer and manure combined, was more than 150% of the recommended amount needed to maximize crop yields.[87] Five of these 13 counties are in the karst region.[88] The total estimated nitrogen overload in these five counties is 26,424 tons per year.[89]

The image below shows the coverage of corn and soybeans in the karst region along with average nitrate concentrations at areas near designated trout streams.[90]

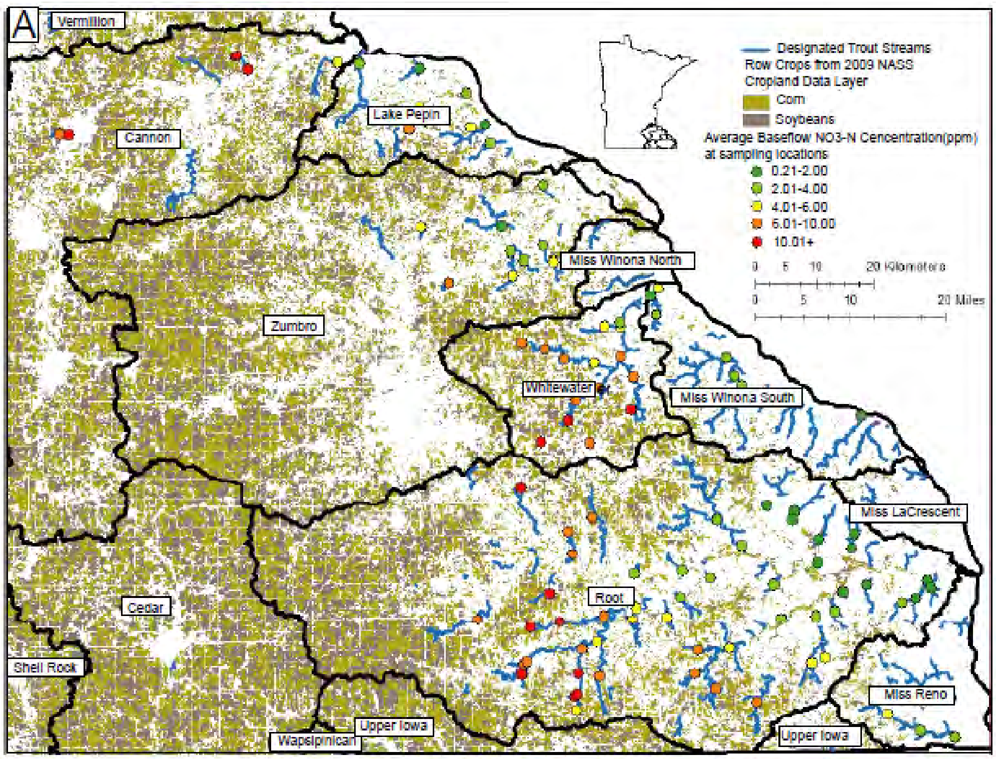

Figure 9: Industrial Agriculture and Nitrate-Contaminated Trout Streams

[85] Up to 40% of domestic corn use is allocated to livestock feed. *See Feed Grains Sector at a Glance*, U.S. DEP'T OF AGRIC., https://www.ers.usda.gov/topics/crops/corn-and-other-feed-grains/feed-grains-sector-at-a-glance/ (last visited Apr. 17, 2023).
[86] *Manure Overload*, *supra* note 75.
[87] *Id.*
[88] *Id.*
[89] *Id.*
[90] RUNKEL 2013, *supra* note 45, at Fig. 37.

The correlation between land used to grow exclusively corn and soybeans and nitrate pollution is well documented. In a 2020 report, researchers at MDA found that the mean nitrate concentration of lysimeters placed on cropland that was in a constant corn or corn-soybean rotation was 22.3 mg/L.[91] The figure below compares this to other land uses.

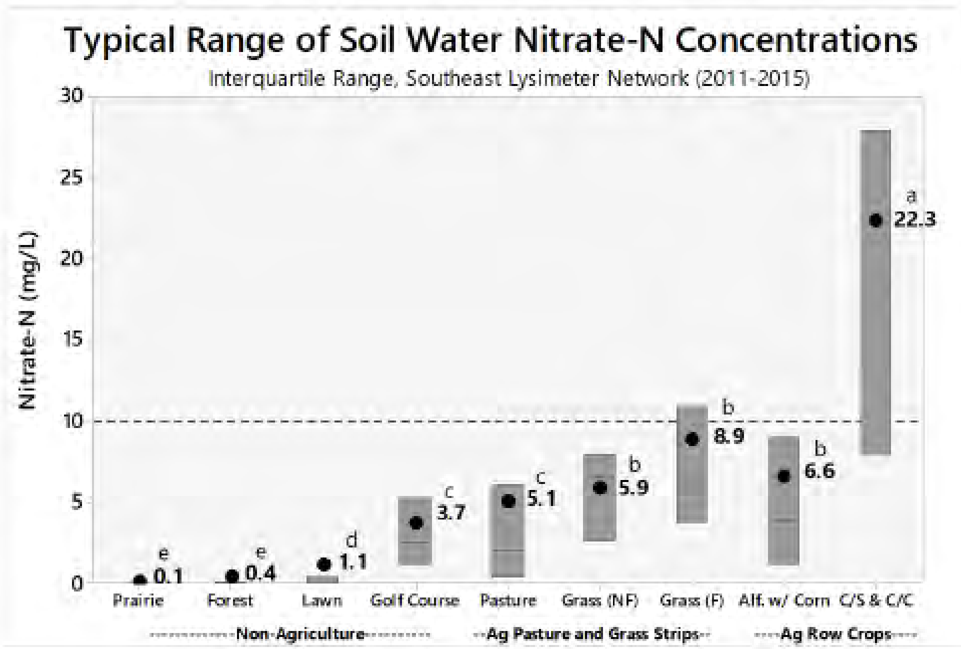

Figure 10: Land Cover and Nitrate Contamination

As Figure 10 demonstrates, industrial agricultural land suffers from significantly more contamination than other types of land uses generating a risk to both surface and groundwater.

D. Conditions in the Karst Region Constitute an Imminent and Substantial Endangerment to Human Health Under the SDWA

The current levels of nitrate in drinking water in the karst region present an imminent and substantial endangerment to human health because consumption of drinking water that is contaminated with nitrate is known to cause serious health risks. Given the thousands of individuals who rely on either contaminated private wells or

[91] KEVIN KUEHNER ET AL., MINN. DEP'T OF AGRIC., EXAMINATION OF SOIL WATER NITRATE-N CONCENTRATIONS FROM COMMON LAND COVERS AND CROPPING SYSTEMS IN SOUTHEAST MINNESOTA KARST 14 (2020), https://wrl.mnpals.net/islandora/object/WRLrepository%3A3654/datastream/PDF/view.

contaminated PWS for drinking water in this region, there is reasonable cause for concern that individuals are, and will be, exposed to this risk at unhealthy concentrations.

Nitrate is plainly an endangerment to public health under the SDWA because EPA not only categorizes it as a "contaminant,"[92] but as an "acute contaminant" known to pose significant health risks. According to EPA, "[n]itrate is an acute contaminant, meaning that one exposure can affect a person's health. Too much nitrate in your body makes it harder for red blood cells to carry oxygen."[93] EPA previously found that nitrate levels above the MCL of 10 mg/L present an imminent and substantial endangerment to human health.[94]

Nitrate is a particularly insidious contaminant because it is colorless, odorless, and tasteless, meaning that people do not have a way of identifying its presence in their drinking water without testing.[95] MNWOO reports that at their testing clinics across the state, many of the people with high nitrate tests were unaware of the contamination and reported that they liked the taste of their well water.

Additionally, boiling nitrate-laden drinking water, as is often done in preparation of baby formula, increases the nitrate concentration of the water because nitrates do not evaporate and become more concentrated in the formula.[96] Shallower aquifers are both more likely to be used for private wells and are more contaminated. For example, in the karst region, the Prairie du Chien aquifer is shallower and much more nitrate contaminated than the deeper Jordan aquifer.[97] But deep wells can also be contaminated. For example, the well on the farm of one of MNWOO's directors is a multi-aquifer well with a total depth of 400 feet, but the water from that well has exceed 13 mg/L nitrates for over 20 years.[98]

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[92] 40 C.F.R. § 141.62(b).

[93] *Frequently Asked Questions About Nitrates & Drinking Water*, ENV'T PROT. AGENCY (Sept. 2012), https://nepis.epa.gov/Exe/ZyPDF.cgi/P10150PM.PDF?Dockey=P10150PM.PDF.

[94] *See, e.g.*, Administrative Order on Consent, *In the Matter of Yakima Valley Dairies*, SDWA-10-2013-0080, at 7 (Mar. 19, 2013) (finding that "above the concentration of 10 mg/L in drinking water, nitrate may present an imminent and substantial endangerment to the health of persons"), https://www.epa.gov/sites/default/files/2017-12/documents/lower-yakima-valley-groundwater-consent-order-2013.pdf.

[95] *Nitrate in Drinking Water*, MINN. DEP'T OF HEALTH (Dec. 8, 2022), https://www.health.state.mn.us/communities/environment/water/contaminants/nitrate.html.

[96] *Frequently Asked Questions About Nitrates and Drinking Water*, ENV'T PROT. AGENCY (Sept. 2012), https://nepis.epa.gov/Exe/ZyPDF.cgi/P10150PM.PDF?Dockey=P10150PM.PDF.

[97] RUNKEL 2013, *supra* note 45, at 45.

[98] Jeffrey S. Broberg, MNWOO founder and board member, personal communication.

Drinking water contaminated with nitrate has well-documented adverse health risks including a variety of cancers, "blue-baby syndrome," and reproductive problems.[99] Childhood brain cancer has been linked to high nitrate levels in drinking water.[100] MDH also reports other potential health effects such as "increased heart rate, nausea, headaches, and abdominal cramps."[101] Nitrate in water supplies has also been linked to spontaneous miscarriages and birth defects.[102]

The numerous studies demonstrating that a contaminant known to cause disease and illness is present at unsafe levels in wells used by tens of thousands of residents proves an unambiguous SDWA "endangerment."

Because the present contamination of the region's drinking water and risk of significant adverse health effects from drinking contaminated water are both thoroughly documented, endangerment is clearly imminent. As explained above, endangerment is "imminent" if conditions that give rise to it are present, even if actual harm has not already been documented in the contaminated area. Unsafe levels of nitrate contamination in the karst region drinking water supply were first identified over 30 years ago,[103] and recent data trends indicate that nitrate contamination is continuing at a persistent—and harmful—level.[104]

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[99] *Nitrate in Drinking Water*, MINN. DEP'T OF HEALTH (DEC. 8, 2022), https://www.health.state.mn.us/communities/environment/water/contaminants/nitrate.html; N. BEAUDET ET AL., NITRATES, BLUE BABY SYNDROME, AND DRINKING WATER: A FACTSHEET FOR FAMILIES, PEDIATRIC ENV'T HEALTH SPECIALTY UNITS (2014), https://ldh.la.gov/assets/oph/Center-EH/envepi/PWI/Documents/PEHSU_Nitrates_Consumer_1.20.15 FINAL.pdf; Roberto Picetti et al., *Nitrate and Nitrate Contamination in Drinking Water and Cancer Risk: A Systematic Review with Meta-Analysis*, 210 ENV'T RSCH. 112988 (2022), https://www.sciencedirect.com/science/article/pii/S0013935122003152#bib109.

[100] A. Zumel-Marne et al., *Environmental Factors and the Risk of Brain Tumours in Young People: A Systematic Review*, 53 NEUROEPIDEMIOLOGY 121 (2019), https://www.karger.com/Article/Fulltext/500601?utm_source=external&utm_medium=referral&utm_campaign=getFTR; *see also*, Yanqi Xu, *Nebraska's Dirty Water,* THE READER (Oct. 28, 2022), https://thereader.com/2022/10/28/nebraskas-dirty-water/ ("Areas of the state that have higher pediatric cancer rates and birth defect rates also have higher nitrate levels, researchers say.").

[101] *Nitrate in Drinking Water*, MINN. DEP'T OF HEALTH (DEC. 8, 2022), https://www.health.state.mn.us/communities/environment/water/contaminants/nitrate.html.

[102] Allison R. Sherris et al., *Nitrate in Drinking Water during Pregnancy and Spontaneous Preterm Birth: A Retrospective Within-Mother Analysis in California*, 129 ENV'T HEALTH PERSPECTIVES, (2021), https://ehp.niehs.nih.gov/doi/full/10.1289/EHP8205.

[103] ORES 1982, *supra* note 50.

[104] TOWNSHIP TESTING UPDATE 2022, *supra* note 62.

The public health risks associated with nitrate contamination in the karst region constitute a "substantial" endangerment under the SDWA. According to EPA's updated guidance on SDWA emergency authority, an example of substantial endangerment is "a substantial likelihood that contaminants capable of causing adverse health effects will be ingested by consumers if preventative action is not taken."[105] Well sampling has consistently shown elevated nitrate levels in residential drinking water wells across the karst region. Thus, residents of the karst region have been, and continue to be, ingesting this contaminant. This alone demonstrates that the endangerment is substantial.

V. Minnesota Officials Have Failed to Achieve Safe Drinking Water Quality Despite Decades of Attempting to Implement Mitigation Plans

EPA should exercise its emergency authority under Section 1431 of the SDWA because users of USDW and PWSs in the karst region face imminent and substantial endangerment and actions by Minnesota officials have been ineffective. The chronology below describes state agencies' recognition of, and attempts to address, the substantial and imminent endangerment posed by nitrate pollution. The persistent contamination despite these efforts demonstrates their ineffectiveness.

Minnesota enacted the Groundwater Protection Act in 1989. It was based on a growing recognition of the vulnerability of Minnesota's groundwater resources.[106] In part, in was based on groundwater testing in the 1980s that showed nitrate levels exceeding the health limits in 40% of private wells tested and 7% of public wells.[107] It was followed closely by the development of the Nitrogen Fertilizer Management Plan by MDA in 1990.[108] Neither of these initiatives resulted in effective protection of Minnesota's groundwater resources from nitrate pollution, as evidenced by the persistent contamination of private and public water supplies at or above the health risk limit.[109] In 2010, MDA began the process of revising the Nitrogen Fertilizer Management Plan.[110] The updated Nitrogen Fertilizer Management Plan was finalized by MDA in 2015 and led to the Township Testing Program discussed above. One of the objectives for the Township Testing Program was to better grasp the extent and severity of the nitrate

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105 EMERGENCY AUTHORITY GUIDANCE, *supra* note 12, at 11 (explaining that an endangerment is substantial "if there is a reasonable cause of concern that someone may be exposed to a risk of harm").
106 JOHN HELLAND, MINN. H.R. RSCH. DEP'T, A SURVEY OF THE GROUNDWATER ACT OF 1989, (2001), https://www.house.mn.gov/hrd/pubs/gdwtract.pdf.
107 *Id*.
108 MINN. DEP'T OF AGRIC., NITROGEN FERTILIZER MANAGEMENT PLAN (2015, addended July 2019), https://www.mda.state.mn.us/sites/default/files/2019-08/nfmp2015addendedada_0.pdf [hereinafter NITROGEN FERTILIZER MANAGEMENT PLAN].
109 JOHN HELLAND, MINN. H.R. RSCH. DEP'T, A SURVEY OF THE GROUNDWATER ACT OF 1989, (2001), https://www.house.mn.gov/hrd/pubs/gdwtract.pdf.
110 NITROGEN FERTILIZER MANAGEMENT PLAN, *supra* note 108, at ix.

contamination problem—which it did. These data were used to inform the development of the Groundwater Protection Rule, which was passed in 2019 but falls short of the regulatory response needed to address the issue for the reasons documented below.

Also in 2010, the Minnesota Legislature approved funds for MPCA to develop aquatic life water quality standards for nitrate, in recognition of the need to protect Minnesota's aquatic life from the toxic effects of high nitrate. In response, MPCA issued its Aquatic Life Water Quality Standards Technical Support Document for Nitrate, which recommended a chronic nitrate standard of 3.1 mg/L to be protective of aquatic life.[111] The MPCA did not adopt water quality standards for nitrate, however, and has continued to defer to that 2010 legislative mandate to this day.

In 2013, MPCA published a report titled "Nitrogen in Minnesota Surface Waters." The report documents the widespread extent of nitrate contamination in Minnesota's waters, noting that in southeastern Minnesota, there are several streams where "groundwater baseflow provides a continuous supply of high nitrate water to streams throughout the year."[112] In other words, MPCA recognized that the groundwater in this area is so polluted, it is polluting the surface water.

In 2014, eleven Minnesota organizations jointly published a Nutrient Reduction Strategy for nitrogen and phosphorous pollution, led by MPCA.[113] The goal was to ultimately reach Minnesota's state water quality goals and downstream impacts like eutrophication in the Gulf of Mexico. In 2020, MPCA issued its 5-year progress report, considering whether the 2014 Nutrient Reduction Strategy was successful. The progress report shows that while phosphorous concentration trends in Minnesota waterways have generally decreased over the past 10-20 years, nitrate concentration trends have increased—in some major rivers by 20-60%. The Progress Report identifies row crop agriculture as the largest source of nitrogen.

Even with overwhelming data and analysis showing the trends and the reasons for concern, more recent strategies have been similarly ineffective. In 2019, MDA finalized

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111 PHIL MONSON, MINN. POLLUTION CONTROL AGENCY, AQUATIC LIFE WATER QUALITY STANDARDS TECHNICAL SUPPORT DOCUMENT FOR NITRATE (2010), https://wrl.mnpals.net/islandora/object/WRLrepository%3A77. Although MPCA's regulatory focus has been on surface water, in the karst region the connection between surface and groundwater is so immediate, that surface water quality standards are highly relevant to protecting groundwater quality.

112 MINN. POLLUTION CONTROL AGENCY, NITROGEN IN MINNESOTA SURFACE WATERS 3 (2013), https://www.pca.state.mn.us/sites/default/files/wq-s6-26a.pdf.

113 MINN. POLLUTION CONTROL AGENCY, THE MINNESOTA NUTRIENT REDUCTION STRATEGY (2014), https://www.pca.state.mn.us/sites/default/files/wq-s1-80.pdf.

the Groundwater Protection Rule, which has several deficiencies.[114] For example, although fall application of commercial fertilizer is restricted in the karst region, as well as in identified DWSMAs, fall application of manure is not. There are other significant flaws in the rule that fail to adequately protect USDWs. First, the regulatory scope of the rule is limited to DWSMAs for community wells and provides no direct assessment or protection of private wells that fall inside a DWSMA and no assessment or protection for those outside of a DWSMA (see Figure 5 above). As both MCEA and MDH noted in comments on the Groundwater Protection Rule, the Rule should include a mitigation process for private wells and non-community public water supply wells that is equivalent to what it establishes for public water supplies.[115] Without this equitable approach, MDH notes that the rule "does not serve the public health needs of rural Minnesotans, many of whom already suffer inequities relative to public health outcomes."[116] Second, there can be a significant lag time from days to years from the initial contamination of groundwater or surface water from sources of nitrogen and the necessary action taken by the state agencies to address the source. The MDA has the general authority to issue penalties for violations of its rules through Minnesota Statutes 18D, but the Groundwater Protection Rule requires a monitoring period that can last decades before enforcement actions are taken.[117] Lastly, the rule only requires best management practices to be used once a water source reaches mitigation level 3 or 4 contamination and even then, MDA cannot require application rates below that recommended by the University of Minnesota's Extension Services. Since the Groundwater Protection Rule went into effect, none of the DWSMAs with elevated nitrates have been classified at mitigation level 3 or 4, and thirteen mitigation level decisions have been "delayed for good cause."[118] This means that thus far, the Rule continues to rely on voluntary approaches that have not remedied the problem over the last several decades.

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[114] Attached to this Petition as Exhibit A is Petitioner MCEA's Comment to MDA, which explains the deficiencies of the rule in greater detail.

[115] Ex. A; *see also* Minn. Dep't of Health Comment Letter on Proposed Minnesota Department of Agriculture Rules Governing Groundwater Protection, Add. 1 (Aug. 14, 2018), https://speakup-us-production.s3.amazonaws.com/uploads/attachment/file/5b746f627d79656b8800e3cb/MDH_GW_ProtRuleComments.pdf.

[116] Minn. Dep't of Health Comment Letter on Proposed Minnesota Department of Agriculture Rules Governing Groundwater Protection, at 2 (Aug. 14, 2018), https://speakup-us-production.s3.amazonaws.com/uploads/attachment/file/5b746f627d79656b8800e3cb/MDH_GW_ProtRuleComments.pdf.

[117] MINN. DEP'T OF AGRIC., STATEMENT OF NEED AND REASONABLENESS IN THE MATTER OF PROPOSED PERMANENT RULES RELATING TO GROUNDWATER PROTECTION 131-133 (2018).

[118] *Delayed for Good Cause: Drinking Water Supply Management Area Mitigation Level Determination*, MINN. DEP'T OF AGRIC., https://www.mda.state.mn.us/delayed-good-cause (last visited Apr. 21, 2023).

In 2021, MPCA released the final General NPDES Permit for CAFOs, which also has several deficiencies.[119] First, there is no monitoring required to ensure that nitrate is not leaching from storage lagoons into groundwater or whether the land application practices are causing or contributing to water quality problems. Both of these practices are known to contribute nitrate to Minnesota's waters, and all NPDES permits are required to have conditions that assure compliance with applicable limitations.[120] Second, there is no prohibition on fall application of manure, and winter application of solid manure is allowed in December and January. There are also no controls on summertime application of manure on hayfields without incorporation into the sensitive soils of the karst region. Third, there is no required pre-plant testing for nitrate to ensure that farmers properly account for residual nitrates that remain from manure applied in previous years when they calculate expected crop nitrogen needs.[121]

The Minnesota Department of Health is charged with insuring that public water supplies meet drinking water standards and implementing wellhead protection measures.[122] In a March 2021 report, MDH stated that "currently, there are approximately 400,000 acres in vulnerable groundwater Drinking Water Supply Management Areas," and that MDH's Source Water Protection Program "has a goal to protect vulnerable land in DWSMAs statewide by 2034."[123] However, the implementation of land use changes in Source Water Protection Plans is largely voluntary and does not protect underground sources of drinking water supply for private well owners who live outside of DWSMA boundaries. Finally, under the Minnesota Well Code MDH regulates private well construction and initial testing for nitrate and other pollutants like total coliform. However, "private drinking water testing and monitoring are otherwise unregulated and voluntary, with no formal tracking of water quality over time."[124]

Most recently, in 2022, MPCA stated that it was still not going to develop water quality standards for nitrate pollution in surface waters used for recreation and aquatic

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[119] Attached to this Petition as Exhibit B is Petitioner MCEA's Comment to MPCA, which explains the deficiencies of the CAFO General Permit in greater detail.
[120] 33 U.S.C. § 1342(a)(2); *see also* 40 C.F.R. § 122.48(b), Minn. R. 7001.0150 subp.2B.
[121] Ex. B at 22-23.
[122] James Lundy et al., *Minnesota's 1989 Ground Water Protection Act: Legacy and Future Directions*, 5 MINN. GROUNDWATER ASSOC. (2022).
[123] *Protecting Vulnerable Drinking Water Sources*, MINN. DEP'T OF HEALTH (March 23, 2021), https://www.health.state.mn.us/communities/environment/water/docs/cwf/vulnacres.pdf.
[124] James Lundy et al., *Minnesota's 1989 Ground Water Protection Act: Legacy and Future Directions*, 5 MINN. GROUNDWATER ASSOC. 34 (2022).

life, despite the recognition that such a standard is necessary.[125] The State's repeated failures to mitigate nitrate levels in drinking water put more and more people at risk of drinking contaminated water. Allowing agricultural practices to continue in the karst region without meaningful changes to commercial fertilizer application, manure management, and manure disposal practices, will perpetuate the imminent and substantial endangerment to residents' health in direct violation of the SDWA. Although Minnesota officials have clear authority to adopt the mandatory regulations necessary to resolve the imminent and substantial endangerment, they have consistently refused to act. EPA must not let Minnesota officials continue to sit on the sidelines for another decade as the threat to the health of Minnesota citizens grows ever more severe.

VI. Requested Emergency Action to Abate Ongoing and Ever-Increasing Endangerment to Human Health from Nitrate Contamination

As discussed in detail above, the statutory prerequisites for emergency action under 42 U.S.C. § 300i are satisfied here. First, nitrate, which is a "contaminant" under the SDWA, is present in and continues to leach into USDW in the karst region. Second, the presence of nitrate contamination in groundwater is causing an imminent and substantial endangerment to public health; an alarming number of karst region residents rely on USDW that have been identified as carrying substantial nitrate risks for users. Finally, the State of Minnesota has not taken timely or effective action to abate the public health endangerment.

EPA has broad authority to investigate and remediate threats to public health under the SDWA. "Once EPA determines that action under Section 1431 is needed, a very broad range of options is available" as necessary to protect users of USDW.[126] The tools available to EPA include conducting studies, halting the disposal of contaminants that may be contributing to the endangerment, and issuing orders such as mandatory changes to manure generation, handling, and land application practices. In fact, "EPA may take such actions notwithstanding any exemption, variance, permit, license, regulation, order, or other requirement that would otherwise apply."[127]

EPA should prioritize investigating and abating nitrate contamination in the karst region. Specifically, Petitioners respectfully request EPA take at least the following measures under its SDWA Section 1431 emergency powers, either by administrative order or through civil action:

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[125] PHIL MONSON, MINN. POLLUTION CONTROL AGENCY, AQUATIC LIFE WATER QUALITY STANDARDS TECHNICAL SUPPORT DOCUMENT FOR NITRATE (2010), https://www.pca.state.mn.us/sites/default/files/wq-s6-13.pdf.
[126] EMERGENCY AUTHORITY GUIDANCE, *supra* note 12, at 14.
[127] *Id.* at 9.

Investigation and Risk Assessment:

- Conduct investigation and monitoring throughout the karst region to more accurately trace the sources and quantities of nitrogen pollution, and to identify which sources are causing nitrate contamination;
- Investigate MPCA's CAFO permit requirements and MDA's and MPCA's best management practices for nutrient management to determine why they have been unsuccessful at protecting groundwater in the karst region;

Engagement and Communication:

- Work with MDH to notify the public of the existing nitrate hazards and provide public updates throughout the process of returning drinking water to a safe condition;

Planning:

- Determine what enforcement measures should be implemented to effectively reduce nitrogen pollution from CAFO and industrial agriculture sources;
- Provide a timetable for implementing a remedy to abate nitrate contamination from identified contaminators;

Assistance:

- Order the parties responsible for the nitrate contamination to supply free water testing and ensure a free source of clean drinking water to residents of the karst region whose private wells or PWSs exceed safe limits for nitrate to prevent blue-baby syndrome, cancer, and other adverse health effects;
- Provide assistance to private well owners to engage in effective private well management practices;

Regulation:

- Prohibit CAFOs from opening, expanding, or modifying operations in the karst region unless and until nitrate concentrations in wells with historically high levels of nitrate consistently fall below the MCL of 10 mg/L;
- Require CAFOs and agricultural operators land-applying CAFO waste or other nitrogen fertilizers to modify their practices so that these operations will cease overburdening the area with nitrogen pollution via lagoon leakage, land application of manure, and/or spills and leaks.

The threat to public health in the karst region from nitrate pollution of groundwater is present and pervasive, and all signs indicate a continuation and exacerbation of dangerous contamination levels absent EPA action. Therefore, the undersigned Petitioners respectfully request that EPA use its emergency powers under the SDWA to take the actions necessary to abate the sources of contamination that increasingly place the public at substantial risk and provide other forms of relief within its authority as long as the endangerment persists.

VII. Conclusion

In conclusion, for the reasons stated above, the undersigned Petitioners respectfully request that EPA invoke its emergency authority under Section 1431 of the Safe Drinking Water Act to urgently address the imminent and substantial endangerment to public health within the karst region of Minnesota caused by ongoing and increasing nitrate contamination. Please contact the undersigned for more information regarding this Petition.

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Exhibit A

Minnesota Center for Environmental Advocacy

Using law, science, and research to protect Minnesota's environment, its natural resources, and the health of its people.

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August 15, 2018

VIA ELECTRONIC SUBMISSION

Administrative Law Judge Jessica Palmer-Denig

Re: *Proposed Rules Governing Groundwater Protection, Minnesota Rules, 1573;*
Revisor's ID Number RD4337,
OAH Docket No. 71-9024-35205

Dear Administrative Law Judge Palmer-Denig:

This letter includes the comments of the Minnesota Center for Environmental Advocacy (MCEA) on the Minnesota Department of Agriculture's (MDA) Proposed Rules Relating to Water Resource Protection Requirements. MCEA is a Minnesota nonprofit environmental organization whose mission is to use law, science and research to preserve and protect Minnesota's wildlife, natural resources, and the health of its people. MCEA has statewide membership. MCEA is concerned about the impacts of agricultural pollution on Minnesota's waters and has been engaged with MDA on issues related to nitrogen fertilizer management for a number of years, including commenting on MDA's 2017 rule proposal.[1]

MCEA has supported its comments with references with numerous published documents which are provided as exhibits to this letter.

I. INTRODUCTION AND SUMMARY OF POSITION

MCEA agrees that a rule to protect groundwater from nitrate contamination is needed: indeed, it is long overdue.[2] Documentation in the record supplied by the Minnesota Department of Agriculture ("MDA") establishes that the voluntary best management practices ("BMPs") have failed to reduce or stabilize nitrate concentrations in groundwater in many areas of the state, and that those

[1] A copy of MCEA's 2017 comment letter is included as an attachment.
[2] Chapter 103H was enacted in 1989, with the goal of preventing degradation of the groundwater by human activities. Where prevention is practicable, it is intended that it be achieved. Minn. Laws 1989, ch. 326, art. 1, section 1.

concentrations continue to grow. Even where fully adopted, the BMPs are not enough to reduce excessive nitrate levels where they already exist.[3] More is needed.

MCEA supports the proposed fall and frozen soils application ban in “vulnerable areas” and in drinking water system management areas (“DWSMAs”) where N has exceeded 5.4 mg/L at any time in the past 10 years. However, the fall application ban part of the rule as proposed is riddled with convoluted and unsupported exclusions and exceptions which will make the fall application ban difficult to implement. Most importantly, the record shows that simply restricting the timing of nitrogen fertilizer application will not meet the statutory goals in those areas that are vulnerable to contamination. In fact, restricting the timing of application is one of the least effective of the University of Minnesota nitrogen fertilizer application recommendations.[4] At the very minimum, the record shows that in these vulnerable areas of the state, all the University of Minnesota “recommended” practices, including rate, timing, source, and placement, must be mandated to have a significant impact on excessive nitrate levels, with a particular focus on the “right rate” of nitrogen fertilizer.[5] And likely more actions must be required in order to prevent exceedances of the nitrate Health Risk Limit (“HRL”) in these areas.[6]

MCEA supports the issuance of Water Resource Protection Requirement orders (“WRPRs”) by the commissioner, but believes that the proposed rule too narrowly restricts the use of such WRPRs to public water supply system protection areas. Protection is also needed for people who drink well water. MCEA also believes that the proposed rule fails to provide adequate due process when a WRPR is issued: both “responsible parties,” and people who drink groundwater, must have the right to challenge the order.

Below, MCEA has provided alternatives that are supported by the record and that will not result in a substantially different rule within the meaning of Minn. Stat. § 14.05, subd. 2, but which will result in a rule that is in compliance with Minn. Stat. § 103H.275, subd. 1(c), by requiring water resources protection requirements that are “designed to prevent and minimize the pollution to the extent practicable” and, most importantly, are “designed to prevent the pollution from exceeding the health risk limits.”

The main issues with the rule are as follows.

A. The Proposed Rule Fails To Comply With Statutory Authority And Is Arbitrary Because It Does Not Protect People Who Drink From Private Wells

Persons who use water supplied by municipal or rural water supply providers are protected against drinking high nitrate levels by existing regulations requiring testing and which ensure a

[3] This is not surprising because, while helpful in controlling nitrogen fertilizer-related pollution, the BMPs were developed from research based on yield optimization and the production economics of corn and not specifically on water quality indices. Randall, *Nitrogen BMP’s for Corn in Minnesota* (provided in the exhibits).
[4] Wall, *Nitrogen in Minnesota Surface Waters*, Minnesota Pollution Control Agency (June 2013). *See also* comments filed by Dr. Gyles Randall, August 1, 2018.
[5] *Id.*
[6] *Id.*

healthy water supply.[7] When a community water supply well becomes contaminated, community water supplies typically have various options to deal with it.[8] In contrast, people drinking from a private well may not test on a regular basis[9] and suffer the same costs[10]—but with fewer options—when their water becomes contaminated. Despite these facts, the rule as proposed only protects persons who use water supplied by municipal or rural water supply providers.[11] The proposed rule should be amended to require mandatory requirements and WRPRs in township areas where excessive nitrate levels are present based on available test results. This change is supported by the record. Indeed, the MDA notes that it initially considered implementing regulatory actions "on the township level" in 2017, and further admits that in at least twenty townships more than 10% of the people who voluntarily sampled their wells are drinking water that exceeds the health risk limit for nitrate.[12] The only reason offered as to why townships with significant private well contamination levels were not included in the published rule is the lack of resources and a preference on the part of affected responsible parties to have the program stay voluntary.[13] These reasons do not provide an adequate basis for the decision to abandon private well users and this decision is inconsistent with the MDA's duty under Minn. Stat. § 103H.275, subd. 1(c)(1) and (2). Furthermore, the MDA has undermined its "limited resources" argument by noting that "the MDA will implement the voluntary parts of the 2015 NFMP in townships up to level 2, including forming [Local Advisory Teams] and conducting groundwater

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[7] The federal Safe Drinking Water Act standards apply to community water systems in Minnesota. *See* 42 U.S.C. § 300f et seq. The Safe Drinking Water Act standards are enforced by the Minnesota Department of Health. *See* https://data.web.health.state.mn.us/drinkingwater.

[8] As noted by the Department of Health, community water systems can take a high nitrate well and reclassify it to only be used in case of emergency, remove the well from service, or seal the well so that it cannot be used again. While these strategies may appear to be more economical than adding a treatment process, there are still costs associated with each strategy - locating a new well site, drilling a new well, or treating for a different contaminant. *See* 2017 Annual Report at 15, available at http://www.health.state.mn.us/divs/eh/water/com/dwar/report2016.pdf.

[9] According to the Minnesota MDA of Health, "Twenty-one percent of Minnesotans (1.2 million people) get their drinking water from a private well. Private well users are not afforded the same water quality safeguards as people who get their water from public water systems. While public water systems make sure water is safe for the end-user, private well users are responsible for making sure their water is safe for everyone in the household to drink." http://www.health.state.mn.us/divs/eh/cwl/wells/index.html.

[10] In 2008, average remediation costs were $190 y-1 to buy bottled water, $800 to buy a NO3 removal system plus $100 y -1 for maintenance, and $7,200 to install a new well. Lewandowski, A. M., Montgomery, B. R., Rosen, C. J., & Moncrief, J. F. (2008*). Groundwater nitrate contamination costs: A survey of private well owners*. Compare to increased public water supply costs cited in http://www.house.leg.state.mn.us/comm/docs/CostofNitrateContaminationtoPublicSuppliers2007.pdf.

[11] The attached map demonstrates how little area is *potentially* covered by the proposed rule (the black circled areas), as opposed to the areas where townships have already tested as having more than 5 percent wells above the HRLs.

[12] Statement of Need and Reasonableness dated April 30, 2018 ("SONAR") p. 110.

[13] *Id*.

monitoring."[14] It is unreasonable for MDA to prioritize its limited resources to require action to reduce nitrate contamination for public water supply users who are already guaranteed clean water over private wells owners who do not have such a guarantee. Moreover, if resources are limited, the MDA has non-arbitrary means for deciding how to allocate these resources, such as phasing in a program based on priorities, which this rule already identifies.[15] MDA's decision to abandon private well owners from the protections of the rule is arbitrary for the same reasons that the Minnesota Department of Labor and Industry was found to have acted arbitrarily in *Builders Ass'n of Twin Cities v. Minnesota Dept. of Labor and Industry*, 872, N.W.2d 263 (Minn. App. 2015). In that case, the Court of Appeals concluded that it was unreasonable for the Minnesota Department of Labor to adopt a building code that failed to require smaller homes to be protected by sprinkler systems where the record supported the potential for a phase-in of sprinkler requirement. MDA has not provided a reasonable basis for making WRPR protection available to only some of the millions of Minnesota residents who use drinking water as their major source of water – the nearly 30% of those residents excluded from these protections are those most in need. Private well users must be included; fundamental fairness compels nothing less.[16]

The following chart reflects a reasonable system to protect private well users from nitrogen fertilizer-related pollution which could be adopted as part of this rule in addition to the current provision protecting those who consume water from community drinking water sources:

Mitigation Level ("ML")	Criteria	Required actions for the commissioner and responsible parties[17]	Transition to higher level
1	At least 3 to less than 5% of private wells tested exceed the HRL within a township	Commissioner provides education and compliance resource information to all responsible parties within the township; Commissioner provides notice of opportunity to form a local advisory team ("LAT"). All responsible parties required to maintain and produce (on request) nitrogen fertilizer application records.	Exceed criteria for ML1.

[14] SONAR p. 111.
[15] *See* proposed 1573.0050, subp. 1, Item D (prioritization criteria for WRPRs).
[16] MCEA refers MDA to the petition filed as a separate comment today, signed by close to 200 individuals, that asks MDA to protect the drinking water of individual well owners contaminated by nitrates, not just city water supplies.
[17] MCEA also proposes, as discussed below, that the designation of a mitigation level area include certain reasonable actions that can be taken by responsible parties prior to the issuance of a WRPR. The actions shown in this chart are the same as those proposed by MCEA for the equivalent DWSMA mitigation level areas, creating a level playing field for responsible parties in DWSMA areas and township areas.

2	At least 5 to less than 10% of private wells tested exceed the HRL within a township	ML 1 actions; Responsible parties: • comply with no-risk nitrogen BMPs; • obtain yearly subsoil nitrogen samples (Nebraska program) and produce upon request.	Exceed criteria for ML2.
3	Greater than 10% of private wells tested exceed the HRL within a township	ML2 actions; Responsible parties: • develop and implement a nutrient management plan; • comply with all other actions required by the commissioner in a WRPR.	Exceed criteria for ML3.
4	Greater than 15% of private wells tested exceed the HRL within a township	ML3 actions; Responsible parties comply with all other actions required by the commissioner in a WRPR.	

B. The Rule Arbitrarily Prolongs Reliance On Voluntary Best Management Practices To Reduce Nitrates In Groundwater Despite Evidence That The Best Management Practices Have Not Succeeded In Controlling Nitrate Levels. Further, The Rule Allows The Voluntary Compliance To Continue For An Indeterminate Period Of Time

Initially, the rule allows the commissioner to establish only Mitigation Level ("ML") 1 and 2 areas. In these areas, there are no mandatory requirements and WRPRs cannot be issued, despite the fact that in ML2 areas the water is predicted to exceed the health risk limit ("HRL") in 10 years or has already had a reading in excess of the HRL. In the ML1 and 2 areas, MDA proposes only to try—again—to get responsible parties to use the nitrogen BMPs to control nitrate levels. This is manifestly unreasonable because the MDA has admitted in the SONAR that the existing nitrogen use BMPs have not proven to be a successful means for reducing nitrate levels, particularly due to adoption failure.[18] Worse, the proposed rule prohibits the commissioner from evaluating the impact of the nitrogen use BMPs for "at least three growing seasons" or the "lag time," whichever is longer. Lag times can be decades. The phrase "at least" is not limiting. As a result, the proposed rule unreasonably and arbitrarily allows the commissioner to prolong this monitoring period, potentially for decades, regardless of whether the nitrogen use BMPs have been implemented and regardless of whether nitrate levels continue to increase in the subsoil.[19] Thus, voluntary activities can be continued for an endless period of time, regardless of result.

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[18] SONAR part IV, pp. 49-59.

[19] Proposed rule 1575.0040, subp. 7, Items G and H allow the commissioner, with unfettered discretion, to postpone mandatory actions for an additional 3 or more growing seasons if the commissioner determines that the "responsible parties…have demonstrated progress in

The MDA cannot have it both ways. The MDA cannot continue to rely on voluntary BMP compliance while admitting that voluntary compliance has not been effective. If the MDA believes one last voluntary period is justified, then that period must be carefully limited by the rule and not be subject to extension. The commissioner should react to the data—not BMP compliance—to determine when more action is needed.[20]

Further, MCEA believes that the record supports a decision to require responsible persons in all areas where elevated nitrate levels are detected (both for public and private wells) to require compliance with certain reasonable requirements such as recordkeeping *before* a site specific WRPR is issued, in particular in areas where exceedance of the health risk limit is statistically likely to occur.

The following table shows reasonable criteria for establishing mitigation levels for areas served by public wells and private wells. This table also shows reasonable actions that MDA could require responsible parties to take prior to WRPR issuance. MCEA believes these actions are needed and reasonable to ensure that the goal of the Groundwater Protection Act—to *prevent* groundwater from exceeding HRLs—is met.

Mitigation Level ("ML")	Criteria	Required Actions for Commissioner and Responsible Parties	Transition to higher level
1	One reading of 3.0 mg/L or greater in a public water supply well(s) At least 3 to less than 5% of private wells tested exceed the HRL within a township	• Commissioner provides education and compliance resource information.[21] • Commissioner provides notice of opportunity to form a local advisory team ("LAT"). • All responsible parties required to maintain and produce (on request) nitrogen fertilizer application records.	ML 1 stays a ML1 so long as it does not meet the criteria for a ML2.

addressing nitrates…" or if there is a "significant change in land use in a drinking water supply management area." Neither "demonstrated progress" nor "significant change" are defined in any manner that would allow a party to determine with any certainty what these statements mean. The lack of enforceability of these rule provisions contravenes the statutory goals and is unsupported by the record.

[20] Although MDA suggests that is it is required by statute to "evaluate" BMP adoption before it can issue a WRPR, Minn. Stat. § 103H.275 says nothing about evaluation of BMP adoption before a WRPR can be issued. Instead, the statute indicates that the contents of a WRPR—the requirements in the WRPR—must be based on "the use and effectiveness of best management practices." The BMPs already exist. If the BMPs have been effective, they can be included in the WRPR. If they have not been effective, they should not be included in the WRPR. But in any event, BMP adoption levels are not mandated as a pre-condition for issuance of a WRPR.

[21] This would include providing the recommended BMPs for the area.

2	One reading of 5.4 mg/L or greater in a public water supply well(s). At least 5 to less than 10% of private wells tested exceed the HRL within a township	All ML1 activities plus: • All responsible persons required to obtain yearly subsoil nitrogen samples (Nebraska program) and produce upon request.	ML2 becomes a ML3 if statistics show HRL will be exceeded in 10 years.
3	One reading of 7.0 mg/L or greater in a public water supply well(s). Greater than 10% of private wells tested exceed the HRL within a township	All ML 2 activities plus: • The No-risk Nitrogen Fertilizer Use BMPs. • Compliance with a Nutrient Management Plan. • [Commissioner issues WRPR based on priority criteria.]	ML3 becomes an ML4 if the health risk limit is exceeded.
4	One reading of 8.0 mg/L or greater in a public water supply well(s). Greater than 15% of private wells tested exceed the HRL within a township	All ML 3 activities plus: Commissioner issues a WRPR based on priority criteria that must include AMTs.	

Neither recordkeeping[22] nor subsoil sampling are presently included in the rule as actions that responsible parties should take at lower mitigation levels, yet these actions would provide the commissioner information that the commissioner could use to determine whether BMPs are being complied with and are being effective, and would not be costly.[23] The sampling is reasonable because it is currently conducted by Nebraska producers and others.[24] Recordkeeping is reasonable because compliance with the BMPs requires recordkeeping, and any producer applying nitrogen fertilizer (or their agent or consultant) would be required to have such records.[25] The requirement for responsible parties in ML3 areas to comply with nitrogen fertilizer BMPs and nutrient management plans immediately upon triggering the ML3 designation is reasonable because these actions will not significantly increase costs for the

[22] Recordkeeping is only required after a WRPR is issued. *See* 1573.0060, Item A(1).
[23] In fact, many Minnesota producers are already keeping such records and taking such samples. *See* testimony of Zach Johnson and Richard Syverson, July 25, 2018.
[24] *See Id.*; SONAR p. 122.
[25] *See* http://www.mda.state.mn.us/nitrogenbmps.

responsible parties,[26] and it may take some time for the commissioner to develop and issue a WRPR. In the interim, because the health risk limit may shortly be exceeded, it is reasonable to require the responsible parties to take immediate actions to better document and control nitrogen fertilizer use.

C. The Rule Lacks Adequate Due Process When The Commissioner Issues A WRPR Order, And Limits The Commissioner's Discretion To Include Effective Conditions

Although the rule requires notice to be given to affected persons prior to issuance of a WRPR as required by statute, only "responsible persons" subject to the order can seek review, which is unfair to the affected persons drinking the water. All persons impacted by the WRPR must be provided an opportunity for administrative and judicial review. Further, no standard is stated in the rule against which the commissioner's decision will be judged to determine whether it meets the standards of the statute. The rule should—at a minimum—require that a WRPR "prevent and minimize the pollution to the extent practicable" and be "designed to prevent the pollution from exceeding the health risk limits."[27] Finally, the review process lacks basic standards necessary to limit frivolous appeals, and appears to confuse "contested case hearings" with "public hearings."

D. The Rule Unreasonably Limits The Commissioner's Discretion To Require Actions That Would Reduce Nitrogen Concentrations Where Necessary To Ensure That The Health Risk Limit For Nitrate Is Not Exceeded

The proposed rule fails to require the commissioner to include certain basic content that should be required in the WRPR, including monitoring, record-keeping, reporting, and the like. But more importantly, the proposed rule limits the commissioner's authority to require certain actions in a WRPR that are immediately effective to reduce nitrogen—alternative management tools—just because the alternative management tool might cost money to implement. Similarly, the proposed rule limits the commissioner's authority to require any changes to the "primary crop" and limits the use of nitrogen fertilizer to levels below rates the University of Minnesota has identified as the most profitable. Although undefined, it would appear that this provision would limit the commissioner's ability to require, for any area for any time, a different crop to be grown (say alfalfa as part of a rotation on a particular field), as part of a WRPR. These limitations are unreasonable and unsupported by the record and do not meet the goals stated in Minn. Stat. § 103H.275. Instead, if there is a particular requirement that would cause hardship for a responsible party to implement, the commissioner should have the authority to enter into a two-year schedule of compliance that would allow a regulated party to make the necessary adjustments to come into compliance.

E. The Rule Contains Many Provisions That Provide The commissioner Too Much Discretion, As Further Described Below

The rule uses the phrase "as determined by the commissioner" in four places and the phrase "if the commissioner determines" in seven places. This language does not meet the standard for a

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[26] Throughout this record it is noted that compliance with nitrogen BMPs may save producers money.
[27] Minn. Stat. § 103H.275, subd. 1(c)(1)(2).

rule, because it vests the decision in the commissioner without establishing a standard or a process. For example, all areas where "exclusions" can be established from the ban on fall nitrate fertilizer application are "as determined by the commissioner." This fails to meet the standard for administrative rules, which cannot allow excessive and unfettered discretion such that a party is unable to determine how the rule will be applied. The Administrative Law Judge must reject a rule if it "is not a "rule" as defined in Minnesota Statutes, section 14.02, subdivision 4, or by its own terms cannot have the force and effect of law."[28] This rule cannot be determined by its own terms, because it relies on decisions by the commissioner based on unstated criteria in many provisions. In fact, this lack of standards for WRPRs makes it extremely difficult to determine whether the rule will have any positive impact – the commissioner could rely on exclusions and issue WRPRs that include very minimal requirements (there is no stated standard for the commissioner's WRPR order, just a list of potential options that could be included in a WRPR), and implement the rule in a manner that contradicts the goals of the Groundwater Protection Act.

F. The Rule Contains Many Provisions That Are Fatally Vague, As Further Described Below

For example, the proposed rule does not establish a deadline in part 1573.0040, subpart 2, for the commissioner to designate a DWSMA as a mitigation level 1 or 2 following receipt of information from the Department of Health ("MDH") that a public well has exceeded a trigger level as set forth in subpart 3. To be enforceable, the rule must establish a deadline for the commissioner to act, i.e., within 60 days of receipt of information from MDH.

In addition to the above, the rule contains numerous provisions that are poorly drafted and should be fixed to ensure that the rule can be enforced.

II. FACTUAL AND LEGAL BACKGROUND

A. Nitrogen Fertilizer Use And Nitrate Contamination In Minnesota

The following are the underlying facts pertaining to these proposed rules that must be taken into consideration in evaluating whether the proposed rule meets the statutory standard.

Despite MDA's years of promoting compliance with the University of Minnesota nitrogen fertilizer use recommendations, nitrogen fertilizer sales in Minnesota skyrocketed by nearly 200,000 tons/year from 1990 to 2016, including a 15% increase over the past 5 years.[29] In addition the acreage of crops that "leak" nitrogen fertilizer into groundwater, corn and soybeans, are consistently expanding, with over 4 million more leaky acres today than in 1990.[30]

The result is widespread nitrate contamination of groundwater in Minnesota's agricultural landscapes. Nearly half of the wells in MDA's shallow groundwater monitoring network exceed

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[28] Minn. R. 1400.2100 (g).

[29] MDA Draft Nitrogen Fertilizer Rule Presentation, at slide 24, found at http://www.mda.state.mn.us/~/media/Files/chemicals/nfmp/nfrpresentation.pdf (last visited Aug. 14, 2018).

[30] *Id.* at slide 25.

the nitrate Health Risk Limit ("HRL") of 10 mg/L.[31] Where shallow wells are contaminated, deeper wells also are likely contaminated.[32]

The Minnesota Department of Health reviewed data for 2014 – 2015 from Minnesota's public water supply wells across the state and found that 537 of 10,519 (5.11 percent) had nitrate levels above 3 mg/L. These include wells for both communities and for businesses, schools, and organizations that provide water to the public.[33]

The Minnesota Department of Agriculture's Township Testing Program ("TTP") provides testing for nitrate to homeowners who have wells in vulnerable areas of the state where groundwater used for drinking water can be affected by agricultural production. As of March 2018, 242 vulnerable townships from 24 counties participated in the TTP from 2013 to 2017. In the 242 townships tested, 113 (47%) have 10% or more of the wells over the HRL for Nitrate-N. Overall, 10.1% (2,583) of the 25,652 wells voluntarily tested exceeded the HRL for Nitrate-N.[34]

And these numbers are expected to rise: changes to cropping practices can be expected to result in an increased risk of nitrogen loading.[35]

B. Statutory Requirement For WRPRs

The Groundwater Protection Act of 1989 has the goal of preventing groundwater degradation.[36] For agricultural chemicals and practices, including the use of nitrogen fertilizer, the statute is implemented by the MDA, and requires MDA to evaluate the detection of agricultural pollutants in the state's groundwater;[37] monitor groundwater for pollutants found to be of "common detection" as the result of normal use of a product or practice;[13] develop voluntary, practicable measures that are capable of preventing and minimizing degradation of groundwater from agricultural chemicals and practices, called BMPs;[38] and promote and evaluate the use and effectiveness of these BMPs.[39]

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[31] *Id.* at 2-83.

[32] In 2010, MDA installed eight new wells in the Central Sands Region, approximately 10-15 feet deeper than existing shallow well sites. Id. at 2-75. 75% of these wells exceeded the Health Risk Limit. *Id.* at 2-83.

[33] *Minnesota Drinking Water 2017*, Annual Report for 2016, Minnesota Department of Health Environmental Health Division Section of Drinking Water Protection, available at http://www.health.state.mn.us/divs/eh/water/com/dwar/report2016.pdf

[34] http://www.mda.state.mn.us/~/media/Files/chemicals/nfmp/ttpudate201806.pdf

[35] Keeler and Gourevitch et al, *The Social Costs of Nitrogen*, Sci. Adv. 2016, at 6. The mechanisms are graphically explained at http://www.bwsr.state.mn.us/practices/farm-bill/FBAP_Winter_Meeting/2015/Estimating_the_External_Costs_of_Nitrogen_Fertilizer_in_MN.pdf.

[36] Minn. Stat. § 103H.001.

[37] Minn. Stat. § 103H.251, subd. 1. 13 Minn. Stat. §§ 103H.251, subd. 1(b) and 103H.005, subd. 5.

[38] Minn. Stat. §§ 103H.151, subd. 2 and 103H.005, subd. 4.

[39] Minn. Stat. §§ 103H.151, subd. 3 and 103H.275, subd. 1.

If implementation of BMPs proves ineffective, the Act provides MDA with the authority to adopt mandatory water resource protection requirements (WRPRs) that include "design criteria, standards, operation and maintenance procedures, practices to prevent releases, spills, leaks, and incidents, restrictions on use and practices, and treatment requirements."[40] WRPRs may be statewide or targeted, but those that are not statewide become effective only in areas designated by order of the MDA Commissioner.[41] WRPRs must be intended to prevent and minimize groundwater pollution to the extent practicable; be designed to "prevent the pollution from exceeding the health risk limits;"[42] and be based on "the use and effectiveness of best management practices, the product use and practices contributing to the pollution detected, economic factors, availability, technical feasibility, implementability, and effectiveness."[43] Although economic factors can be considered in decisions, these factors do not trump the overall goals established for the Act and cannot be paramount in view of overarching state policy in support of maintaining the resources of the state for the use of future generations.[44] Further, economic considerations cannot be limited to just those related to the cost to the responsible party; MDA must consider the cost of not acting on the affected public, who must pay to replace contaminated water supplies, as noted above.

Where this rule does not meet the intent of Groundwater Protection Act, MCEA requests that the Administrative Law Judge recommend changes to the rule that will ensure that it meets the minimum goals of the Groundwater Protection Act, in particular that the actions "prevent the pollution from exceeding the health risk limits" rather than allowing the status quo to continue, as that status quo has not succeeded in reducing impacts from nitrogen fertilizer to the groundwater as required by law.

III. MDA'S PROPOSED RULE: DETAILED PART BY PART ANALYSIS

MCEA provides detailed comments on the proposed rule below. In addition, MCEA has prepared a separate redline document of the proposed rule (attached). The proposed redline language addresses the problems identified in the proposed rule language and includes MCEA's proposed language.

A. DEFINITIONS (1573.0010):

1573.0010, subp. 2. Alternative management tools ("AMTs") are "specific practices and solutions described in part 1573.0090, subpart 1. . .that are approved by the commissioner to address groundwater nitrate problems," but in fact no specific practices are described in the referenced part. Instead, the referenced subpart merely indicates that the commissioner will post a list. Based on the SONAR, the AMTs are intended to "go beyond the nitrogen fertilizer BMPs" and could be identified by the local advisory teams, and could include a variety of management

[40] Minn. Stat. § 103H.005, subd. 15.
[41] Minn. Stat. § 103H.275, subd. 2(c).
[42] Minn. Stat. § 103H.275, subds. 1-2.
[43] Minn. Stat. § 103H.275, subd. 2(a).
[44] In addition to the Act, Minn. Stat. § 116D.02 makes clear that economic impacts are not more important than the value of preserving natural resources for future generations.

practices. Because the commissioner may allow these practices to substitute for nitrogen fertilizer best management practices,[45] the rule must define all the practices that would be approvable AMTs and establish a standard for new practices that might not be currently known. As currently drafted, the rule is too vague and provides too much unfettered discretion to the commissioner in allowing the unknown AMTs to substitute for mandated best management practices.

Needed definition: Health Risk Limit or HRL. The definitions should reference the particular health risk limit at Minn. Stat. § 103H.201 because this term is used throughout the rule and has a particular meaning.

Needed definition: Interested Person. To simplify references to public notice procedures, MCEA recommends that the commissioner define "interested persons" as those who have registered with the department to receive public notices concerning actions of the commissioner under the rule.

1573.0010, subp. 12. The definition of lag time is limited to areas "being monitored." The definition is too restrictive. Areas that have been monitored in the past will have an established lag time. It is unclear who is performing the monitoring referenced in this definition. Lag time should be defined to include all areas where data is adequate to support a determination of how long it takes for nitrogen fertilizer applied at the surface to enter the groundwater.

1573.0010, subp. 14. The rule must establish a process by which members of a "local advisory team" ("LAT") are "approved" by the commissioner and the definition should reference that process, or the rule should establish that the LAT must have a certain constitution, but does not require "approval" by the commissioner. The rule must better define the role of the LAT.

1573.0010, subp. 17. For the purpose of this rule, it does not make sense to use additional concepts from Minn. Stat. § 18C.215, which is a chapter designed for the regulation and control of the manufacture, distribution, and sale of fertilizer in this state. The intent of this rule is to ensure that the MDA can regulate agricultural practices that are leading to excess nitrate levels, and the definition of nitrogen fertilizer must reflect all fertilizers that are applied to supply nitrogen. The MDA should amend this definition to simply reference the statutory definition.

1573.0010, subp. 18. Subpart 18 defines a "public well" as a "community water system" which includes permanent (but not necessarily municipal) water supplies. MCEA supports this definition, but notes that the definitions of municipal public water supply well, and public well, as used in the rule, create confusion. The rule should cover all drinking water supply management areas that have been established to protect public water supplies, whether municipal or non-municipal. There is no basis under this rule for a distinction.

1573.0010, subp. 19. It is unclear why this definition restricts soil tests to those conducted by or under the direction of the commissioner within a drinking water supply management area. Residual soil nitrate tests should include any tests conducted under appropriate controls in any area by any person. MCEA recommends striking the phrase "conducted by or under the direction

[45] *See* Minn. R. 7040.0040, subp. 6 (evaluation of BMP adoption as part of determination of whether a "level 2" mitigation area continued).

of the commissioner" from this definition. The phrase "that are representative" will prevent non-standard test results from being considered. MCEA recommends that MDA reference a standard method of obtaining results from soil testing.

B. FALL AND FROZEN SOILS VULNERABLE AREAS BAN (1573.0030):

This part of the rule establishes a ban on application of nitrogen in areas with vulnerable soils in the fall and when there are frozen soil conditions. However, part 1573.0030, subp. 2 and subp. 3 establishes numerous exclusions and exceptions that undermine the intent of the ban. MCEA supports the ban, but does not agree with the language that allows the commissioner excessive discretion.

1573.0030, subp. 1. The proposed provision contains an odd wording. A DWSMA is not "from" a municipal public water supply well. The rule should state that the water supply management area is "established for" a public water supply well. Item A (3)(b) needs to worded in a similar fashion, i.e., reference that it is a drinking water supply management area established for a public water supply well with (or "which has had") nitrate-nitrogen levels greater than or equal to 5.4 mg/L at any point in the previous ten years. DWSMAs are established for public wells that are not municipal. MCEA believes that all public wells should be included.

1573.0030, subp. 1, Item C. Item C indicates that a responsible party in charge of cropland depicted on the commissioner's map is subject to the prohibition on fall application that is stated in part A. This sets up a potential conflict between the criteria in part A and duty to comply with the map in part C. It is important that the map not undermine the prohibition in part 1573.0030, Subp. 1, Item A. If Item A says "a responsible person shall not," then Item C, which states that "any responsible person is subject to Item A," is not needed.

1573.0030, subp. 2. Exclusions.

In general, this section of the proposed rule is drafted in a convoluted manner that makes it difficult to understand. However, closely read, the "exclusion" section appears to remove a significant portion of the vulnerable and DWSMA areas[46] subject to the prohibition on fall application based on certain broad soil ("leaching index") and climactic ("frost-free") assumptions. In Item G, the proposed rule also authorizes the commissioner to allow, based on unstated criteria and without any process whatsoever, fall applications in areas within a high-reading DWSMA if the commissioner believes "that the area is not contributing significantly to the contamination of the well" in the drinking water supply management area. Thus, the overall impact of Subpart 2 is to undermine the protection provided by prohibiting fall application of nitrogen fertilizer in vulnerable areas and threatened drinking water supply management areas.

The "exclusions" allow fall application of nitrogen fertilizer based on frost-free dates "in the county or a portion of the county" and a "leaching index" of various levels.[47] Later, however, the proposed rules state (Item B) that the exclusion applies to the entire county if a condition is represented on 50 percent or more of the land area of the county, but (Item C) commissioner can

[46] MCEA notes that MDA has proposed to correct this section to include DWSMA areas.
[47] The proposed rule states that the "leaching index" is "determined by the commissioner," but the definition of "leaching index" references the gridMet dataset for 1981-2010.

also subdivide a county by geographical boundary "if there is a clear change in conditions represented in a specific area of the county," but there is no description of what this "clear change in conditions" might be, or how the commissioner will make this determination or announce this determination. Finally, as noted above, the proposed rule appears to limit the exclusions to areas that are not drinking water supply management areas "with nitrate-nitrogen levels greater than or equal to 5.4 mg/L."[48] It is unclear whether these areas are the same as the areas subject to the fall application prohibition, which are stated to be those with a well having "nitrate-nitrogen levels greater than or equal to 5.4 mg/L at any point in the previous 10 years." Even so, as previously noted, this "exception to the exclusion" is undermined by Item G, which broadly allows the commissioner to exclude high-reading DWSMAs without any particular criteria for such an exclusion being set forth, nor any process by which the commissioner will exercise this authority.

The SONAR demonstrates that the MDA has proposed these exclusions based on the notion that cooler spring soils, combined with lower leaching indices, would result in reduced risk of groundwater contamination. However, although the MDA documents that it "heard many concerns from farmers in the western and northern parts of the state about the importance of fall nitrogen applications because of the short application window in the spring,"[49] there is little evidence of *scientific support* for the theory advanced by the MDA cited in the SONAR. No peer-reviewed or published articles are cited as support for the two-factor theory. One can only conclude that the MDA put the exclusions into this rule not on the basis of science, but instead because "there are logistical problems such as with an insufficient numbers (sic) tender trucks and spreaders to complete all fertilizer applications in this compressed spring period."[50]

If the MDA's theory that cooler spring temperatures and a reduced leaching index is scientifically based, MCEA would support removing areas that have these characteristics from the fall application ban area. However, the language creating the exclusion areas must be clear and not subject to the discretion of the commissioner, as detailed below.

1573.0030, subp. 2, item E. This Item appears intended to exclude non-agricultural counties, but references the wrong "Item A." The exclusion should be for *subpart 1,* Item A.[51]

1573.0030, subp. 2, items F and G. These are both problematic because they are vague. In Item F, what does it mean for a point source to be "a significant source" of N contamination? In Item G, the rule fails to specify the criteria that the commissioner will use to determine that the area is "not contributing significantly" to the N problem. Both of these exclusions are too vague to be enforceable unless amended. They both allow the commissioner free-rein to determine that an area will not be subject to the fall nitrogen prohibition, without any possibility of review. And

[48] As above, it is assumed that this reference is to the wells in the drinking water supply management areas.
[49] SONAR p. 97.
[50] SONAR p. 98.
[51] MDA has identified this as a needed change in an errata document published on the MDA website.

such discretion is unnecessary: state law already provides a variance procedure that a person needing relief can use if the application of the rule is unreasonable as applied to the person.[52]

1573.0030, subp. 3. Exceptions.

The MDA asserts that these exceptions are needed because they are a "necessary agricultural practice."[53] MCEA supports the requirement that the fall application allowed by the rules must be consistent with the BMPs or the rates in the Fertilizer Guidelines published by the University of Minnesota Extension.[54] However, in a number of cases, the information presented in the SONAR undermines the assertion that the exceptions are needed as a necessary agricultural practice.

For example, for item 2, the SONAR states that, for pasture fertilization, "an early spring nitrogen application is the recommended timing." The fall application exception is only necessary, apparently, if the producer is seeking a "high yield system," and then only ¼ of the application is to occur in the fall, a limit which is not reflected in the exception.[55] As a result, a reasonable "exception" would be "when nitrogen fertilizer is required for a high yield pasture, provided that only ¼ of the yearly application is made in the fall." Similarly, for item 4, grass seed production, the cited reference indicates that "either a fall application or very early spring application is recommended."[56] As a result, fall application is not a necessary practice. Where fall application is a necessary practice, it should be done by October 1 to get plant root uptake of the nitrogen.

Item C is arbitrary as drafted. The SONAR notes that when farmers are adding phosphorus to fields, it generally is formulated with up to 40 pounds per acre of nitrogen and applied in the fall for use over two seasons. The Item states that "notwithstanding subpart 1" and "in addition to item A" (it is assumed that rule intended to reference *Subpart 2*, Item A), fall application is allowed so long as the applied N rate does not exceed an average of 40 pounds per acre in a field. However, without explanation, the rule then allows more than 40 pounds per acre (without any upper limit whatsoever), if a soil analysis demonstrates that the fields have "low to very low phosphorus levels." Although the SONAR argues that this exception will be temporary, the language in the rule does not reflect any temporal limit. No scientific information is provided to explain what the impact of this exception would be on soil nitrate levels. Because (as noted in the SONAR), there are other methods to increase P where needed, this exception is arbitrary and

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[52] *See* Minn. Stat. §§14.055-.056. For example, a farmer who applies nitrogen in the fall using techniques and equipment that ensure that leaching does not occur might be able to apply to the commissioner for a variance from the fall application ban, on the ground that it is unreasonable under the unique site conditions and techniques being used. The commissioner, in granting such a variance, could agree so long as the farmer continued to use the techniques and documents the results.

[53] SONAR p. 102.

[54] Proposed rule, 1573.0030, Subpart 3, Item B. It would appear that this document is no longer available on the internet, making it difficult to check the references.

[55] SONAR p. 103.

[56] *Id.*

undermines the intent of the rule. Only the first part of the phosphorus-related exception is justified.

C. DRINKING WATER SUPPLY MANAGEMENT AREA; MITIGATION LEVEL DESIGNATION (1573.0040).

This part of the rule establishes the preconditions for the issuance of "water resource protection orders" or "WRPRs." This part provides various duties for the commissioner: establishing mitigation level areas ("MLs"); "determining" BMPs; monitoring; and evaluating. The rule requires no actions by responsible parties until WRPRs are issued. The rule is unreasonable and will not meet the goals of the Groundwater Protection Act where it continues voluntary actions in areas where nitrate levels threaten to exceed the HRL. The rule is defective because it fails to establish a clear deadline for an ML2 to move to a ML3, a level at which the commissioner could issue a WRPR. In particular, MCEA believes that the current rule language, which allows unlimited "evaluation time" for a ML2, is unreasonable and not supported by the record.

MDA has the authority to require, by rule, statewide actions applicable to areas where specific evidence exists of the threat of public (and private) well contamination and should use this authority to establish reasonable conditions, such as recordkeeping, sampling, and nutrient management planning, that apply where a threat has been documented and a "mitigation area" established, *prior to a WRPR being issued.*

It is not reasonable for all sites—even sites where statistical evidence suggests that the HRL will be exceeded—to be classified in the "voluntary" ML1 and ML2 categories. More serious sites—where the HRL has been exceeded or is statistically likely to be exceeded or where a significant number of private wells already exceed the HRLs—must immediately be prioritized for WRPRs. Under Minn. Stat. § 103H.275, the commissioner is required to ensure that the water source protection requirements are "designed to prevent the pollution from exceeding the health risk limits." As currently drafted, this rule fails to meet this standard.

1573.0040, subp. 1.[57] Although subpart 1 notes that the application of the part is "to responsible parties in drinking water supply management area," it would be more accurate to state that this part establishes the procedures that the *commissioner* will use to establish and evaluate mitigation level areas prior to issuance of a water resource protection requirement order. MCEA proposes that requirements for responsible parties in designated mitigation areas prior to the issuance of a WRPR also be included in this section of the rule.

1573.0040, subp. 2. This states that the commissioner will use public well nitrate-nitrogen concentration data provided by the commissioner of health to designate a DWSMA with a "mitigation level." While there is no problem with using data provided by the Department of

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[57] As noted above, MCEA finds no support in the record for the commissioner's decision to limit the designation of mitigation levels to DWSMAs, because the decision arbitrarily leaves persons depending on private wells—persons who are more vulnerable to health impacts from nitrate levels with fewer options for addressing the exceedance—without regulatory protection.

Health (and indeed, the MDA should defer to the Minnesota Department of Health), this rule subpart cannot be enforced because it does not provide a deadline for the commissioner to act on the data provided. To address this issue, the rule must provide an action deadline, i.e., 60 days from the date that the Department of Health provides the necessary data.

1573.0040, subp. 3. This section establishes the criteria for "being designated" by the commissioner at a particular "mitigation level."

A ML2 is where, within a rolling 10-year period, (a) based on a "statistical analysis[58]. . .the groundwater. . .is projected to exceed the health risk limit in the next ten years; or (b) a reading has been 8 mg/L or greater. It is unreasonable to classify an area as an ML2 if it is statistically likely to exceed the HRL, or has in fact documented an exceedance of an HRL. Immediate mandatory actions are needed for such sites, i.e., a WRPR, if the statutory goal of Minn. Stat. § 103H.175 to prevent exceedance of the health risk limit is to be achieved. Under the rule as currently proposed, a public well could have had a reading of 12 mg/L nitrate, but still have its associated DWSMA characterized as a "voluntary only" mitigation level 2. This approach is not supported by the record, and does not comply with the Minn. Stat. § 103H.275.

Having established these "voluntary only" mitigation levels, the rule provides that the commissioner can, nevertheless, exclude portions of the affected DWSMA from the ML area. Subpart 3, item B provides that the commissioner "may make exceptions for increasing a mitigation level" for a "nonmunicipal" public supply well based on "significant change" in land use, and "the severity of nitrate" in "other wells" and the "population affected" and "other factors."[59] Item C provides that the commissioner "may exclude" an area if there is a point source "that is…significant" and item D provides that the commissioner "may exclude" a part of a DWSMA from the mitigation level if the commissioner determines that the area is not contributing "significantly" to the contamination. These exclusions are all purely subject to the discretion of the commissioner and fatally vague, and must be eliminated from the proposed rule or amended to remove the vague language and excessive discretion.

1573.0040, subp. 4. Subpart 4 requires the commissioner to "determine" the nitrogen fertilizer BMPs for the affected DWSMA, but this is unnecessary because the BMPs for various areas of the state are well-established.

1573.0040, subp. 5. In subpart 5, the commissioner is required to conduct some form of monitoring, but that monitoring may only be to obtain data from the public well. As the commissioner is already obtaining data from the public well, this part fails to define any new mandated monitoring activities and therefore fails to protect the public. To the extent that this provision was written because of limited resources for monitoring, MCEA proposes that the monitoring criteria include priorities for monitoring.

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[58] The method should be described in the rule.

[59] This provision suffers from the same "substantive due process" defect as the decision to abandon private wells from protection under the rule: it provides lesser protection to smaller public well user groups based on the argument that MDA needs to prioritize work in other areas.

1573.0040, subp. 6. In subpart 6, the commissioner is required to conduct an evaluation of the ML2 to determine whether the BMPs have been implemented. There is no time limit on the commissioner to conclude this evaluation, but only a minimum time (3 years) that the commissioner must allow for evaluation. In general, voluntary implementation of BMPs has not protected the groundwater from nitrate contamination, and should not be continued under this rule. MCEA believes that BMP implementation is not a valid criterion on which to base continuous voluntary action, particularly when a significant percentage (20 percent) of responsible parties are not counted, the criteria for determining BMP compliance are not clearly stated, and the time and resources needed to accomplish this survey has not been justified. At any rate, it is manifestly unreasonable for the rule to allow evaluation of compliance for an unlimited period of time. The rule must establish a firm limit for the time that the commissioner can take to evaluate BMP compliance. Given the prolonged period of time that BMPs have been the subject of outreach to agricultural communities, this time should be short.

1573.0040, subp. 7. Subpart 7 is important, because it describes how the commissioner can redesignate a ML2 (where nothing is required) to a ML3 (where a WRPR can be issued).

Item A. This item suffers from the same defect as subpart 6: no limit is put on the time during which the commissioner will evaluate ML2 designation. The length of the allowed evaluation period is “no fewer than three growing seasons” or “the lag time”—whichever is longer.[60] This means that the commissioner could “evaluate” for an unlimited amount of time. If BMP compliance is maintained as part of this rule, it must be changed to provide a firm end-date for the evaluation period, such as 3 years. This period should be adequate for the commissioner to determine whether the BMPs have been implemented, and whether they are having an impact.

Item B. MCEA does not support item B, which allows a ML2 to become and ML1. Once the criteria for an ML2 have been met, the ML2 should not be redesignated as a lower-priority ML1, as that may allow the conditions under which the nitrate contamination developed to re-occur. MCEA supports adding mandated actions for responsible parties once a ML has been designated. For example, at a ML2, MCEA believes that responsible parties should conduct soil sampling. This soil testing requirement is reasonable because it has been implemented in Nebraska for many years, is not burdensome and is likely in use where a crop consultant is employed, and (where manure is used) can be combined with required testing under MPCA’s rules. It is reasonable for the responsible parties and the commissioner to collect this data to ensure that actions that are being taken are having a positive effect, and to be able to better determine where additional resources and actions may be necessary.[61] The SONAR also notes that “Canadian researchers have used nationwide residual soil nitrate information from shallow sampling over time to make policy decision related to fertilizer use efficiencies and groundwater implications (Yang et al., 2007; Drur et al., 2007).” *Id.* The SONAR rejects the idea of requiring testing on the basis of unstated “cost” and because “this testing requires access to a large number of acres.”[62]

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[60] MCEA notes that the proposed rule also states that, “however,” if residual soil nitrate testing is conduced, the review period shall not be less than three growing seasons. As the word “however” seems to be wrong in this context because nothing is changed, MCEA wonders if MDA meant to propose that the review period would “not be *more* than three growing seasons.”
[61] *See* SONAR pp. 122-4
[62] *Id.*

However, if the producers are doing the testing themselves, no access is needed. The unstated cost cannot be unreasonable given that the requirement is one of longstanding in Nebraska. Other state rules require regular soil testing without compensation.[63] The BMPs recommend use of soil nitrate tests in a number of cases.[64] Testimony at the St. Cloud rulemaking hearing supports that producers are testing their soils voluntarily. Similarly, responsible parties in an ML3 area should prepare nutrient management plans in accordance with National Resources Conservation Service Practice Nutrient Management guidelines.[65]

Items C-E. Items C-E establish criteria for moving a well from a ML2 to a ML3. MCEA does not support item C, which appears to allow the area to remain a ML2 so long as 80 percent of the responsible parties are in compliance with the BMPs, even if the statistical analysis still demonstrates that exceedance of the HRL is probable. Item D provides that the commissioner "shall" move to a ML3 if the net residual nitrate in soil below the root zone is increasing "after not less than 3 growing seasons." MCEA cannot support this criterion, because there is no limit on the number of growing seasons that could be considered, but could support this criterion if the evaluation was required after 3 years. Item E provides that the commissioner "shall" move to a ML3 "if the statistical analysis indicates the nitrate-nitrogen concentration is increasing for the public well or groundwater monitoring network." MCEA supports this criterion, provided this evaluation is not viewed as being limited by the time criterion stated in Item A.

Item G. This item allows the commissioner to "grant a onetime exemption" from the move to ML3 on the vague criteria that "responsible parties...have demonstrated progress." Because there are no criteria for "demonstrating progress," MCEA does not support granting the commissioner this authority.

Item H. MCEA does support item H, which allows the commissioner to "make exceptions for increasing a mitigation level designation if there has been a significant change in land use." Because what is "significant" is not defined, this criterion is fatally vague and should be eliminated.

1573.0040, subp. 8. Subpart 8 suffers from many of the same defects as subpart 7, in particular the language allowing the commissioner an unlimited period in which to evaluate whether a ML3 should be redesignated as a ML4. MCEA refers the ALJ to its comments on subpart 7.

1573.0040, subp. 9. Subpart 9 describes how ML4 area can be redesignated as a ML 3 area, if the water will not exceed the HRL in 10 years based on statistical analysis, and no three samples have reached or exceeded 9.0 mg/L. As noted above, MCEA does not believe that it is appropriate for an area that has demonstrated the potential to exceed the HRL to "drop back" to a level of lessor protection that may allow the prior conditions to re-occur.

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[63] *See* Minn. R. 7020.2225, Subp. 3, Item C (phosphorus).
[64] *See*, e.g., sugarbeet production.
[65] Available at https://www.nrcs.usda.gov/wps/portal/nrcs/detail/mn/technical/ecoscience/nutrient/?cid=nrcseprd1369002 (last visited August 14, 2018).

1573.0040, subp. 10. MCEA does not support the artificial and unsupported limit stated in Subpart 10, which limits the move to one ML. If an area should suffer a sudden increase in nitrate levels, there is no reason for the rule to limit the authority of the commissioner not to take action as required by the Groundwater Protection Act.

D. WATER RESOURCE PROTECTION ORDER PROCESS (1573.0050):

Part 1573.0050 establishes the requirement for the commissioner to issue a WRPR, but does not provide adequate due process or standards for WRPR development.

1573.0050, subp. 1 requires the commissioner to issue a WRPR to responsible parties in ML3 and ML4 areas, but does not establish any deadline or any standard that must be met. As a result, there is no stated basis on which the order can be challenged or reviewed, except broadly as not meeting the requirements of the statute.

Item A. Item A notes that the commissioner will issue WRPRs based on the monitoring in part 1573.0040, subp. 5, but, as discussed above, this provision does not require the commissioner to do any monitoring as currently drafted.

Item B. Item B requires the WRPR to apply to the "entire" DWSMA—but only if a groundwater monitoring well network is installed or residual soil nitrate testing is conducted. As noted above, such testing is not mandated. As a result, the commissioner's authority to issue a WRPR to the entire DWSMA is likely quite limited and will not achieve the statutory mandate of Minn. Stat. § 103H.275 to prevent exceedances of the health risk limit.

Item C. This item includes another unnecessary and complicating limitation on the scope of the WRPR that can be issued. If the commissioner has not installed a groundwater monitoring network,[66] subpart 1, item C, limits the scope of the WRPR based on estimated lag time and travel time.[67] Again, the WRPR will not necessarily apply even to the whole DWSMA established by the Commissioner of Health. MCEA objects to this unreasonable limitation on the commissioner's authority.

Item D. This item prioritizes the issuance of WRPRs. It is reasonable for the commissioner to establish criteria for prioritization, but these criteria could be expanded.

Item E. Item D states what must be included in a WRPR, but isn't specific other than including "the water resource protection requirements."[68] For a meaningful order, there needs to be

[66] Although the commissioner is required by part 1573.0040, Subp. 5 to monitor a DWSMA, the commissioner is **not** required to install a groundwater monitoring network. Thus, it is impossible to predict how many DWSMAs will be fully subject to the WRPR, once issued.

[67] The process by which the commissioner will make the determination is vaguely described in part 1573.0050, Subp. 1, Item C. As a DWSMA is generally based on the 10-year travel time to the protected well, it is unclear why the commissioner here would choose a different area to protect, and this provision therefore introduces unnecessary complication into the process. *See* Minn. R. 4720.5510.

[68] These requirements are evidently intended to be the requirements in part 1573.0060, but those requirements are only to maintain and provide upon request the field-specific records documenting nitrogen fertilizer use, to comply with the already applicable fall application and

language (at a minimum) such as "the commissioner's order must include water resource protection requirements that are necessary to ensure that pollution is minimized to the extent practicable and to prevent the pollution from exceeding the health risk limits." Even better, MDA should establish that each WRPR must include basic items, such as mandated practices, monitoring, recordkeeping, and reporting requirements, to be adequate.

Item F. Item F is unnecessary and redundant with Item A.

Item G. Item G is vague and cannot be enforced because no standards are established under which the commissioner will determine than an "area is not contributing significantly to the contamination in the well or that it is not practicable to include that part." As a result, it should simply be eliminated from the proposed rule.

1573.0050, subp. 2. This subpart addresses notice that will be given regarding the WRPR, but lacks properly articulated due process.

Item A. This item requires the commissioner to hold "at least one" public information meeting in the county affected by the proposed MRPR before it is published. Normally, a proposed permit, environmental review document, or other administrative action would first be published so that the public attending the meeting have an opportunity to review and raise questions that are meaningful. Subpart 2 should be amended to require the public informational meeting(s) to be held during the public comment period following publication of the proposed WRPR notice. The rules should specify how the commissioner will conduct the public informational meeting, particularly if the commissioner decides to use the public informational meeting as a forum for receipt of comments on the rule in lieu of or in addition to the right to request a contested case hearing under the Minnesota Administrative Procedures Act. The rule should provide that the commissioner must include a record of comments and responses to all substantive comments received during the public informational meeting when the final WRPR is issued as part of the findings on the WPRP.

Item B. This item deals with notice. It should be amended to specify that the commissioner must provide a copy of the proposed order, proposed findings, and a technical support document explaining its terms and conditions, to the "affected parties" who must include persons who are drinking the water that is threatened with nitrate contamination. This is reasonable because other agencies (i.e., the MPCA) typically provide fact sheets or technical support documents in support of their proposed actions.[69]

1573.0050, subp. 3 addresses contested case hearings.

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frozen soils prohibitions, and "comply with any water resource management requirements orders that apply to the drinking water supply management area governing the cropland over which the responsible party has control" which adds nothing and is circular in the extreme. In proposed part 1573.0070, the rule lists only content that the commissioner "shall consider." Alternative management practices can only be mandated if they are "funded" meaning that a responsible party does not bear the cost of compliance.

[69] *See, e.g.,* Minn. R. 7001.0100.

Item A. This item should be amended to provide that "any person or entity subject to the water resources protection requirements order *or affected by the water resource protection requirements order*" can petition for a contested case hearing. It is necessary to include affected persons (i.e., persons who depend on the water supply) to ensure that the persons who are supposed to be protected by the rule can exercise their rights if the commissioner's order is deficient.

Item C. This item requires the commissioner to order a "public hearing" if one is requested. A "public hearing" is not the same as a "contested case hearing." In the SONAR, MDA states that the process that it intends to follow was based on that used to create the "public waters inventory." It is unlikely that MDA has correctly selected the necessary due process, because the public waters inventory did not create any new requirements on the owners of the listed waters. The public waters inventory simply created a record of which waters were or were not public waters based on existing statutory criteria, and did not impose new requirements.[70] Furthermore, the proposed rule does not, in fact, set forth or follow the procedures that were used to adopt the public waters inventory, which involved county review and approval and special hearing teams.[71]

MCEA recommends that the commissioner create a "two option" process for receiving comments and recommendations on the proposed WRPR. The first process would be informal: holding a public informational meeting where members of the public could testify before department representatives who would then have to draft a formal "response to comments" document as part of the WRPR findings. The second process would be formal: holding a contesting case hearing under chapter 14 rules if the criteria for requesting a formal hearing are met.[72] Minn. Stat. § 14.57 provides that, unless otherwise provided by law, "an agency shall decide a contested case only in accordance with the contested case procedures of the Administrative Procedure Act." As there is no other law establishing a separate procedure, MDA must order any "contested cases" as provided under Chapter 14.

1573.0050, subp. 5. This subpart appears to allow amendments to the WRPR just with notice and comment. MCEA does not object to this process, provided that the final amended order is subject to judicial review as a final agency order. MCEA proposes that the commissioner have the duty to review and amend issued WRPRs on a 5 year basis to ensure that the terms are having the desired impact on nitrogen levels.

1573.0050, subp. 6. This subpart allows "any person subject to a final . . .order or amended order to seek judicial review." This provision suffers from the defect that it limits review only to those persons "subject to" orders, which (MCEA assumes) means that only the responsible person can appeal. Minn. Stat. § 103H.275 does not limit rights to persons "subject to" orders,

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[70] *See* Minn. Laws 1979, ch. 199, § 7 (required DNR publication, county board review, DNR notice to counties of accepting or rejecting county recommendations, publication of final listings, process by which "any person" or county could challenge the designation of specific waters as public waters, publication of final listing).
[71] *Id.*
[72] MCEA recommends that MDA use the criteria employed by other state agencies for ordering contested case hearings. *See, e.g.,* Minn. R. 7000.1900 (MPCA); Minn. Stat. § 93.483, subd. 3 (DNR mining permit).

but instead refers to "persons affected by the rule and order of the commissioner."[73] The rule must be clarified to ensure that any affected party (i.e., party that can establish standing and who has participated in administrative proceedings) can appeal an order. The rule also fails to specify how a party can obtain judicial review. Is the judicial review provided under the Minnesota Administrative Procedures Act for a "contested case" (Minn. Stat. § 14.63), which provides that an appeal must be filed in 30 days, or would review be provided under the "generic" certiorari statute, Minn. Stat. ch. 606, which provides for 60 days in which to seek review? If MDA intends that review be under the Minnesota Administrative Procedures Act, then a hearing under that act must be offered.

1573.0050, subp. 7. This provision requires the commissioner to record all final WRPRs. MCEA respectfully suggests that MDA ascertain whether this is possible, and what the effect of a "blanket" recording would be.

E. REQUIREMENTS FOR RESPONSIBLE PARTIES SUBJECT TO WRPRs (1573.0060-90).

In this part, the proposed rule establishes certain requirements for responsible parties subject to WRPRs, such as recordkeeping. Above, MCEA has proposed to include certain of these requirements (such as recordkeeping) when mitigation levels are established, and does not agree with limiting these requirements to parties that are subject to a WRPR. If MCEA's proposal is accepted, this part is needed only to specify what records must be kept and for how long, and to provide conditions on access consistent with MDA's statutory authority.

1573.0060. This provision requires a responsible party in a mitigation level 3 or 4 area to maintain field-specific records "starting with the effective date of the water resource protection requirements order." As noted above, it is unreasonable to wait to require such record-keeping until a WRPR is issued as this is a low-impact requirement that producers should be using under the BMPs to monitor their nutrient use. Item A(3) requires compliance with the fall application prohibition, but this would already be required for these producers if the DWSMA protected well has had a reading over 5.4 mg/L, which would be the case for ML3 and 4 areas receiving a WRPR, so it adds nothing and could be confusing, causing persons subject to the "part 1" fall application ban to believe that nothing is required until a WRPR is issued.

1573.0070, subp. 1. This section requires the commissioner "to consider" including the listed requirements in a WRPR. As a result, the content of the order is not cabined in any way by this rule. Under these circumstances, only the due process related to the draft order will allow parties to challenge the content of the order, but this due process is deficient as noted above. MCEA supports making certain of these content requirements mandatory with any order, i.e., field testing, monitoring, crediting of all nutrient sources, nutrient management plans, and the use of alternative management tools that the commissioners specifically finds are necessary to reduce soil nitrogen-nitrate levels in the area subject to the WRPR.

[73] Minn. Stat. § 103H.275, subd. 2(d).

MCEA is deeply troubled by the limit posed by subpart 1, item B. Item B limits the commissioner's ability to impose alternative management tools by stated that such tools can only be mandated as part of an order "provided a source of funding for increased costs related to the implementation of the alternative management tool is available to responsible parties." This is arbitrary and will thwart achievement of the goals of the Groundwater Protection Act. Other parties required to protect public resources (for example, those who are regulated under air, water or solid waste permits issued by the MPCA) must internalize the cost of compliance, and are not allowed to avoid compliance unless government money pays for it. In other regulatory programs, if a regulated party finds that the cost of compliance is unreasonable, the regulated party has the burden of seeking relief.[74] The same process should be applied to agricultural producers, especially where there are numerous sources of public funds available to defray the cost of compliance.[75] Compliance should not be limited to funded activities unless the cost of compliance would present a hardship, and then only if reasonable conditions are established in a schedule of compliance to ensure that any damage caused by the delay is limited. The proposed rule does not require any showing of hardship, and therefore is unreasonable. The prohibition on requiring AMTs, the very practices that the MDA has acknowledged will be necessary to achieve the HRL in vulnerable areas, unless funding is provided, must be removed from the rule because it is contrary to the goals of the Groundwater Protection Act. If MDA wants to provide some limited time for a responsible party to obtain funding necessary to comply with the AMTs, a schedule of compliance process could be included in the part of the rule addressing WPRPs, limited to agreements with the commissioner lasting no longer than two years. This should be adequate to address temporary situations resulting from weather events and temporary financial situations affecting a particular responsible party.[76]

1573.0070, subp. 2. This subpart addresses requirements for mitigation level 4. In the SONAR, the MDA states that in mitigation level 4, "alternative management practices that meet the requirements listed under Minn. Stat. § 103H.275, subd. 2(a) shall be considered for inclusion in a water resource protection requirements order regardless of whether or not funding is available" but this authority is not found in the rule. If ML4 area regulated parties can be mandated in a WRPR to use alternative management tools, it should be expressly stated. The cost of compliance should not be the deciding factor in determining whether a management practice should be imposed. Cost is but one factor that should be considered under the statute.[77] Item B in this section limits the commissioner's authority to require fertilizer application rates that are less than the recommended rate set by the University of Minnesota. Fertilizer application rates are set to ensure the maximum harvest level, not to protect groundwater. As the purpose of the WRPR is to protect groundwater, the commissioner must have the authority to require application rates

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[74] *See, e.g.,* Minn. R. 7000.7000.
[75] The various funding opportunities are listed on MDA's website and the website of the Board of Water and Soil Resources.
[76] For other parts of the rule, MCEA notes that state law already contains a variance process, which could be utilized by responsible parties. The proposed rule might be amended to include a reference to that process. See Minn. Stat. §§ 14.055-.056.
[77] Minn. Stat. § 103H.275, subd. 2.

that are less than recommended if the particular circumstances of the situation make such reduced rates reasonable.

1573.0070, subp. 2, item C. Subpart 2, item C, prohibits the commissioner from restricting the selection of the "primary crop." The term "primary crop" is undefined. It is unclear whether this term means that the commissioner is prohibited from requiring, as an alternative management tool, the inclusion of a nitrogen-reducing crop in a rotation, and thus is fatally vague. To achieve the goal of the Act, the commissioner must have the authority to require, if circumstances demand, that extremely vulnerable acres not be planted with crops that contaminate drinking water supplies, or that a different crop be added into a crop rotation, such as alfalfa or grasses, that would quickly reduce soil nitrate levels.[78] To eliminate the commissioner's authority to require a technique that is well-established as a method to reduce soil nitrogen-nitrate levels is arbitrary.

1573.0070, subp. 3. Subpart 3 provides the commissioner, with unlimited discretion, the authority to provide exemptions to a WRPR "on a site-specific basis." There is no description whatsoever of how this process would be made public or controlled. As a result, this provision is fatally vague. Instead, the commissioner should establish a fair temporary schedule of compliance process whereby particular conditions that create hardship, on a site-specific basis, can be fairly evaluated and addressed in a controlled fashion.

1573.0080. This rule provides that a responsible party who is certified through the Minnesota Agricultural Water Quality Certification Program ("MAWQCP") is "deemed to be in compliance" with this chapter. MDA's rule proposal requires the Department to presume that land certified under the MAWQCP is cropland where the nitrogen fertilizer use recommendations have been fully implemented. However, the MAWQCP does not require certified farms to either meet these recommendations, or implement any other practices that reduce nitrate contamination in groundwater.[79] Unless MDA provides evidence that a certified farm has implemented the nitrogen fertilizer use recommendations, this presumption is not justified.

1573.0090. subp. 1. This subpart requires the commissioner to maintain a list of alternative management tools ("AMT") on the MDA website, and to note if the tool can be substituted for a nitrogen fertilizer best management practice. No standard is provided for when this substitution is to be authorized, making this rule fatally vague. The commissioner should, *in this rule*, list the alternative management tools and which AMTs can be substituted for specific BMPs or amend the rule to provide a more functional definition of AMT.

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[78] *See* De Haan et al, *Residual soil nitrate content and profitability of five cropping systems in northwest Iowa*, PLOS One, March 1, 2017; 12(3); e0171994, available at https://www.ncbi.nlm.nih.gov/pmc/articles/PMC5332022/. *See also* Comment of Dr. Gyles Randall, August 1, 2018.

[79] *See Minnesota Agricultural Certainty Program: Is It Working for Water Quality, An Assessment of Minnesota's Agricultural Water Quality Certification Program*, MCEA, December 2015.

Item C. Item C allows a responsible party subject to a WRPR to implement an AMT if the commissioner's list allows it, subject only to keeping records of all AMTs used "and the specific water resource protection requirements order that allows the alternative management tool to be used." This is reasonable if the only time an AMT is allowed to substitute for a BMP is under the control of a WRPR, but the rule is not clear.

1573.0090, subp. 2. This subpart allows a person who is subject to a WRPR to apply to the commissioner for an alternative protection requirement pursuant to statute. However, the rule fails to establish any due process concerning how such a substitution will be approved, and is therefore deficient. MCEA suggests requiring such alternative protection requirements to be proposed during the comment period on the WRPR.

IV. CONCLUSION

MCEA supports the need for a rule to prevent and mitigate nitrate pollution in groundwater. The instant rule falls short of what is needed and what Minn. Stat. § 103H.275 demands, in particular because it offers little protection to persons who get their drinking water from private wells, and because it continues to lean on BMPs to reduce nitrate levels despite the fact that BMPs have not succeeded in reducing nitrate levels to date. In order to be approved, the rule must be amended to eliminate vague and unenforceable language and the rule must ensure that groundwater is protected and that the HRL is not exceeded. Finally, where the rule is to be used as the basis for issuance of an order, it must include adequate standards and procedures to ensure that all affected parties have an opportunity to seek meaningful relief, and should not prevent the commissioner from requiring reasonable agricultural practices that reduce soil nitrate/nitrogen levels.

Sincerely,

<u>/s/Ann Cohen</u>
Ann Cohen
Staff Attorney
Minnesota Center for Environmental Advocacy

Exhibit B

Clean Water Organizations'
Comments on the Proposed 2021 NPDES General Permit
for Concentrated Animal Feeding Operations

July 23, 2020

INTRODUCTION

Nitrate pollution from manure and commercial fertilizer is a serious problem in Minnesota. Despite laws intended to limit manure application, nitrate pollution from excess manure continues to contaminate drinking water and degrade aquatic habitats. Minnesota Center for Environmental Advocacy,[1] Friends of the Mississippi River,[2] Minnesota Well Owners Organization,[3] and Sierra Club North Star Chapter[4] (collectively, "Clean Water Organizations") have concluded that the

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[1] Minnesota Center for Environmental Advocacy ("MCEA") is a Minnesota non-profit organization that defends every aspect of Minnesota's environment, relying upon facts, science, and the law. For nearly half a century, MCEA has worked with community members, decision makers, and other partners to protect Minnesota's natural resources and the health and wellbeing of all the state's citizens. As a public interest organization, MCEA works to ensure that Minnesota's bedrock environmental laws are enforced and defended. It has a particular interest in water quality, and it has engaged in legislative and administrative advocacy, rulemaking and permitting proceedings, and litigation to protect Minnesota's water quality.

[2] Friends of the Mississippi River ("FMR") is a nonprofit established in 1993 to engage Minnesotans to protect, restore, and enhance the Mississippi River and its watershed in the Twin Cities Metro area. As part of its efforts to protect and preserve a clean Mississippi River, FMR works with 2,500 members, 2,000 advocates, and over 5,000 volunteers yearly. A major part of FMR's work is focused on watershed protection for the Mississippi River, including preserving water quality by advocating for land use policies and practices that will lead to cleaner water throughout the entire watershed.

[3] Minnesota Well Owners Organization ("MNWOO") is a nonprofit organization for private well owners that works to preserve, protect, and restore Minnesota's water resources and to ensure the safety of those who use private wells for drinking water. MNWOO also provides education, technical and legal services, and advocacy for private well owners. MNWOO works to protect the water quality of the 1.2 million private wells in Minnesota, more than 10% of which are contaminated at levels above allowed health risk limits. This includes many private wells with elevated levels of nitrates.

[4] The Sierra Club North Star Chapter ("SCNS") is a nonprofit organization that is the Minnesota branch of the national Sierra Club, America's oldest, largest, and most influential grassroots environmental organization. SCNS works through grassroots political action, including its 80,000 members, to strategically address Minnesotans' most pressing environmental issues. One of SCNS's priorities in its water program is fighting agricultural pollution in Minnesota, including nitrate pollution.

newly proposed National Pollutant Discharge Elimination System ("NPDES") General Permit for Concentrated Animal Feeding Operations ("Proposed General Permit") drafted by the Minnesota Pollution Control Agency ("MPCA") does not effectively address this problem or follow Minnesota's laws regarding land application of manure. Unless MPCA revises the Proposed General Permit to better reflect the protective standards of the law, Minnesota's water quality is likely to worsen during the permit's tenure.

Since the MPCA issued the 2016 NPDES General Permit for Concentrated Animal Feeding Operations ("2016 General Permit"), Minnesota's nitrate pollution problem has intensified. The drinking water for nearly half a million Minnesotans is now tainted with elevated levels of nitrates, which can cause cancers and other diseases. Now, MPCA has an opportunity to provide better protections for Minnesota's waters, while ensuring farmers can meet their crops' nitrogen needs, through the Proposed General Permit. Yet, the Proposed General Permit perpetuates the same problems that exist in the 2016 General Permit, which will lead to continued contamination of water needed for drinking, recreation, wildlife, and aquatic habitat. Accordingly, the Clean Water Organizations suggest changes to the Proposed General Permit to ensure the protection of water quality and compliance with Minnesota laws regarding manure application.

Most importantly, the Clean Water Organizations propose that the MPCA revise the Proposed General Permit to limit manure application rates to truly reflect expected crop nitrogen needs. As it did in the 2016 General Permit, the MPCA has referenced recommendations for manure application based on maximizing the economic return for farmers, not on the actual plant needs for nitrogen. These recommendations are inconsistent with the governing rules for land application of manure and have led to over-application by many farmers. MPCA must amend the Proposed General Permit to ensure that the referenced recommendations are consistent with the rule's requirements. In addition, the Clean Water Organizations request that the MPCA revise Proposed General Permit to restore the section from the 2016 General Permit regarding pre-plant testing for nitrates, provide clearer requirements to farmers about determining soil temperatures prior to manure application, strengthen October restrictions on manure application, prohibit application of solid manure in December and January, and require geographic-information-system ("GIS") identification of fields in manure management plans. The Clean Water Organizations ask that MPCA revise the permit to make these changes or grant a contested case hearing so that material issues of fact can be heard by a neutral administrative law judge who can develop the record and present a recommendation to the MPCA.

I. MINNESOTA'S DRINKING WATER AND AQUATIC HABITATS ARE ALREADY POLLUTED WITH DANGEROUS LEVELS OF NITRATES

Minnesota takes great pride in its water. Minnesotans depend on their lakes, rivers, and groundwater as sources of clean, drinkable water and habitats for wildlife. While the "Land of 10,000 Lakes" claims the headwaters of the Mississippi River and other historical, cultural, and economically significant waterways, increasing levels of nitrates, which have profound impacts on aquatic and human life, are threatening the health of many of Minnesota's great waters.

A. Minnesota's Nitrate Pollution Is Worsening.

Nitrate contamination in Minnesota's drinking water systems is getting worse. Data collected by the U.S. Environmental Protection Agency ("EPA") showed that between 1995 and 2018, 63% of Minnesota's 115 community wells experienced growing nitrate contamination, with the southern part of the state experiencing the largest increases.[5] As one example, in the Rock County Rural Water System, located in southwestern corner of the state, 24 of the 107 tests

[5] Envtl. Working Grp., *Nitrate Trends in Minnesota Drinking Water*, https://www.ewg.org/interactive-maps/2020-in-minnesotas-farm-country-nitrate-pollution-of-drinking-water-getting-worse/map/ (last visited July 17, 2020).

collected during this time frame revealed nitrate levels exceeding 10 milligrams per liter ("mg/l"), the "safe for consumption" threshold set by the EPA in 1962.[6] Across the state in Winona County, nitrates in the Utica water system surged between 2016 and 2018.[7] Nitrates also threaten metropolitan area community water supplies. EPA tests collected from the Kjellberg system in Wright County, which serves approximately 1,000 people, revealed nitrate levels greater than 3 m/l in more than half of the 204 tests obtained during the study period.[8] In Hastings, 217 out of 313 tests of its groundwater supply, which serves over 22,000 Minnesotans, showed nitrate concentrations exceeding 5 mg/l.[9]

The Minnesota Department of Health's ("MDH") testing also shows troubling trends for private wells. Prior to 2011, less than 1% of MDH private well tests showed nitrate contamination exceeding 10 mg/l.[10] However, with the exception of 2016, beginning in 2011 and every year thereafter, more than 1% of tested private wells were contaminated with nitrate levels exceeding the federal safe consumption limit.[11]

MPCA data confirms that nitrate levels in Minnesota's surface waters are also increasing. Data collected between 1976 and 2010 reveal that 22 of Minnesota's 32 major rivers shows a statistically significant upward trend in overall nitrate concentrations.[12] These rivers showed increases in nitrate concentrations as much as an astonishing 268% during the 30 to 35 year study

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[6] *Id.*
[7] *Id.*
[8] *Id.*
[9] *Id.*
[10] Minn. Dep't of Health, *Nitrate in Private Wells*, https://data.web.health.state.mn.us/nitrate_wells (last visited July 17, 2020), attached as Ex. 3.
[11] *Id.*
[12] Minn. Pollution Control Agency, *Nitrogen in Minnesota Surface Waters* 150 (2013), *available at* https://www.pca.state.mn.us/sites/default/files/wq-s6-26a.pdf, [hereinafter "Nitrogen in Surface Waters].

period.[13] Most of MPCA's regularly monitored testing sites along the Mississippi River have recorded an explosive growth of nitrate concentrations, with MPCA noting that, except for two specific sites, "nitrate concentrations [in the Mississippi River] have been increasing everywhere downstream of Clearwater at a rate of 1% to 4% per year" in recent years.[14] MPCA monitoring sites on the St. Croix River reflected a 49% growth in nitrate concentration between 1976 and 2004.[15] MPCA data collected from major tributaries similarly shows nitrate concentrations increased in the majority of sampled waterways during the study period, with the greatest recorded growth reaching 207%.[16] And the contaminated Rock County Rural Water System discussed above is a surface water source of drinking water.[17]

B. Nitrate Pollution Poses Dangers For People And Aquatic Life.

This increase in nitrate pollution is a serious problem for Minnesotans, as elevated nitrate levels are hazardous to human health and wreak havoc on aquatic life. Increasing nitrate contamination threatens the health of the nearly 75% of Minnesotans who rely on groundwater for their drinking water.[18] Consuming water contaminated with nitrates is associated with adverse birth outcomes, thyroid disease, neural tube defects, and several cancers.[19] Elevated nitrate levels in drinking water are especially dangerous for infants, pregnant women, and people with certain

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[13] *Id.* at 151.
[14] *Id.* at 398.
[15] *Id.* at 177.
[16] *Id.* at 150-51, 53.
[17] Envtl. Working Grp., *supra* note 2.
[18] Minn. Dep't of Agric., *Minnesota Nitrogen Fertilizer Management Plan* 20 (2019), *available at* https://www.mda.state.mn.us/sites/default/files/2019-08/nfmp2015addendedada_0.pdf, attached as Ex. 4.
[19] Alexis Temkin et al., *Exposure-Based Assessment and Economic Valuation of Adverse Birth Outcomes and Cancer Risk Due to Nitrate in United States Drinking Water*, 176 ENVIRONMENTAL RESEARCH 1-2 (2019), *available at* https://www.sciencedirect.com/science/article/pii/S001393511930218X, attached as Ex. 5.

blood disorders, who are at risk of methemoglobinemia, or "blue-baby syndrome," which causes severe oxygen deficiency that, without medical treatment, can lead to death.[20]

The EPA set the current health standard for nitrate in water at 10 mg/l in 1962 largely to protect against blue-baby syndrome. New studies strongly suggest that the current standard does not reflect the present understanding of nitrate associated health risks.[21] According to a recent study by Environmental Working Group ("EWG"), lower levels, even below 5 mg/l, are associated with higher risks of certain cancers and adverse birth outcomes.[22] EWG concluded that nitrate pollution of drinking water at levels far below the legal limit may cause up to 12,594 cases of cancer each year in the United States.[23] This tracks large-scale studies in Spain and Italy, published in 2016, and Denmark, published in 2018, which found statistically significant increases of colorectal cancer risks associated with nitrate levels below 2 mg/l.[24] Minnesota regulators should be exceedingly concerned by these new studies because hundreds of thousands of Minnesotans currently access public water systems contaminated with nitrates exceeding 3 mg/l.[25] Even worse, the data shows that over 150,000 Minnesotans accessed public water systems with nitrate contamination levels exceeding Minnesota's health standard of 10 mg/l.[26] Nitrates also plague private water supplies. Minnesota Department of Agriculture data collected pursuant to its Nitrate Clinic Outreach Program shows that 7.7% of 2,063 private well tests reported nitrate levels

[20] Minn. Dep't of Agric., *supra* note 15, at 7-8.
[21] Minn. Dep't of Health, *Nitrate in Well Water*, https://www.health.state.mn.us/communities/environment/water/wells/waterquality/nitrate.html#:~:text=Safe%20Level,water%20for%20public%20water%20supplies (last visited July 17, 2020), attached as Ex. 6; Sarah Porter & Anne Weir Schechinger, Envtl. Working Grp., *Tap Water for 500,000 Minnesotans Contaminated with Elevated Levels of Nitrate* (Jan. 14, 2020), attached as Ex. 7.
[22] Temkin et al., *supra* note 16, at 11; Porter & Schechinger, *supra* note 18.
[23] Porter & Schechinger, *supra* note 18.
[24] *Id.*
[25] Minn. Dep't of Health, *supra* note 18.
[26] Porter & Schechinger, *supra* note 18.

exceeding 10 mg/l.[27] The 2012 data shows an increase in the percentage of private wells exceeding the current standard from samples tested in 2011, suggesting nitrate infiltration into well water supplies throughout Minnesota is an increasing problem.[28] In fact, due to a lack of testing, the number of contaminated wells in Minnesota may actually be much greater.[29]

In addition to impairing drinking water, elevated nitrate concentrations in Minnesota's waterways are significant contributors to aquatic habitat destruction. High nitrate levels in surface waters directly contribute to eutrophication, which stimulates excessive plant growth and depletes oxygen levels in the water, causing harm or death to fish.[30] Nitrate also is directly toxic to fish and other aquatic organisms, causing heart and liver problems, electrolyte imbalance, and increased vulnerability to bacterial and parasitic diseases.[31] Due to nitrate's solubility in water, its ultimate intrusion into the Mississippi River is in part to blame for the hypoxic "dead zone" in the Gulf of Mexico.[32] One study estimates that the 158 million pounds of nitrate that leave Minnesota annually via the Mississippi River has caused nearly $2.4 billion in annual damages to fish stocks and habitat for more than 30 years.[33]

C. Much Of Minnesota's Nitrate Problem Is Caused By Agriculture.

Agriculture is Minnesota's largest contributor to nitrate pollution—specifically, nitrate runoff or leaching from farmland from commercial nitrogen fertilizer or manure. According to the

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[27] Minn. Dep't of Agric., *2012 Nitrate Clinic Outreach Summary Report* 2 (2012), *available at* https://www.mda.state.mn.us/sites/default/files/inline-files/2012nitrateclinic.ashx.pdf.
[28] *Id.*
[29] Jennifer Bjorhus, *One in Eight Minnesotans Drink Nitrate-Tainted Tap Water, Report Says*, STAR TRIBUNE (Jan. 14, 2020), *available at* https://www.startribune.com/one-in-eight-minnesotans-drink-nitrate-tainted-water/566960262/.]
[30] Nitrogen in Surface Waters, *supra* note 9, at 43.
[31] *Id.*
[32] *Id.* at 36, 46.
[33] Rebecca Boehm, Union of Concerned Scientists, *Reviving the Dead Zone* 3 (2020), *available at* https://www.ucsusa.org/sites/default/files/2020-06/reviving-the-dead-zone.pdf.

Minnesota Department of Agriculture, approximately 2.7 million tons of inorganic nitrogen are added to Minnesota soils each year, and 80% of that nitrogen is attributable to agriculture.[34] Unfortunately, a significant portion of that nitrogen reaches state waters. In its 2013 study, MPCA estimated that cropland sources account for almost 73% of the statewide nitrate load to streams and lakes in an average year.[35] A "significant" part of this comes from applied manure.[36] Notably, MPCA found that the largest increases in nitrate pollution are clustered in the southern third of the state, where most of Minnesota's confined animal feeding operations are located.[37]

This is unsurprising. Domestic and international studies have long confirmed an association between livestock concentration and a documented degradation in water quality. For example, Iowa watersheds with the highest livestock density had some of the highest stream concentrations of nitrates in the state.[38] In the Chesapeake Bay watershed, for example, land application of manure contributes to elevated ground water nitrate concentrations and suffocating algae blooms.[39] This connection is not new. In the 1960s, nutrient runoff from the Danube River seriously degraded the northwestern Black Sea.[40] Conditions rapidly improved after the fall of communist regimes in the late 1980s precipitated the closure of many large animal farms.[41]

The ease with which nitrate escapes the fields is largely to blame. A significant amount of nitrogen from applied manure is lost through volatilization, runoff, and leaching. The University of Minnesota Extension Service ("Extension Service") estimates that up to 50% of the nitrogen

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[34] Minn. Dep't of Agric., *supra* note 15, at 33-34.
[35] Nitrogen in Surface Waters, *supra* note 9, at 205.
[36] *Id.* at 219.
[37] *Id*. at 295; Minn. Pollution Control Agency, https://resources.gisdata.mn.gov/pub/gdrs/data/pub/us_mn_state_pca/env_feedlots/preview/preview.jpg (last visited July 17, 2020).
[38] Dr. Christopher Jones, *Expert Report* 6 (2020), attached as Ex. 1.
[39] *Id.*
[40] *Id.*
[41] *Id.*

from manure may be lost through these processes.[42] University of Minnesota research indicates that applications of nitrate above the economically optimum nitrogen rate for a specific crop significantly increase the potential for nitrate losses.[43]

Partly to blame for the nitrogen losses is the way manure is applied by farmers and how it is used by plants. Manure contains both organic and inorganic forms of nitrogen.[44] While inorganic nitrogen—in the form of nitrate or ammonium—is available to be used by plants for growth immediately, the organic form is not.[45] Before plants can take up organic nitrogen, it must first be mineralized by microorganisms in the soil to inorganic forms.[46] After this conversion process, however, the inorganic form ammonium can be easily converted into gas and lost into the atmosphere through volatilization, only to cause water pollution when it dissolves in rain and returns to earth.[47] But more significantly, since inorganic nitrates are soluble, they are prone to leaching.[48] Thus, the converted nitrate is highly susceptible to filtering through the soil profile and into the groundwater.[49]

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[42] Univ. of Minn. Extension, *Manure Application Methods and Nitrogen Losses*, (2018), https://extension.umn.edu/manure-land-application/manure-application-methods-and-nitrogen-losses, [hereinafter "Manure Application Methods"], attached as Ex. 8.
[43] Melissa Wilson, Univ. of Minn. Extension, *Guidelines for Manure Application Rates*, https://extension.umn.edu/manure-land-application/manure-application-rates (last visited July 17, 2020), [hereinafter "Guidelines for Manure Application"], attached as Ex. 9.
[44] Melissa Wilson, Univ. of Minn. Extension, *Manure Characteristics*, https://extension.umn.edu/manure-land-application/manure-characteristics (last visited July 17, 2020), [hereinafter "Manure Characteristics"], attached as Ex. 10.
[45] *Id.*; Manure Application Methods, *supra* note 39.
[46] Manure Characteristics, *supra* note 41; Ron Wiederholt, N.D. State Univ. Extension Serv., *Environmental Implications of Excess Fertilizer and Manure on Water Quality* (2017) https://www.ag.ndsu.edu/publications/ environment-natural-resources/environmental-implications-of-excess-fertilizer-and-manure-on-water-quality, attached as Ex. 11.
[47] *Id.*
[48] Scott C. Killpack & Daryl Bucholz, Univ. of Mo. Extension, *Nitrogen in the Environment: Leaching*, https://extension2.missouri.edu/wq262 (last visited July 17, 2020).
[49] Wiederholt, *supra* note 43.

In addition, if a farmer applies manure incorrectly—in too large of quantities, on vulnerable soils, or at improper times—leaching or runoff is more likely. If too much manure is applied, plants do not take it up, allowing nitrates to leach away.[50] If manure is applied to coarse-textured soils, nitrates can sink past plant roots and into groundwater.[51] If manure is applied early in the fall on ground that is too warm, it will quickly convert to into nitrate and likely be lost before spring planting; but if manure is applied in the winter on frozen soils, it is unlikely to be incorporated into the soil and instead runs off during melts or spring rains.[52]

In addition, multiple factors make manure challenging to manage as fertilizer and encourage over-application. First, the nutrient concentration in manure is far lower and much more uncertain than commercial fertilizer.[53] Time windows for effective manure application are narrower than with commercial fertilizer, and farm implements designed to distribute manure to fields can apply material non-uniformly.[54] Nitrogen loss to the atmosphere through volatilization can be significant and difficult to predict.[55] And insufficient storage capacity for manure may lead to farmers applying manure at ineffective times, when it is more likely that nutrients will run off or leach into the water and be lost to plants.[56] These uncertainties may lead farmers to over-apply manure in their eagerness to ensure that plants have abundant sources of nitrogen to use as they grow—or may even cause them to apply manure in the fall followed by commercial fertilizer in

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[50] Guidelines for Manure Application, *supra* note 43.
[51] *Id.*
[52] Melissa Wilson, Univ. of Minn. Extension, *Manure Timing*, https://extension.umn.edu/ manure-land-application/manure-timing (last visited July 17, 2020), [hereinafter "Manure Timing'], attached as Exhibit 12.
[53] Jones, *supra* note 35, at 6.
[54] *Id.*
[55] *Id.*
[56] *Id.*

the spring.[57] These factors "frequently result in manured land receiving larger amounts of nutrient than those that receive only commercial N [fertilizer]."[58]

This is not necessarily a problem for the farmer, however. Unlike commercial fertilizer, which must be purchased, farmers with large livestock operations have access to free, always available manure in ample quantities. In some scenarios, research has found maximizing nitrogen loss to the environment is more profitable than attempting to use all of the nutrients from the manure.[59] For these farmers, manure is a waste product, and squandering its nutrients is not necessarily economically wasteful.[60] In fact, because of the costs of hauling manure, farmers may find it more profitable to concentrate manure applications on the fields closest to the animal confinements and buy commercial fertilizer—with its higher, uniform, and known nitrogen content—for the remaining fields.[61]

Overall, for farmers, the economic risk of under-applying manure is far greater than that of over-applying.[62] When a farmer under-applies nitrogen, the farmer takes on a considerable economic risk: that crop growth will not be maximized, leading to lower yields and less product to sell.[63] But when a farmer over-applies nitrogen, the farmer is only taking on the risk of the cost of the additional manure—which in many cases costs nothing at all—while increasing the opportunity to maximize crop yields and product for sale.[64] While the economic risk to the *farmer* of over-application is small, however, the *environmental* risk of over-application is severe.[65] Any

[57] *Id.*
[58] *Id.*
[59] *Id.* at 6.
[60] *Id.*
[61] *Id.*
[62] *Id.* at 8.
[63] *Id.*
[64] *Id.*
[65] *Id.*

excess nitrate not taken up by crops is vulnerable to loss to the atmosphere, aquifers, lakes, and streams.[66] This increases the costs to the public, which takes on the burden of addressing pollution, but does not increase costs to the farmer.[67] Accordingly, over-application of nitrogen "transfers the economic and natural risks associated with nitrogen application from the individual farmer to the public." [68]

Preventing nitrate from reaching water is vital to successfully addressing the growing nitrate pollution problem. Prevention is far less costly than treatment of contaminated water—when treatment is even possible.[69] Accordingly, controlling manure application to prevent nitrate runoff and leaching is critical to protecting public health from still worse increases in nitrate pollution. MPCA must ensure that the Proposed General Permit imposes restrictions that will adequately limit nitrate pollution to protect the people and aquatic habitats of Minnesota.

II. MINNESOTA LAW PLACES LIMITS ON LAND APPLICATION OF MANURE

Because of the harm posed by the threat of nitrate pollution, and the economic incentive of farmers to over-apply nitrogen, MPCA adopted a rule—Minn. R. 7020.2225, subp. 3 ("Land Application Rule")—that imposes limits on the amount of manure that can be applied to fields as fertilizer. The Proposed General Permit must include those limitations.[70]

The Land Application Rule requires that manure application be "limited" so that "the estimated plant available nitrogen from all nitrogen sources does not exceed *expected crop nitrogen needs* for nonlegume crops and *expected nitrogen removal* for legumes."[71] In other words,

[66] *Id.* at 2.
[67] *Id.* at 8.
[68] *Id.*
[69] Minn. Dep't of Agric., *supra* note 15, at 18, 68.
[70] Minn. R. 7001.1080, subp. 1 (stating that any NPDES permit issued by the MPCA must "contain conditions necessary for the permittee to achieve compliance with all Minnesota or federal statutes or rules").
[71] Minn. R. 7020.2225, subp. 3(A) (emphasis added).

farmers must determine how much nitrogen their crops are expected to need or remove from the soil, how much nitrogen is available to their crops from all sources, and how much manure is needed to make up the difference between the needed nitrogen and available nitrogen. Then farmers must limit their manure application to ensure the application does not provide more nitrogen than the crops "need" or "remove."

To perform this calculation, farmers must first determine "expected crop nitrogen needs," "crop nitrogen removal rates," and "estimated plant available nitrogen." According to the rule, these variables "must be based on the most recent published recommendations of the University of Minnesota Extension Service or of another land grant college in a contiguous state."[72] Farmers must also identify all sources of nitrogen available to their crops, including "commercial fertilizer nitrogen, soil organic matter, irrigation water, legumes grown during previous years, biosolids, process wastewater, and manure applied for the current year and previous years."[73]

The rule provides some flexibility for farmers, however. Once the manure application calculation has been performed, farmers may deviate up to 20% from the Extension Service recommendations "where site nutrient management history, soil conditions, or cool weather warrant additional nitrogen application."[74] And if crop nitrogen deficiencies are "visible" or "measured," farmers may be able to apply even more nitrogen than the extra 20%.[75]

III. THE PROPOSED GENERAL PERMIT SHOULD BE REVISED TO PROTECT WATER QUALITY AND COMPLY WITH MINNESOTA RULES

While the Proposed General Permit includes some positive changes, the draft does not go far enough to protect Minnesota's water quality or comply with the Land Application Rule. Unless

[72] *Id.*, subp. 3(A)(1).
[73] *Id.*, subp. 3(A)(3).
[74] *Id.*, subp. 3(A)(2).
[75] *Id.*

MPCA makes changes, nitrate pollution in Minnesota is likely to worsen during the five-year tenure of the Proposed General Permit. Accordingly, the Clean Water Organizations request MPCA make the following changes to the Proposed General Permit.

A. Section 13.3: Limitation Of Manure Application Rates

First, MPCA must revise the Proposed General Permit to limit rates of manure application so that application is truly restricted to the amount of nitrogen the crop needs, as required by the Land Application Rule. As written, the Proposed General Permit references recommendations from the Extension Service and the MPCA for plant nitrogen needs that are based on economic risk and cost factors that are unrelated to the amount of nitrogen a typical crop will actually need or remove. This is called the Maximum Return to Nitrogen, or MRTN, system. Based on analysis by experts Dr. Gyles Randall, professor emeritus at the University of Minnesota's Department of Soil, Water, and Climate, who has conducted numerous studies relating to plant nitrogen needs and removal; and Dr. Christopher Jones, research engineer at Iowa State University, the MPCA's referenced recommendations are not consistent with the standard established by the Land Application Rule.

1. MRTN is not a measure of expected crop nitrogen needs or expected nitrogen removal.

Under the Land Application Rule, farmers must "limit[]" manure application so that the plant available nitrogen in the soil from all nitrogen sources is no more than "expected crop nitrogen needs" for nonlegumes and "expected nitrogen removal" for legumes.[76] The Land Application Rule states that the "expected crop nitrogen needs" and "expected nitrogen removal" must be based on the most recent published recommendations from the Extension Service (or of

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[76] *Id.*, subp. 3(A).

another land grant college in a contiguous state).[77] The Proposed General Permit, accordingly, identifies recommendations from the Extension Service and specifically two fact sheets from MPCA to use in determining "expected crop nitrogen needs" and "expected nitrogen removal."[78] These fact sheets direct users to an Extension Service website, entitled "Calculating Manure Application Rates," which directs users to first "find the nutrient needs of the crop."[79] To do so, users are directed to another Extension Service website, called "Guidelines for Manure Application Rates." This website provides recommendations based on the MRTN system, for example, 195 pounds of nitrogen per acre for corn following corn and 150 pounds of nitrogen per acre for corn following soybeans.[80]

The MRTN referred to in these documents is based on three variables: expected crop price, expected nitrogen source cost, and expected crop production in response to the amount of fertilizer

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[77] *Id.*, subp. (3)(A)(1).

[78] Minn. Pollution Control Agency, Proposed General Permit § 13.3 (2020) [hereinafter "Proposed General Permit"] (directing permit holders to "the most recent recommendations of the Extension Service and the MPCA fact sheets '*Manure Nitrogen Rates For Corn Production (wq-f8-18)*' and '*Manure Management For Corn On Irrigated Sandy Soils (wq-f8-52)*'" (emphasis added)); *see also* Minn. Pollution Control Agency, *Manure Nitrogen Rates for Corn Production (wq-f8-18)* (2019) [hereinafter "Manure Nitrogen Rates for Corn"], attached as Ex. 13; Minn. Pollution Control Agency, *Manure Management For Corn On Irrigated Sandy Soils (wq-f8-52)* (2016), attached as Ex. 14.

[79] Melissa Wilson, Univ. of Minn. Extension, *Calculating Manure Application Rates* (2019), https://extension.umn.edu/manure-land-application/calculating-manure-application-rates, attached as Ex. 15.

[80] Guidelines for Manure Application, *supra* note 40. Concerningly, the MRTN recommendations under the current Extension Service documents are much higher than under previous versions of the recommendations. For example, the 2011 recommendations from Extension Service identify the MRTN at the 0.05 ratio as 155 lb. N/acre for corn after corn, and 120 lb. N/acre for corn after soybeans (and are even lower for less productive soils). It is unclear to MCEA why the recommendations have risen by 25% in both cases: 40 lb. N/acre for corn after corn and 30 lb. N/acre for corn after soybeans. This is a substantial and unexplained change that is almost certain to have significant environmental effects. *See* Univ. of Minn. Extension, *Fertilizer Guidelines for Agronomic Crops in Minnesota* 15 (2011), available at https://conservancy.umn.edu/bitstream/handle/11299/198924/Fertilizer%20Guidelines%20for%20Agronomic%20Crops%20in%20Minnesota.pdf?sequence=1&isAllowed=y.

applied.[81] While the expected crop production is based on research into plant nitrogen needs, the other variables can significantly change the recommended amount of nitrogen farmers should apply.[82] Accordingly, recommendations based on the MRTN system are intended to maximize economic performance for farmers, not simply to provide the crop with the nitrogen it needs to grow.[83]

Specifically, the MRTN calculates a ratio of the cost of commercial nitrogen fertilizer to the expected sale price for that crop. For example, if anhydrous ammonia fertilizer is being sold for $0.30/lb.-N, and the price of corn is $3.00 per bushel, the ratio will be 0.10.[84] This ratio is then used to determine how much nitrogen should be applied to a field to achieve the most *cost-effective* outcome.[85] Plants can only use a certain amount of nitrogen—at some point, plants stop taking in nitrogen from the soil and further application will produce no additional plant growth. However, at a certain point before plants reach this maximum growth, the incremental increase of nitrogen applied to the crop will produce a diminishing return in terms of crop yield.[86] Thus, the cost of adding that extra fertilizer to achieve the smaller potential growth becomes less cost-effective for the farmer.[87] The MRTN identifies the crucial point that produces the *maximum economic return for the farmer*. Beyond that point, the revenue generated from the additional bushels produced by additional fertilizer will (in theory) be less than the cost of the extra fertilizer applied to produce those bushels.[88] But if fertilizer is cheap, the MRTN system recommends additional applications

[81] *See* Iowa State Univ. Agronomy Extension & Outreach, *Corn Nitrogen Rate Calculator* (2020) [hereinafter "Corn Nitrogen Calculator"], available at http://cnrc.agron.iastate.edu/.
[82] *See id.*
[83] *See* Manure Nitrogen Rates for Corn, *supra* note 75, at 1.
[84] Jones, *supra* note 35, at 5-6.
[85] Corn Nitrogen Rate Calculator, *supra* note 78.
[86] Jones, *supra* note 35, at 5.
[87] *Id.*
[88] *Id.* at 6.

in the hope that additional grain yields will occur, even if plants are unlikely to need the additional nitrogen and nitrogen loss to groundwater is highly likely. For this reason, the MRTN does not strictly focus on the magnitude of the grain yield or the crop needs for nitrogen, but instead on the economic return to the farmer.[89]

The recommendations generated by the MRTN system do not align with the Land Application Rule's requirement that manure application be limited to "expected crop nitrogen needs" for nonlegumes or "expected nitrogen removal" for legumes.[90] Contrary to the rule's language, the recommendations identified by the Proposed General Permit do not in fact define "expected crop nitrogen needs" or "expected nitrogen removal." Instead, they define the *maximum economic return to nitrogen* for farmers. The growth needs of a plant are not the same as a farmer's desire to maximize economic return. Actual crop nitrogen needs are dependent on a number of variables, including the timing, intensity, and total amount of precipitation; amount of sunshine; insect, weed, and disease pressures; other nutrient deficiencies (such as phosphorus, potassium, and sulfur); the amount of soil organic matter (which breaks organic nitrogen down into a form plants can use); and soil type and texture.[91] The MRTN system includes no variables for these factors. Instead the MRTN recommendations are explicitly based on *fertilizer and crop price*, not *crop needs,* and accordingly these recommendations allow manure applications that likely exceed crop needs if it appears the farmer may economically profit.

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[89] *Id.* at 6.
[90] Minn. R. 7020.2225, subp. 3(A).
[91] Jones, *supra* note 35, at 3. Notably, the MPCA fact sheet recognizes that some fields can be highly productive without applying the maximum MRTN, based on different conditions. *See* Manure Nitrogen Rates for Corn, *supra* note 75, at 1. For example, the fact sheet acknowledges that fields in southeastern Minnesota with loess soils need less nitrogen to maximize yields. *Id.* But MPCA provides no recommendation for what the nitrogen level should be in these situations.

Because the section of the Proposed General Permit that identifies the MPCA fact sheets and Extension Service websites is based on the MRTN, the Proposed General Permit is inconsistent with the requirements of the Land Application Rule. The MPCA must adjust the recommendation to reflect the rule's requirement that the application rate must be strictly based on expected crop nitrogen needs and expected nitrogen removal. The Clean Water Organizations therefore propose that Section 13.3 be revised as follows:

> The Permittee shall ~~control~~ limit manure application rates so the estimated nitrogen available to crops from all nitrogen sources (including commercial fertilizer) does not exceed expected annual crop nitrogen needs for non-legumes and expected nitrogen removal for legumes. Expected crop nitrogen needs, crop nitrogen removal rates, and estimated plant available nitrogen from manure and legumes must be based on the most recent published recommendations of the University of Minnesota Extension Service, but must not be based on recommendations incorporating cost-factors for nitrogen fertilizer (i.e., MRTN system).. ~~based on the most recent recommendations of the MES and the MPCA fact sheets "*Manure Nitrogen Rates For Corn Production (wq-f8-18)*" and "*Manure Management For Corn On Irrigated Sandy Soils (wq-f8-52)*".~~ The Permittee may use recommendations for annual crop nitrogen needs from another land grant college in a contiguous state ~~may be utilized~~ in the MMP provided the field and climate conditions at the land application site are similar to those within the contiguous state, and do not incorporate cost-factors as set forth above. [Minn. R. 7020.2225]

2. The MRTN for manure should not be calculated using a lower cost ratio than that used for commercial nitrogen fertilizer.

The manure application rates identified by Extension Service are also improper and inconsistent with the Land Application Rule because the rates are formulated based on the cost of commercial nitrogen fertilizer and often produce excessive results when used for manure. If MPCA uses the MRTN recommendations, at a minimum those recommendations should be the same for manure as for commercial fertilizer. After all, expected crop nitrogen needs should not change based on whether the farmer applies commercial fertilizer or manure.

As explained above, the MRTN is calculated based on the ratio of the cost of *commercial nitrogen fertilizer* to the expected sale price of the crop. Minnesota's recommendations for the

MRTN for commercial fertilizer include calculations that use ratios of 0.05, 0.10, 0.15, and 0.20 to account for price fluctuations in fertilizer and corn.[92] However, because the ratio of the prices of fertilizer to corn has remained approximately the same, the 0.10 ratio usually been used for commercial fertilizer recommendations in Minnesota.[93]

For manure, considerations are different. Often, the farmer owns or manages livestock and may obtain manure without paying for it.[94] Presumably to account for that fact that manure is cheaper than fertilizer, the Extension Service recommendations identified in the Proposed General Permit do not use the 0.10 ratio that would be used for commercial fertilizer. Instead, the recommendations use the 0.05 ratio.[95]

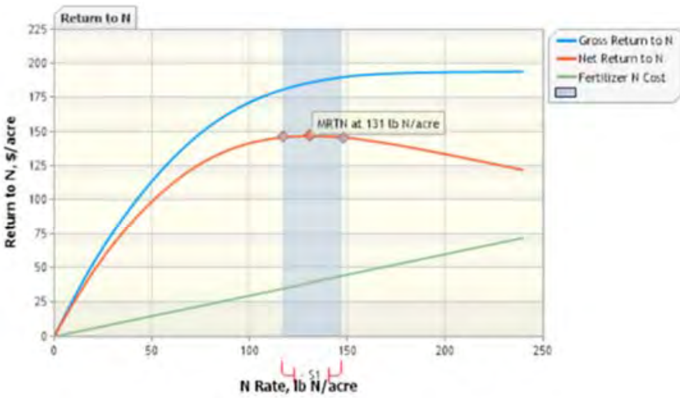
This leads to a significantly larger nitrogen recommendation for manure application than for commercial fertilizer, Dr. Jones explains. As an example, using the 0.10 ratio for corn grown after soybeans produces a recommended MRTN of 131 lb. N/acre, with a profitable range of 118–144 lb. N/acre.[96] Using the 0.05 ratio, by contrast, increases the MRTN Rate to 150 lb. N/acre and the profitable range to 135–169 lb. N/acre.[97] Thus, under the Extension Service recommendations, for the same field, a farmer could add 19 lb. N/acre when applying manure instead of commercial fertilizer. These two examples are shown below in Figure 1:

[92] Daniel Kaiser, et al., Univ. of Minn. Extension, *Fertilizing Corn in Minnesota* (2020), https://extension.umn.edu/crop-specific-needs/fertilizing-corn-minnesota#standard-n-guidelines-2237060, attached as Ex. 17.
[93] Dr. Gyles Randall, *Expert Report* 1 (2020), attached as Ex. 2.
[94] Jones, *supra* note 35, at 7.
[95] Manure Nitrogen Rates for Corn, *supra* note 75; Guidelines for Manure Application, *supra* note 40.
[96] Jones, *supra* note 35, at 7.
[97] *Id.*

Rates and Charts

State: Minnesota
Number of sites: 121
Rotation: Corn Following Soybean

Nitrogen Price ($/lb):	0.30
Corn Price ($/bu):	3.00
Price Ratio:	0.10
MRTN Rate (lb N/acre):	131
Profitable N Rate Range (lb N/acre):	116 - 147
Net Return to N at MRTN Rate ($/acre):	$146.86
Percent of Maximum Yield at MRTN Rate:	99%
Anhydrous Ammonia (82% N) at MRTN Rate (lb product/acre):	159
Anhydrous Ammonia (82% N) Cost at MRTN Rate ($/acre):	$39.30



Rates and Charts

State: Minnesota
Number of sites: 121
Rotation: Corn Following Soybean

Nitrogen Price ($/lb):	0.15
Corn Price ($/bu):	3.00
Price Ratio:	0.05
MRTN Rate (lb N/acre):	150
Profitable N Rate Range (lb N/acre):	135 - 169
Net Return to N at MRTN Rate ($/acre):	$168.13
Percent of Maximum Yield at MRTN Rate:	99%
Anhydrous Ammonia (82% N) at MRTN Rate (lb product/acre):	182
Anhydrous Ammonia (82% N) Cost at MRTN Rate ($/acre):	$22.50

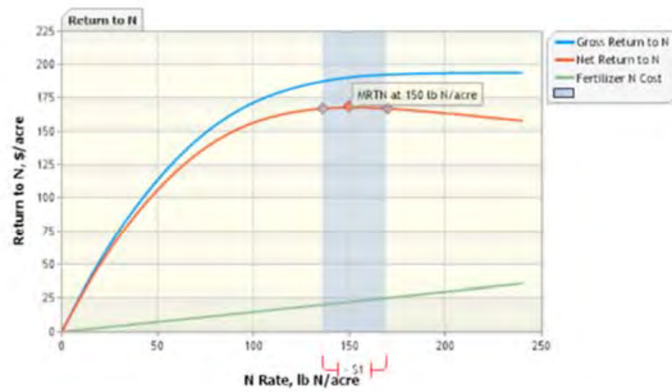


Figure 1. Two scenarios using the MRTN Calculator for commercial anhydrous ammonia (left) and manure (right), at current prices for N fertilizer and corn, using the Proposed General Permit's guidelines for manure application rate at 0.05 MRTN.[98]

Importantly, the orange line's downward slope to the right of the MRTN shows that a farmer who uses commercial fertilizer beyond the MRTN will incur an economic penalty.[99] By contrast, as Dr. Jones explains, "there is almost no economic consequence for the farmer to keep applying manure far beyond the MRTN rate, which is already 19 lbs./acre higher than the recommended rate using commercial nitrogen."[100] In addition, the difference between the total net return to the farmer for commercial fertilizer and manure is notable. When using commercial fertilizer at the 0.10 MRTN rate, the farmer achieves a net return of $146.86/acre. When using

[98] *Id.* at 7.
[99] *Id.*
[100] *Id.*

manure, the farmer could achieve that same net return using an application rate far below the 0.05 MRTN rate—about 80 lbs./acre in this example.[101] Clearly, the farmer using manure can achieve economic parity with the farmer using commercial fertilizer, even while applying manure at a rate far below the Extension Service recommendations.[102] But, according to Dr. Jones, "the Extension Service guidelines do quite the opposite—they encourage application of [nitrogen] far beyond that threshold."[103]

For this additional reason, the Extension Service's recommendations, which are referenced in the Proposed General Permit, do not comply with the Land Application Rule requirement that limits manure application to "expected crop nitrogen needs" or "nitrogen removal rates." The actual crop needs for nitrogen do not change based on whether a farmer applies commercial nitrogen fertilizer or manure, or based on a change in the cost of fertilizer. Accordingly, if the MPCA elects to use the MRTN, it is unreasonable and inconsistent with the Land Application Rule to use a different MRTN for commercial fertilizer than for manure.[104] If the 0.10 MRTN rate provides sufficient nitrogen for plant growth when commercial fertilizer is used, that same rate will provide sufficient nitrogen to meet the expected crop nitrogen needs or nitrogen removal rates when manure is used.[105]

Accordingly, if the MPCA determines that the recommended rate should remain the MRTN, the Clean Water Organizations propose that Section 13.3 be revised as follows:

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[101] *Id.*
[102] *Id.*
[103] *Id.*
[104] Notably, one of the original MRTN developers has stated that the price of commercial nitrogen fertilizer *should* be used to calculate the MRTN ratio for manure, instead of the lower rate indicating that manure is less expensive. Randall, *supra* note 90, at 1.
[105] Maximizing the amount of manure to apply is particularly inappropriate when the Land Application Rule already allows farmers to deviate up to 20% in excess of recommendations when needed under the circumstances. Minn. R. 7020.2225, subp. 3(A)(2).

> The Permittee shall ~~control~~ limit manure application rates so the estimated nitrogen available to crops from all nitrogen sources (including commercial fertilizer) does not exceed expected annual crop nitrogen needs for non-legumes and expected nitrogen removal for legumes. Expected crop nitrogen needs, crop nitrogen removal rates, and estimated plant available nitrogen from manure and legumes must be based on the most recent published recommendations of the University of Minnesota Extension Service, but must not be based on recommendations incorporating cost-factors for nitrogen fertilizer (i.e., MRTN system) unless the MRTN recommendation used is based on a cost factor of at least 0.10. ~~based on the most recent recommendations of the MES and the MPCA fact sheets "*Manure Nitrogen Rates For Corn Production (wq-f8-18)*" and "*Manure Management For Corn On Irrigated Sandy Soils (wq-f8-52)*".~~ The Permittee may use recommendations for annual crop nitrogen needs from another land grant college in a contiguous state ~~may be utilized~~ in the MMP provided the field and climate conditions at the land application site are similar to those within the contiguous state, and if the recommendations are based on the MRTN, they use a cost factor of at least 0.10. [Minn. R. 7020.2225]

B. Section 13.3(a): Pre-Plant Testing For Nitrate.

Next, the Clean Water Organizations request that MPCA add back into the Proposed General Permit a section relating to pre-plant testing for nitrate. MPCA included such a section in the 2016 General Permit, and it is needed to comply with the Minnesota Rules and to ensure that farmers are not over-applying manure that will cause water pollution.

The Land Application Rule requires that manure management plans include "plans for soil nitrate testing in accordance with University of Minnesota Extension Service recommendations."[106] Under the rules, any required testing must be sufficient to yield representative data to determine whether a permittee is complying with the conditions of the permit and state rules.[107] In this case, the Land Application Rule and the Proposed General Permit require farmers to limit manure applications to "expected crop nitrogen needs" or "nitrogen removal rates." The Land Application Rule and the Proposed General Permit also require that in calculating these amounts, farmers consider *all* sources of nitrogen available to their crops, including

[106] *Id.*, subp. 4(D)(12).
[107] Minn. R. 7001.0150, subp. 2(B).

"commercial fertilizer nitrogen, soil organic matter, irrigation water, legumes grown during previous years, biosolids, process wastewater, and manure applied for the current year and previous years."[108] Accordingly, nitrate testing is needed to ensure that farmers properly account for all nitrogen sources, and that farmers do not apply nitrogen in excess of expected crop nitrogen needs. In short, farmers cannot limit their application to the crop's expected nitrogen needs if they do not know how much nitrogen is already in the soil, and they cannot know how much nitrogen is in the soil without testing.

Determining how much nitrogen farmers should credit from previous years is not an easy task without testing. Many factors affect how much residual nitrogen remains in the soil, including the previous crop grown, the soil texture, and historic rainfall.[109] One of the most important factors—with the most difficult-to-predict effects—is the amount of residual nitrates that remain from manure applied in previous years.[110] As the Extension Service explains, microbes require several years to mineralize organic forms of nitrogen in manure into nitrate that can be used by plants, and the length of the process depends on soil moisture and temperature conditions.[111] Accordingly, manure applied in one growing season will continue to provide nitrate to plants for several growing seasons.[112] The amount of residual nitrogen, however, can vary greatly, is difficult to predict, and can have substantial effects on the amount of preplant nitrogen that should be added to the soil.[113] As Dr. Randall explains, a soil test of 13 sites where manure had been applied in the

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[108] Minn. R. 7020.2225, subps. 3(A)(1), (A)(3)
[109] Univ. of Minn. Extension, *Soil Testing for Corn Nitrogen Recommendations* (2018), https://extension.umn.edu/nitrogen/soil-testing-corn-nitrogen-recommendations, [hereinafter "Soil Testing for Corn"], attached as Ex. 18.
[110] *Id.*
[111] Manure Characteristics, *supra* note 41, at 6.
[112] *Id.*
[113] *Id.*; *see also* Randall, *supra* note 90, at 2.

previous five years showed that the amount of nitrogen to be applied should be reduced by an average of 43 lb. N/acre based on the residual nitrogen.[114] For several sites, the recommended rate of nitrogen to be applied was reduced by 70 lb. N/acre, and for others it was reduced by only 19 lb. N/acre, showing the wide range of results that manure application can have at different fields.[115]

Accounting for nitrates released from manure over time can be done using a "credit" for manure from the previous two years.[116] But the crediting system cannot precisely account for the actual amount of nitrates, and in some cases may result in excessive fertilizer recommendations.[117] Measuring nitrates in the soil is more reliable than other methods of estimating the need for additional nitrogen application.[118] As the Iowa State University Extension Service explains, using a late-spring test for soil nitrate "should help corn producers manage N to increase their profits while reducing environmental degradation."[119]

Currently, the Proposed General Permit does not include any requirement for soil testing for nitrogen, although it does require soil testing for phosphorus.[120] The 2016 General Permit, however, *does* require soil nitrate testing "according to the method and frequency recommended by the most recent MES-published guidelines."[121] It is unclear why MPCA removed this requirement in the Proposed General Permit. To comply with the requirements of the Land

[114] Randall, *supra* note 94, at 2.
[115] *Id.*
[116] Manure Characteristics, *supra* note 41, at 4.
[117] Soil Testing for Corn, *supra* note 106, at 4 (explaining that using the standard manure nitrogen crediting system without a soil test when manure was applied in October or November "may result in high fertilizer recommendations if significant residual nitrogen was present before the manure was applied.")
[118] A.M. Blackmer et al., Iowa State Univ. Extension Serv., *Nitrogen Fertilizer Recommendations for Corn in Iowa* 4 (1997), attached as Ex. 19.
[119] *Id.* at 1.
[120] *See* Proposed General Permit, *supra* note 75, § 12.6.
[121] Minn. Pollution Control Agency, *NPDES General Permit for Concentrated Animal Feeding Operations* § 4.5.4 (2016).

Application Rule and ensure farmers are able to accurately determine the proper amount of manure they should apply, the Clean Water Organizations propose that the following language be added to the Proposed General Permit:

> The Permittee shall ensure that fields receiving manure are sampled and tested for soil nitrates according to the method and frequency recommended by the most recent MES-published guidelines. The Permittee shall use the results of the sample in calculating a residual N credit. [Minn. R.7020.2225, subp. 3.A(3)].

C. Section 14.6: October Restrictions On Manure Application.

The Clean Water Organizations also request changes to the section regarding October Restrictions on Manure Application to better guard against nitrate pollution. The Clean Water Organizations appreciate that the Proposed General Permit now requires best management practices ("BMPs") for any manure application in October, but believes that those requirements should be strengthened to further protect water quality.

First, with regard to the soil temperature, the proposed language provides no direction about how to determine soil temperature. This is important, because fall manure application when temperatures exceed 50º F is highly likely to cause nitrate pollution. In such cases, the organic nitrogen will be mineralized to inorganic nitrate at a time when the crops are not growing.[122] Then, the nitrate will remain in the soil until the crop takes it up, possibly not until the following June.[123] The longer the nitrate remains in the soil, the more likely it is to leach into the groundwater—particularly during heavy rains in the fall or early spring.[124] Accordingly, ensuring that soil temperatures prior to manure application are below 50º F, and are likely to *remain* that way until spring, is critical. Allowing farmers to apply manure as soon as their area has one 50º F soil

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[122] Fred Madison et al., Univ. of Wis. Extension Serv., *Guidelines for Applying Manure to Cropland and Pasture in Wisconsin* 11 (2014), https://soilsextension.webhosting.cals.wisc.edu/wp-content/uploads /sites/68/2014/02/A3392.pdf, attached as Ex. 20.
[123] Randall, *supra* note 90, at 2.
[124] *Id.* at 2; Madison, *supra* note 119, at 11.

temperature reading will not prevent nitrate leaching, as mineralization to nitrate will begin again if the soil temperatures rise after manure application. To ensure consistency, Dr. Randall recommends that soil temperature readings be taken at a depth of six inches and be less than 50 degrees for three consecutive days before farmers apply manure.[125]

Second, with regard to cover crops, the Proposed General Permit indicates manure may be applied in October if a cover crop "is established in accordance with the requirements of this Permit for June, July, August, or September applications." But the likelihood that a cover crop can be established drops quickly after the first half of September, particularly in the northern half of the state.[126] After October 1, establishing a cover crop would be very difficult even in southern Minnesota and extremely unlikely in northern Minnesota.[127] To effectively prevent nitrate pollution, a cover crop must not merely be germinated—it must be well-established and sufficiently robust to take up a substantial amount of nitrate from the manure.[128] This means the crop must be well-grown—perhaps six to eight inches tall—by mid-to-late October.[129] A cover crop planted in October is extremely unlikely to fulfill its intended function as a temporary fixer of nitrates.[130] But the Proposed General Permit would allow a farmer to seed a cover crop in October within 10 days of manure application and hope for the best—and there would be no way to remove the manure if the cover crop does not sprout. Any manure applied under these circumstances is very likely to mineralize to nitrate and leach into the groundwater.[131] If, however,

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[125] Randall, *supra* note 90, at 3. For the same reason, this standard—three consecutive days of temperatures below 50 degrees, measured at a soil depth of six inches below the surface—also should be added to section 14.4, relating to manure application on coarse-textured soils.
[126] Randall, *supra* note 90, at 3.
[127] *Id.*
[128] *Id.*
[129] *Id.*
[130] *Id.*
[131] *Id.*

a cover crop has already been established prior to October, application of manure through an injector into the growing cover crop could be a potential BMP.[132] Therefore, the Proposed General Permit should be revised to indicate that cover crops may be used as a BMP for October manure application only if the cover crop has been planted in a previous month and already established before the October application.

Third, for the split application of nitrogen, the Proposed General Permit does not indicate when the second half of the nitrogen could be applied. Applying the second half of the manure soon after the first half—in early November, for example—would negate the effectiveness of splitting the nitrogen application. And manure application during the winter months, to frozen or snow-covered soils, is prohibited or subject to strict conditions under the terms of the permit.[133] Even under those conditions, winter manure application is risky and likely to lead to runoff, as explained in the next section. Under no circumstances should applying manure during winter months be considered a BMP. Accordingly, the Proposed General Permit should specify that the second half of the split application of nitrogen should be applied only in the spring, when the ground is no longer frozen.

Finally, the Proposed General Permit does not require implementation of BMPs during an "emergency" manure application, perhaps on the assumption that BMPs would not be feasible. But in some cases, farmers may in fact be able to implement these BMPs despite an emergency. For example, a nitrogen stabilizing agent potentially could be added to the manure before spreading, despite poor weather conditions or equipment failure that prevented an earlier manure

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[132] *Id.*
[133] *See* Proposed General Permit, *supra* note 75, §§ 14.8, 14.10.

application.[134] In such cases, when following the BMPs remains feasible, farmers should not be excused from following the BMPs intended to prevent nitrate pollution.

Accordingly, to better protect water quality, the Clean Water Organizations propose the following revisions to Section 14.6:

> October Restrictions - The Permittee shall not apply manure in October to harvested fields unless at least one of the following nitrogen BMPs are implemented:
>
> a) Soil temperature ~~is~~ has been below 50 degrees for three consecutive days at the time of manure application based on temperatures taken six inches below the soil surface;
>
> b) A nitrogen stabilizing agent/product is added at the recommended inclusion rates;
>
> c) A cover crop ~~is~~ has been established prior to October in accordance with the requirements of this Permit for June, July, August, or September manure applications; or
>
> d) A split application of nitrogen is used where no more than 1/2 of the recommended nitrogen rate is applied before October 31 and the remainder is applied after April 1 or after the soil is no longer frozen or snow-covered, whichever is later.
>
> ~~Alternatives developed by a land grant University can be used if approved by the MPCA and included as part of the approved MMP.~~
>
> Nitrogen BMP implementation is ~~not~~ required for emergency manure application, as defined by this Permit, unless implementation of BMPs is infeasible due to the emergency conditions necessitating the application. [Minn. R. 7001.0150]

D. Section 14.8: Winter Application Of Solid Manure.

Similarly, while the Clean Water Organizations appreciate MPCA's efforts to strengthen the Proposed General Permit's section on winter application of solid manure, a broader prohibition could make this section even stronger. Prohibiting application of solid manure in December and January, along with February and March, will provide even better protection against nitrate pollution.

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[134] *See id.* § 30.19 (defining "emergency manure application").

When farmers apply manure to snow-covered or frozen soil, nutrients cannot soak into the soil, and the potential for nitrate loss is "extremely high."[135] When farmers apply manure during the winter months, the majority of the inorganic nitrogen is likely to be lost to the air through volatilization.[136] And winter-applied manure is very likely to be "carried off to lakes and streams during thaws or during winter or early spring rains."[137] For these reasons, the Proposed General Permit contains a prohibition on applying solid manure during February and March. However, these same considerations apply with equal force to December and January, when the ground is also likely to be frozen or snow-covered.[138] Accordingly, the Clean Water Organizations propose the following revision:

> Winter application of solid manure - Winter application of solid manure during the months of December, January, February and March is prohibited. When allowed, winter application must comply with all of the following:
>
> a) Manure is applied on fields identified in the MPCA approved MMP for winter application;
>
> b) Manure is applied more than 300 feet from sensitive features including lakes, streams, open tile inlets, sinkholes, water supply wells, mines and quarries, intermittent streams, un-bermed drainage ditches, or public water wetlands;
>
> c) Air temperatures are less than 40 degrees Fahrenheit during, and for at least 24 hours from the end of, the application process when two or more inches of snow are on the field;
>
> d) Less than a 50% probability of rainfall in excess of 0.25 inches predicted by the National Weather Service within 24 hours of the end of the application period;
>
> e) Slopes are less than or equal to six percent on the entire portion of the field where manure is land applied;

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[135] Manure Timing, *supra* note 52. This Extension Service publication recommends, unless there is an emergency, "Do not apply in winter." *Id*.
[136] Soil Testing for Corn, *supra* note 106, at 4.
[137] Madison et al., *supra* note 119, at 15.
[138] If the ground is not frozen or snow-covered in December or January, then the application would not qualify as a "winter manure application" under the Proposed General Permit definition and therefore would not be prohibited. *See* Proposed General Permit, *supra* note 75, § 30.53.

f) Water or ice do not occupy tillage furrows to the extent that additional snowmelt or precipitation cannot be contained between furrows or in other depressions within the field; and

g) Fields used for land application meet a total phosphorus loss risk index number of two or less (low to very low relative risk) as calculated according to the Minnesota Phosphorus Index.

In the event of significant snow accumulation within animal holding areas, the Permittee may obtain approval from the MPCA for winter application of the snow and manure-snow mix during December, January, February and March. If approved, the application fields must, at a minimum, meet the requirements above. Additional measures/practices may be required by the MPCA. [Minn. R. 7001.0150]

E. Section 11.4: Review Of Manure Management Plan.

Finally, revising Section 11.4 to require farmers to identify fields in manure management plans ("MMP") using GIS information will assist MPCA staff. Using GIS information will make it easier for MPCA to determine whether any fields receive double applications of manure because they are identified in more than one MMP and receiving manure from more than one farmer.

Pursuant to the Land Application Rule, MMPs "must include acreage available for manure and process wastewater application including maps or aerial photos showing field locations and areas within the fields that are suitable for manure or process wastewater application."[139] The rule, accordingly, requires farmers to specifically identify fields in the MMPs. Identification through GIS information will make descriptions on MMPs more readily comparable for MPCA staff. Under the current system, two applicants could describe the same field using different descriptors, and determining whether there is overlap between two plans is cumbersome for MPCA staff, who must compare different maps or aerial photographs to determine whether the same field has been identified in more than one MMP. Using GIS information would standardize descriptions of fields

[139] Minn. R. 7020.2226, subp. 4(D)(3).

in the MMPs, making it clear to both MPCA staff and applicants which fields are being referred to in the MMP.

Accordingly, the Clean Water Organizations propose the following revision to Section 11.4:

> The Permittee shall annually review and update the approved MMP to ensure that it meets all applicable requirements. The annual review and update shall include information for each field where manure will be applied during the following growing season. The permittee shall provide an area delineation of each manure application site in a GIS polygon geospatial file format (.kml, .shp, .json, etc.) with detailed coordinate system information, including a description of the site. Annual updates to the MMP do not require a modification of coverage under this Permit provided the updates are consistent with the methodology of the approved MMP. [Minn. R. 7001.0190, Minn. R. 7020.2225]

IV. THE CLEAN WATER ORGANIZATIONS REQUEST A CONTESTED CASE HEARING

The Clean Water Organizations request a contested case hearing on the issue of whether the recommendation MPCA has referenced in Section 13.3 of the Proposed General Permit is consistent with "expected crop nitrogen needs, crop nitrogen removal rates, and estimated plant available nitrogen from manure and legumes" as required by the Land Application Rule.

The information required by Minn. R. 7000.1800 is provided below.

1. Statement of reasons or proposed findings supporting an MPCA decision to hold a contested case hearing.

(A) There is a material issue of fact in dispute concerning this matter.

As noted in the Clean Water Organizations' comments above in section V.A, the Proposed General Permit references recommendations from the University of Minnesota that incorporate economic risk and cost factors unrelated to the amount of nitrogen a typical crop[140] will actually need or remove to support plant growth. As a result, these recommendations are inconsistent with

[140] MCEA notes that Minn. R. 7020.2225, subp. 3 already provides for increased nitrogen application if conditions particular to the crop or field require additional applications to secure the crop.

what the Land Application Rule requires and will allow permittees to apply manure at rates resulting in excess loss of nitrate to the groundwater, exacerbating the issues the Clean Water Organizations describe in section II.B above. Whether the recommendations conform to the objective requirement of the rule is a factual issue that can be resolved with expert testimony.[141] This expert testimony will identify the results of research into "expected crop nitrogen needs, crop nitrogen removal rates, and estimated plant available nitrogen from manure and legumes," why the economic components incorporated into the current recommendation result in applications not supported by the scientific data, and why the recommendations will lead to excess application inconsistent with the text and intent of MPCA's land application rule.

(B) The MPCA has the jurisdiction to make a determination on this issue.

In the proposed general permit, MPCA has referenced a particular recommendation of the Extension Service. If MPCA agrees with the Clean Water Organizations that the recommendation it references is not consistent with the standard established by the Land Application Rule, MPCA could ask the Extension Service to modify its recommendation, or MPCA could modify the Proposed General Permit to ensure that a modified version of the Extension Service's recommendations are referenced in the Proposed General Permit. As a result, this issue is within MPCA's jurisdiction.

(C) There is a reasonable basis underlying the disputed material issue of fact or facts such that the holding of a contested case hearing would allow the introduction of information that would aid the MPCA in resolving the disputed facts in making a final decision on the matter.

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[141] *See In re City of Owatonna's NPDES/SDS Proposed Permit Reissuance for the Discharge of Treated Wastewater*, 672 N.W.2d 921, 928 (Minn. Ct. App. 2004) (finding a fact issue supporting a contested case hearing request existed when relator submitted expert affidavits and a report challenging MPCA's interpretation of its modeling and explaining, "When experts disagree, a fact question arises.")

The Clean Water Organizations support this request with two expert reports, by Dr. Christopher Jones, research engineer at Iowa State University (attached as Exhibit 1) and Dr. Gyles Randall, professor emeritus at the University of Minnesota (attached as Exhibit 2).[142] These experts will testify that the recommendation currently included in the Proposed General Permit is not consistent with the standard established by the Land Application Rule.[143] These experts will base their testimony on research conducted in Minnesota and Iowa. These experts will demonstrate that the economic factors incorporated into the current recommendations, particularly as applied to manure, result in excess application inconsistent with "expected crop nitrogen needs, crop nitrogen removal rates, and estimated plant available nitrogen from manure and legumes" and that this excess application can be predicted to lead to enhances nitrogen loss to the groundwater.

2. A statement of the issues proposed to be addressed by a contested case hearing and the specific relief requested or resolution of the matter.

The issue to be addressed by a contested case hearing is whether the recommendation referenced in the Proposed General Permit conforms to the standard established by the Land Application Rule. The relief requested is amendment of the Proposed General Permit to include a recommendation that will result manure application rates consistent with plant needs established by scientific research, as required by the Land Application Rule.

Clean Water Organization has identified two changes that MPCA could make to the Proposed General Permit to address this issue, in section V.A, above. First, MPCA could request the Extension Service to prepare a recommendation that does not include the economic factors on which the current MRTN recommendation is based. Second, MPCA could request the Extension

[142] *See* Jones, *supra* note 35; and Randall, *supra* note 90.
[143] *See City of Owatonna,* 672 N.W.2d at 929 (explaining that relator had sufficiently supported the requested for a contested case hearing when it submitted affidavits of experts who challenged MPCA's methodology and interpretation of the modeling at issue).

Service to prepare a recommendation specific to manure that utilizes the MRTN, but includes a higher cost factor ratio similar to the one used for commercial fertilizer, which is less likely to result in over-application of manure.

3. Witnesses, exhibits, and estimate of time.

At a contested case hearing, the Clean Water Organizations would intend to present the following witnesses: Dr. Christopher Jones and Dr. Gyles Randall. Proposed exhibits would include all exhibits attached to this comment or referenced herein. The estimated time for the contested case hearing would be a half-day. The Clean Water Organizations reserve the right to introduce other witnesses or exhibits in accordance with Minn. R. 7000.1800, subp. 2(C). The Clean Water Organizations note that MCEA has been seeking a meeting with MPCA and Extension Service representatives to discuss the use of MRTN recommendations, which could lead to changes that would resolve this issue without a contested case hearing.

CONCLUSION

While the Clean Water Organizations appreciate that the Proposed General Permit makes some incremental changes that are likely to help improve water quality, the Clean Water Organizations' position is that the Proposed General Permit will allow the continued pollution of Minnesota's water, endangering drinking water and aquatic life. Already, hundreds of thousands of Minnesotans are drinking water with elevated levels of nitrates, which will increase their risks of cancers and other health problems. If farmers are allowed to continue to apply manure to their fields in excess of crop nitrogen needs, and at times and using methods that pose high risk of nitrate leaching and runoff, dangerous nitrate pollution will continue to increase across Minnesota. Accordingly, the Clean Water Organizations respectfully request that MPCA revise the Proposed General Permit as follows:

(1) revise Section 13.3 to limit manure application rates to "expected crop nitrogen needs" or "expected nitrogen removal"; or in the alternative, to ensure that the MRTN uses a cost factor of at least 0.10;

(2) add Section 13.3(a) to require pre-plant testing for nitrate according to Extension Service recommendations;

(3) revise Section 14.4 to require soil temperature measurements below 50 degrees for three consecutive days, measured at a soil depth of six inches below the surface;

(4) revise Section 14.6 to strengthen October restrictions on manure application;

(5) revise Section 14.8 to prohibit application of solid manure in December and January; and

(6) revise Section 11.4 to require GIS field identification in MMPs.

Respectfully submitted,

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Cover crops | UMN Extension

extension.umn.edu/soil-and-water/cover-crops

Cover crops

Cover crops are grown outside of the cash crop growing season, usually seeded in the fall and killed before spring planting.

Keeping living roots in the ground year-round can improve water management, soil protection and nutrient scavenging, but they need to be given the same attention as a cash crop to ensure success.

Try cover crops on a small scale first, and look into cost-share from state and local governments.

Some of the best opportunities are with early-harvested cash crops like corn silage, small grains, and canning crops like beans and peas, as you'll get more vigorous fall growth if you plant in late summer and early fall.

In fields where wheat was just harvested, simply allowing it to reseed itself without tilling the land would work as a cover crop. But cover crops can work with standard corn-soybean rotations as well.

Benefits of cover crops

Erosion control

Cover crops reduce erosion in a few different ways.

- Aboveground, living cover crops protect the soil from rainfall impact and reduce the effect of wind. Runoff is reduced along the way.
- Belowground, roots hold soil in place during active erosion events and build structure. Better soil structure means the soil is less likely to erode even if left bare later in the season, such as between harvest and cover crop planting.
- Runoff sediment also contains soil phosphorus, so reducing runoff is an important strategy for reducing P loading in surface water.

Infiltration and water management

Cover crop root systems create large channels through the soil to allow increased infiltration. This effect is especially significant for species with large taproots, but other cover crops also increase infiltration.

- Increased infiltration means fields are less likely to stay saturated during Minnesota's rainy springs.
- Many farmers report dry field conditions more quickly after a rain event when they use cover crops.

Cover crops can also help soil store water by building soil structure and creating a network of large and small pores.

- Once water enters the soil through infiltration, this pore network retains water for plants to take up as necessary.
- This increase in soil water holding capacity can be especially beneficial in dry years.

Nitrate reduction

Soil nitrate reduction is well-established in Minnesota for a variety of cover crops.

- Nitrate is often left in the soil after fall harvest of corn.
- A winter cover crop takes up soil nitrogen, so less nitrogen is leached. This is an important benefit for reducing groundwater nitrate contamination.
- Farmers should expect some nitrate drawdown by cover crops and plan the subsequent season's fertility accordingly.
- Soil testing before applying N to cash crops can help with field-specific recommendations.

September 3, 2024
Clean Water Organizations Comments Exhibit 36

Minnesota cover crop recipes

For a quick way to get started, Minnesota cover crop recipes provide step-by-step guidance to some of the lowest-risk starting points for cover crops. These recipes don’t cover all possibilities, but they can help beginners incorporate cover crops into a farm operation.

- Post corn, going into soybean: Use cereal rye
- Post soybean, going to corn: Use oats
- Post corn silage, going to corn: Use cereal rye
- Post corn silage, going to soybean: Use cereal rye

Learn more about reducing tillage and incorporating cover crops:

Watch Video At: https://youtu.be/videoseries

Getting started with cover crops

- Benefits of cover crops.
- Choosing a cover crop (consider crop rotation, harvest timing, overwintering, etc.).
- Recommended planting dates and seeding rates for cover crops.
- Comparison of cover crop benefits by crop.

Planting green in Minnesota

- Benefits of biomass production
- How termination date affects biomass production

Planting date matters for cover crops, too

- Timing of fall seeding
- Termination timing on biomass production

Reduce risk of fallow or flooded soil syndrome with cover crops

- How and when fallow syndrome occurs.
- How it affects crops.
- How cover crops can help.

- How to manage fallow syndrome.

Spring management of cover crops

- Guidance on mechanical and chemical termination, including carbon-to-nitrogen ratios of common crops.
- Factors affecting residue.
- Pest management tips.
- How to time spring termination for cash crop planting.

In this Strategic Farming webinar, researchers Monica Schauer, UW-Madison, and Anna Cates, UMN Extension educator, discuss fertility and crop rotation with cover crops.

Watch Video At: https://youtu.be/XEYbPRzbGN4

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Reductions in soil water nitrate beneath a perennial grain crop compared to an annual crop rotation on sandy soil

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Nitrate (NO_3^--N) leaching into groundwater as a result of high nitrogen (N) fertilizer rates to annual crops presents human health risks and high costs associated with water treatment. Leaching is a particularly serious concern on sandy soils overlying porous bedrock. Intermediate wheatgrass (IWG) [*Thinopyrum intermedium* (Host.) Barkw. & D.R. Dewey], is a perennial grass that is being bred to produce agronomically and economically viable grain, which is commercially available as Kernza®. Intermediate wheatgrass is a low-input crop has the potential to produce profitable grain and biomass yields while reducing NO_3^--N leaching on sandy soils compared with common annual row crop rotations in the Upper Midwest. We compared grain yields, biomass yields, soil solution NO_3^--N concentration, soil extractable NO_3^--N, soil water content, and root biomass under IWG and a conventionally managed corn (*Zea mays* L.) and soybean [*Glycine max* (L.) Merr.] rotation for 3 years on a Verndale sandy loam in Central Minnesota. Mean soil solution NO_3^--N was 77–96% lower under IWG than the annual crop rotation. Soil water content was greater under annuals compared to IWG early in the growing season, suggesting greater water use by IWG during this time. Interactions between crop treatments and depth were observed for soil water content in Year 3. Root biomass from 0 to 60 cm below the soil surface was five times greater beneath IWG compared to soybean, which may explain differences in soil extractable and solution NO_3^--N among crops. With irrigation on coarse structured soils, IWG grain yields were 854, 434, and 222 kg ha^{-1} for Years 1–3 and vegetative biomass averaged 4.65 Mg ha^{-1} yr^{-1}; comparable to other reports on heavier soils in the region. Annual crop grain yields were consistent with local averages. These results confirm that IWG effectively reduces soil solution NO_3^--N concentrations even on sandy soils, supporting its potential for broader adoption on land vulnerable to NO_3^--N leaching.

KEYWORDS

intermediate wheatgrass, nitrate, leaching, Kernza, groundwater, perennial grains

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Introduction

Water quality in the Upper Midwest is threatened by the intensive management practices used in annual cropping systems, including tillage and fertilizer application that lead to nutrient losses and water contamination through leaching and runoff (Randall and Mulla, 2001; Dinnes et al., 2002; Feyereisen et al., 2006; Erisman et al., 2013). While annual commodity crops like corn provide the potential for high economic return, nutrient losses cause eutrophication and hypoxia in surface waters and contamination of groundwater, posing significant risks to human health (Ward et al., 2010, 2018; Brender et al., 2013). Impacts are often high where shallow aquifers and sandy soils make drinking water sources vulnerable to contamination. This leads to additional water treatment costs of over $5 million for some counties (Keeler et al., 2016). In Southeast Minnesota, for example, conversion of grassland to agriculture is expected to cause a 45% increase in private wells exceeding 10 ppm NO_3^--N, resulting in between $700,000 and $12,000,000 in associated costs over a 20-year period (Keeler and Polasky, 2014). New alternative cropping systems that provide economic returns comparable to those of annual systems and which effectively reduce nutrient losses will be essential for protecting drinking water sources in the future.

Replacing annual crops with perennials has the potential to help reduce NO_3^- leaching to groundwater and provide other ecosystem services (Asbjornsen et al., 2014; Ferchaud and Mary, 2016). Cropping systems that include perennial grasses for conservation, forage, and biofuel production have lower NO_3^- leaching losses than corn-soybean systems, largely because perennial grasses have greater root biomass that extends deeper into the soil, increasing N recovery and reducing leaching (Culman et al., 2013b; Pugesgaard et al., 2015; Ferchaud and Mary, 2016). Deep roots may be particularly important in reducing NO_3^- leaching since they can expand the total volume of soil from which NO_3^--N is taken up, and because NO_3^- is highly mobile and more prone to leaching from deep soil horizons (Maeght et al., 2013). NO_3^- losses in the subsurface drainage water for a corn-soybean system were about 37 times higher than from a Conservation Reserve Program (CRP) planting dominated by perennial grasses (Randall et al., 1997). This reduction was attributed to the greater season-long evapotranspiration (ET) that resulted in less drainage and greater uptake and/or immobilization of N. In that study, average NO_3^- concentrations in the water during the flow period were 24 mg/L for the corn-soybean rotation and 2 mg/L for the perennial grass CRP (Randall et al., 1997). Although plantings that include perennial grasses are effective at reducing NO_3^- leaching, a lack of economic return has prevented their large-scale adoption in Midwestern agricultural landscapes.

Intermediate wheatgrass (IWG), [*Thinopyrum intermedium* (Host.) Barkw. & D.R. Dewey] is a perennial cool-season grass being domesticated to produce a grain marketed as Kernza® (DeHaan et al., 2018) with the first commercial variety, "MN-Clearwater," released in 2020 (Bajgain et al., 2020). The crop has potential to provide economic return for producers (Hunter et al., 2020a,b; Law et al., 2022) while reducing NO_3^- leaching compared to corn (Jungers et al., 2019). Intermediate wheatgrass initiates growth earlier in the season than warm-season forage and bioenergy grasses and is thus better able to reduce NO_3^--N losses early in the season (Jungers et al., 2019) when losses are typically the highest in the Upper Midwest (Randall and Mulla, 2001; Crews and Peoples, 2005). Vegetative regrowth following IWG grain harvest helps reduce post-harvest nitrate losses and erosion late into the fall.

One potential mechanism by which IWG can reduce NO_3^- leaching compared to annual crops is related to water demand. Although total growing season ET and drainage were similar between IWG and corn, soil water content was lower under IWG compared to corn and switchgrass at 50 and 100 cm depths (Jungers et al., 2019), suggesting that soil moisture may be stored in other regions of the soil profile. Compared to annual wheat (*Triticum aestivum* L.), IWG had lower soil moisture up to a depth of 70–100 cm, which was associated with NO_3^--N leaching reductions of up to 86% (Culman et al., 2013b). The distribution of IWG root biomass and its effects on soil water content throughout the soil profile are largely unknown.

Reductions in NO_3^- leaching beneath IWG compared to annual crops can also be related to differences in nitrogen fertilization regimes and associated losses of N in the form of soluble NO_3^--N in the soil water. Soil solution NO_3^- increased from 0.1 to 0.3 mg L^{-1} when IWG was fertilized with 120 kg N ha^{-1} compared to an unfertilized control, yet this was still lower than the 24.0 mg L^{-1} measured beneath corn fertilized at 160 kg ha^{-1} (Jungers et al., 2019). Integrating legumes such as soybean into annual crop rotations can limit N fertilizing needs, yet the effects of legume crops in rotation on NO_3^--N leaching compared to IWG are unknown.

Our objective was to assess the potential of IWG grain production to reduce NO_3^--N leaching compared to an annual soybean-corn-soybean rotation on irrigated sandy soil by measuring soil solution NO_3^--N concentration and soil water content. We hypothesized that soil water NO_3^--N concentrations and soil water content would be lower under IWG, and that this would be related to increased root biomass and rooting depth of IWG compared to corn and soybean. Crop yields and vegetative biomass were measured to assess potential profitability.

TABLE 1 Average air temperature, precipitation, irrigation, and 30-year averages for each month of the growing season in Staples, MN.

	Mean monthly air temperature (°C)				Monthly and season total precipitation (P) and irrigation (I) (mm)						
	2018	2019	2020	30-year avg.	2018		2019		2020		30-year avg.
					P	I	P	I	P	I	P
April	2	5	3	5	4.6	0	25.7	0	22.4	0	36.8
May	17	11	12	12	62.8	0	62.5	0	33.8	0	72.9
June	20	18	21	18	78.3	12.7	68.4	12.7	57.2	25.4	117.3
July	21	21	22	20	62.5	38.1	103.2	63.5	102.7	38.1	99.1
Aug.	19	18	20	19	66.6	38.1	93.8	12.7	158.6	38.1	74.4
Sept.	14	15	14	15	73.7	0	106.3	0	16	0	71.1
Oct.	4	5	3	7	80.0	0	92.3	0	10.9	0	56.6
					428.5	88.9	552.2	88.9	401.6	101.6	528.2

Methods

Site description

Field research was conducted from 2018 to 2020 at the Central Lakes Community College in Staples, MN, USA (lat. 46.38, long. −94.80). The soil type was a Verndale sandy loam (Typic Argiudoll). The soil contains 1–1.7% organic matter, is excessively well-drained, and is considered low fertility potential (USDA-NRCS, 2021). Local climate data are reported in Table 1. Plots had previously been planted to a corn-soybean rotation followed by barley fertilized with 40 kg N ha^{-1} applied in spring prior to IWG planting in 2017. Baseline soil samples from 0 to 30 cm were collected by block in the fall of 2017. Soil extractable nitrogen was 10.0 mg kg soil^{-1} for NO_3^--N and 3.9 mg kg soil^{-1} for ammonium (NH_4^+-N). Soil phosphorus (P) and potassium (K) concentrations were 9.13 and 72.21 ppm, respectively.

Experimental design

Treatments were applied in a randomized block design with two cropping systems replicated once in each of six blocks for a total of twelve plots. Plots were 4.11 by 9.14 m (13.5 by 30 ft.). The annual cropping system was a soybean-corn-soybean rotation. The perennial system was IWG. Soybeans were planted as the first phase of the soybean-corn rotation in May 2018, followed by corn in May 2019 and soybean again as the third phase in June 2020. Corn and soybeans were seeded in 75 cm rows at rates of 346,000 and 84,000 seeds ha^{-1}, respectively, with four rows per plot. The corn variety was Organic Viking O.84-95UP Seed Corn and the soybean was Organic MN0810CN.

An improved population of IWG bred for increased grain yield was used in this study. The population came from the fourth cycle of selection by Land Institute (Salina, KS) and was seeded at a rate of 15 kg ha^{-1}. The IWG was seeded in 15-cm rows with 20 rows per plot on 20 August 2017. Intermediate wheatgrass was fertilized with urea at rates of 80, 100, and 100 kg N ha^{-1} in May 2018, 2019, and 2020, respectively. Urea was split-applied to corn at 140 and 80 kg Nha^{-1} in May and June 2019. Soybean was not fertilized. Weed pressure was low and when present, weeds were manually removed in all plots. The experiment was irrigated with a linear irrigation system with events based on ET estimates and water demand for the annual crop. The fields received 89 mm of irrigation water over five events in 2018, 89 mm over seven events in 2019, and 102 mm over eight events in 2020. Dates of irrigation events are in Figure 1. Each individual irrigation event resulted in an application of 13 mm of water with the exception of 7/16/2018 and 8/22/2018, which received 25 mm.

Soil fertility and extractable N

Soil was sampled at four depth intervals (0–15, 15–30, 30–45, and 45–60 cm) in June 2019 and October 2020 and analyzed for organic matter, K, P, pH, and extractable NO_3^--N and NH_4^+-N. Samples were taken from eight cores in each plot and aggregated by depth, stored in a cooler when transported, and kept refrigerated until analyzed or processed for shipping. All soil analyses except extractable N were conducted by Agvise Laboratories (Benson, MN; www.agvise.com). Agvise samples were oven-dried prior to shipping. Soil extractable N was determined by extraction with a 2 M KCl solution, where 40 ml solution was added to 10 g fresh soil followed by 1 h shaking (Culman et al., 2013a). Extractions were performed within 48 h of field collection. NO_3^--N and NH_4^+ analyses of the extractions were performed at the UMN Research Analytical Lab. Method details can be found at http://ral.cfans.umn.edu/tests-analysis/soil-analysis.

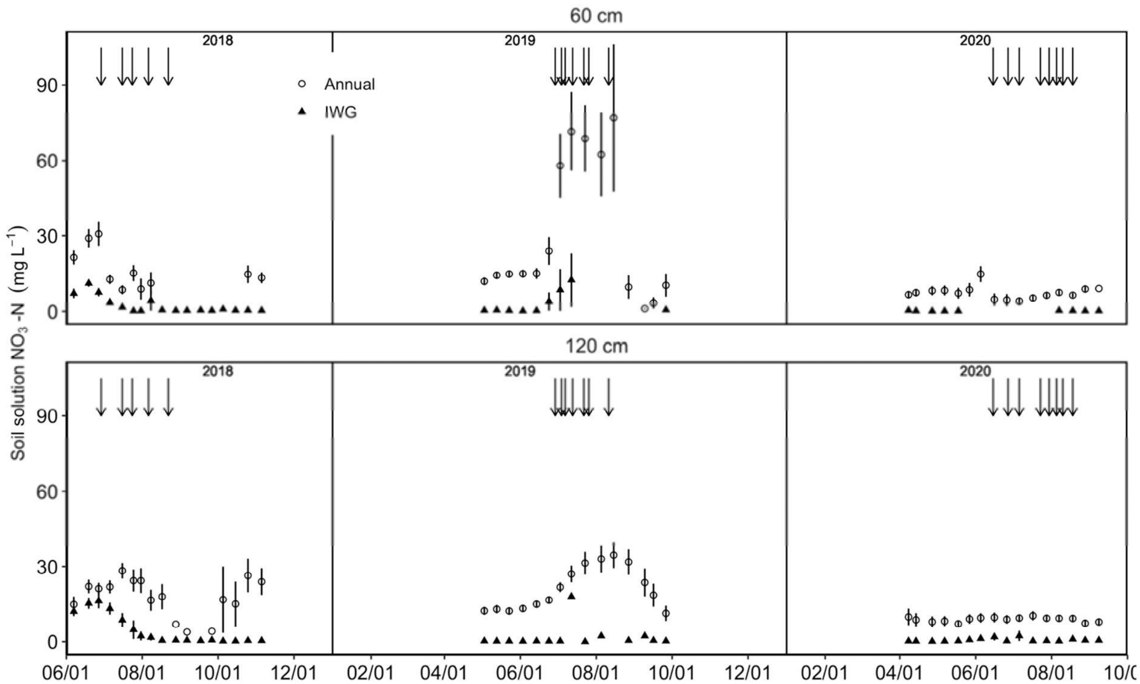

FIGURE 1
Mean soil solution NO_3^--N from lysimeters 60 and 120 cm below annual crops (soybean in 2018 and 2020, corn in 2019) and intermediate wheatgrass (IWG) sampled during the growing season in 2018, 2019, and 2020. Points are means from two lysimeters per treatment replicate and six replicates (n = 12), while error bars indicate standard error of the mean. Arrows indicate dates of irrigation events.

Crop yields

Crop yields were estimated each year from 2018 to 2020. Samples were taken in August of each year when the IWG had reached physiological maturity from two 76 by 76 cm quadrats with a total area of 0.58 m^2. Seed heads were removed from all IWG plants within the quadrat by cutting approximately 2 cm below the basal spikelet. After seed heads were removed, all remaining IWG biomass was harvested to an 8 cm stubble height. The remaining biomass was mechanically harvested and removed from the plots following quadrat sampling.

Biomass and seed heads were dried at 35°C for 72 h or until constant mass before being weighed. Grain was removed from spikes using a Wintersteiger LD 350 laboratory thresher (Wintersteiger; www.wintersteiger.com/us/Plant-Breeding-and-Research). Grain was separated from the chaff and other debris by hand-sieving and with a fractionating aspirator (Carter-Day International, Inc.; http://www.carterday.com).

Corn and soybean yields were determined by harvesting a subsection of the middle two rows of each plot. For corn, two 2-m sections of rows were cut from each corn plot. The number of corn stalks cut was recorded for each plot. All ears from the cut stalks were collected, dried (35°C for 72 h), shelled, and both cobs and kernels were weighed. Three stalks from each row section were randomly selected, dried, and weighed to estimate stover mass. Soybean yields were determined by harvesting whole plants from two 1-m sections of rows from each plot, followed by drying, threshing, and weighing. Following harvest for yield measurement, the remaining corn and soybean plants were mechanically harvested and removed from the plots.

Root biomass

Root biomass samples were taken in September 2020 with two 5-cm diameter manual push cores per plot at depths of 0–15, 15–30, 30–45, and 45–60 cm. Roots were separated from soil and debris using a hydropneumatic elutriation system (Smucker et al., 1982), then removed manually from sieves using tweezers. Due to the difficulty of distinguishing live from dead roots, no effort was made to separate them. Roots were dried at 35°C for 72 h. Samples were checked after drying for any remaining sand and debris, which was removed before weighing.

Soil solution NO_3^--N concentration

Soil solution NO_3^--N concentrations were determined by collecting soil solution samples with suction lysimeters. Lysimeters consisted of a porous ceramic end cap, a PVC tube, and an airtight rubber stopper (Jungers et al., 2019). Two pairs of 60 and 120 cm lysimeters were installed in each plot. Samples were collected every 7–10 days from April to October each year and analyzed by depth for soil solution NO_3^--N concentration using a colorimetric assay with a HACH DR 6000 spectrophotometer (Hach, https://www.hach.com).

Soil water content

Soil water content was measured on four dates in 2019 (June 17, July 19, August 21, October 31) and six dates in 2020 (May 12, June 23, July 15, August 5, September 1, and September 25) at 10, 20, 30, 40, 60, and 100 cm using a Delta-T Devices PR2/6 Probe (Delta-T Devices, 2021).

Statistical analysis

Analysis of variance (ANOVA) was conducted using mixed effects models to explain variation in soil water NO_3^--N concentration, soil water content, soil extractable NO_3^--N, root biomass, and crop yields. Predictor variables for the ANOVA were cropping system, depth (for soil variables), and their interaction. Years were analyzed separately because the annual crop varied. Cropping system was treated as a categorical variable; depth was treated as a categorical variable for root biomass and soil extractable NO_3^--N. Soil solution NO_3^--N concentrations from the 60 and 120 cm depths were not statistically different, based on preliminary statistics, and thus were averaged for the analysis. The treatment applied to the nearest neighboring plot was included in the model as a covariate to account for possible lateral movement of N applied to the neighboring plot. Data were analyzed with block as a random effect. For the soil solution NO_3^--N, which included two pairs of lysimeters per plot, plot was nested within block in the random effects structure. An autoregressive 1 correlation structure was fit to the model to account for temporal correlation in sample results within each plot. Analysis of variance was used to explain variation in soil water content for each sampling date, with a model including treatment, depth, and their interaction. Total water content from 0 to 100 cm was calculated for each plot and date using trapezoidal integration (Hupet et al., 2004) and compared among treatments using ANOVA. Mean comparisons using Tukey's adjusted P-value were used to generate estimated means for effects. Statistical analysis was carried out using statistical software program R (Version 3.5.2 GUI 1.70) including *emmeans* and *nlme* packages (R Core Team, 2018; Length, 2019; Pinheiro et al., 2019).

Results

Soil solution NO_3^--N concentration

Annual average soil solution NO_3^--N concentration differed by cropping system treatment in 2018 ($P < 0.001$), 2019 ($P = 0.004$), and 2020 ($P = 0.003$; Table 2; Figure 1), but did not vary by sampling depth or show an interaction effect in any year ($P > 0.05$). The average soil solution NO_3^--N concentration was 77%, 96%, and 96% lower in the perennial system than the annual system in Years 1–3, respectively (Table 2).

Throughout the seasons, both intra- and inter-annual variation was observed (Figure 1). Soil solution NO_3^--N concentrations under IWG initially had mean values between 10 and 20 mg L^{-1} in Year 1 but declined to nearly zero by the end of July 2018 and remained at those levels for all 3 years except for occasional deviations. In 2018, soil solution NO_3^--N concentrations under soybean were initially high at levels above 20 mg L^{-1}, declining to near zero in mid-September, but increasing to early season levels after harvest. In 2019, however, soil solution NO_3^--N concentrations under corn were between 10 and 20 mg L^{-1} but spiked to levels over twice that between late June and late August. Concentrations slowly declined over the remainder of the year. In 2020, mean soil solution NO_3^--N concentrations under soybean were consistently around 10 mg L^{-1}.

Soil extractable NO_3^--N

There was an effect of cropping system treatment, depth, and a depth by treatment interaction (p-values < 0.001) on soil extractable NO_3^--N measured at the end of the study in 2020 (Table 3). Soil NO_3^--N was greater in the annual cropping system compared to IWG at 0–15, 15–30, and 30–45 cm depths at the end of the study ($P < 0.001$), but extractable NO_3^--N levels were similar among treatments at the 45–60 cm depth. Soil extractable NO_3^--N was greatest at the 0–15 cm depth below the annual crops and decreased with each depth interval until 45–60 cm, which was similar to the 30–45 cm depth interval. There was no difference in soil extractable NO_3^--N across depths beneath the IWG.

Root biomass

Root biomass collected at the end of the study in 2020 was affected by treatment ($P = 0.006$), depth ($P < 0.001$), and a treatment by depth interaction ($P < 0.001$). Root biomass was

TABLE 2 Average soil solution NO_3^--N, grain, and biomass yields in the annual and IWG systems in 2018, 2019, and 2020.

	2018		2019		2020	
	Annual	IWG	Annual	IWG	Annual	IWG
Soil solution NO_3^--N (mg L^{-1})	19.0a	4.3b	22.1a	0.8b	7.8a	0.3b
Grain yield (Mg ha^{-1})	3.05a	0.85b	7.33a	0.43b	1.98a	0.22b
Biomass yield (Mg ha^{-1})	2.43b	4.12a	5.85	5.41	2.86b	4.41a

Crops in the annual system were soybean, corn and soybean in 2018, 2019, and 2020, respectively. Soil solution NO_3^--N were averaged across depths. Lower-case letters denote statistical significance between treatments at $P < 0.05$ within each year.

TABLE 3 Mean root biomass and soil extractable nitrate (mg NO_3^--N kg $soil^{-1}$) at four depth intervals from 0 to 60 cm at the end of the study in 2020.

	Root biomass (Mg ha^{-1})		Soil extractable nitrate (mg NO_3^--N kg $soil^{-1}$)	
	Annual	IWG	Annual	IWG
0–15	1.69b	8.57aA	2.77aA	0.17b
15–30	0.42b	2.82aB	1.38aB	0.00b
30–45	0.25	1.30B	0.48aC	0.00b
45–60	0.17	1.03B	0.25C	0.00

Letters denote statistical significance at $P < 0.05$; lower-case indicates difference between treatments; upper-case indicates difference between depths.

greater under IWG compared to the annual cropping system at all depths (Table 3). Soybean root biomass was 80%, 85%, 81%, and 83% lower than IWG root biomass at 0–15, 15–30, 30–45, and 45–60 cm, respectively. Summed over all the depths, total IWG root biomass was 13.73 Mg ha^{-1} while soybean root biomass was 2.54 Mg ha^{-1}, 82% lower ($P < 0.001$).

Crop yield

Grain yield was higher for the annual crops than for IWG in all years ($P < 0.001$, Table 2). Intermediate wheatgrass vegetative biomass yields (Table 2) were higher than soybean in 2018 ($P = 0.001$) and 2020 ($P = 0.009$) but similar to corn in 2019 ($P = 0.322$).

Soil water content

Of the four dates when soil water content was measured in 2019, there were very few effects of treatment, depth, or an interaction. Dates had a significant treatment by depth interaction. There was a main effect of cropping system treatment on soil water content on July 19 and October 31 ($P < 0.001$), in which soil water content was greater beneath the annual cropping system (0.09 m m^{-3}) compared to the perennial (0.03 m m^{-3}) on July 19 but lower in the annual (0.04 m m^{-3}) compared to the perennial (0.05 m m^{-3}) on October 31, 2019. In 2020, soil water content varied by treatment on June 23 ($P < 0.001$), in which soil water content was greater beneath the annual compared to the perennial. There was a significant interaction between treatment and depth on three other dates in 2020. Soil water content by treatment and depth is shown in Figure 2 to illustrate the interaction.

Discussion

Soil solution NO_3^--N concentration

Consistent with previous findings, we observed drastically lower concentrations of soil solution NO_3^--N beneath IWG compared to the annual cropping system (Figure 1). Concentrations under IWG were initially between 10 and 20 mg L^{-1} during June and July of 2018, the first spring after seeding, but approached zero by August and remained very low for the duration of the experiment. A previous study in Minnesota found that soil solution NO_3^--N beneath IWG averaged 0.09–0.3 mg L^{-1} when fertilized with 80 kg N ha^{-1} (Jungers et al., 2019). Despite only receiving 20 kg N ha^{-1} more fertilizer annually in this study, annual average soil solution NO_3^--N concentrations ranged from 4.3 mg L^{-1} in the first-year to 0.3 mg L^{-1} at the end of the study. Higher NO_3^--N concentrations found in this study compared to previous finding in Minnesota could be related to the potentially higher drainage rate associated with coarse structured soil at our study. These relatively higher soil solution NO_3^--N levels observed in the first-year of our study were also likely attributable to lower root biomass during stand establishment and thus reduced ability to capture and assimilate soil solution NO_3^--N. In line with this thinking, our results were similar to a study on sandy soil in

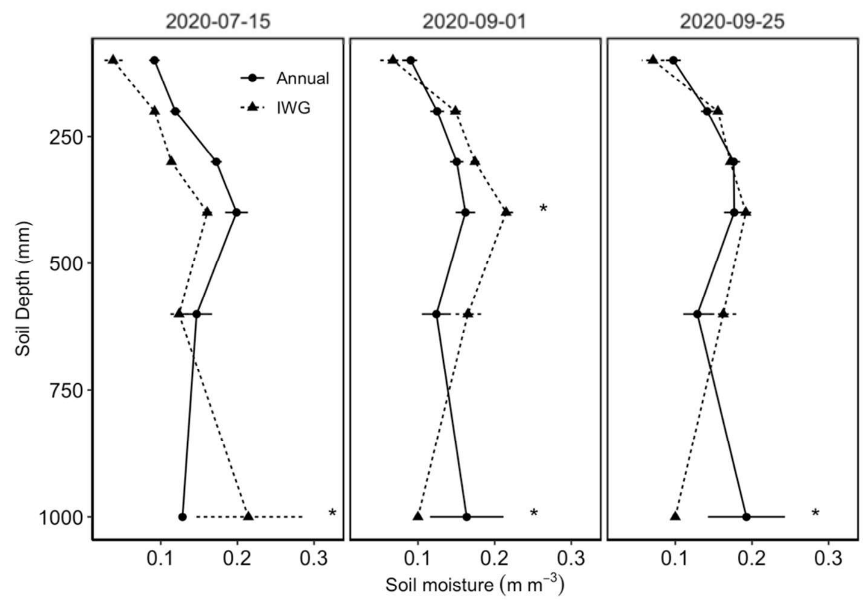

FIGURE 2
Soil water content beneath soybean (annual) and intermediate wheatgrass (IWG) on days when there was a significant interaction between cropping system treatment and depth. Asterisks indicate depths for which soil water content differed significantly between cropping systems.

Michigan during stand establishment (Culman et al., 2013b). Despite the slightly higher soil solution NO_3^--N concentrations observed in Year 1 here and on other sandy soils, values were comparable to mixtures of perennial grasses and forbs found in CRP plantings (Randall et al., 1997) and consistently below the EPA safe drinking standard of 10 mg L^{-1}.

Average annual soil solution NO_3^--N concentrations beneath the annual crops were similar to or slightly lower than those reported by other studies in Minnesota. During the corn phase of the annual rotation, our annual soil solution NO_3^--N of 22.1 mg L^{-1} was similar to findings by Ochsner et al. (2017), who reported an average soil solution NO_3^--N of 21.2 mg L^{-1} beneath a corn-soybean rotation with corn phases fertilized at 146 kg N ha^{-1} as urea annually. In another study also conducted on coarse-structured soils in Minnesota, Struffert et al. (2016) reported an average annual soil solution NO_3^--N concentration of 18.8 mg L^{-1} beneath soybean, and determined that soil solution NO_3^--N during the soybean phase was not affected by N fertilizer rates applied to corn the previous year.

This is also among the first studies to compare soil solution NO_3^--N levels of fertilized IWG to an unfertilized legume crop. Despite applying 100 kg N ha^{-1} of urea annually to the IWG, lower soil solution NO_3^--N concentration were observed in the IWG compared to the unfertilized soybean. Biologically fixed N may have been mineralized after exudation or sloughing of soybean roots, which may have contributed to higher soil solution NO_3^--N levels compared to IWG. The elevated soil solution NO_3^--N in the soybean could also have originated from N fertilizer applied during the previous crops. However, as previously mentioned, N fertilizer rates applied to a previous corn crop did not affect soil solution NO_3^--N beneath subsequent soybean (Struffert et al., 2016). Significant N demand by IWG may have also contributed to the large difference in soil solution NO_3^--N.

Soil extractable NO_3^--N

In addition to lower soil solution NO_3^--N concentration, we also found less extractable NO_3^--N in the soil after 3 years of IWG production compared to the annual rotation system. This suggests that the IWG assimilated NO_3^- more thoroughly from the soil than the annual rotation system, especially because the Year 3 crop was unfertilized soybean. Extractable NO_3^--N remaining in the soil is a major factor determining the concentration of dissolved NO_3^--N in soil solution, which in turn determines total leaching loads (Randall and Mulla, 2001; Culman et al., 2013a; Jungers et al., 2019).

The low levels of extractable NO_3^--N under IWG also suggest that the plants may have been N-limited, despite being fertilized at the high end of optimal rates (Jungers et al., 2017). Nitrogen removal during IWG grain and biomass harvest can exceed 150 kg N ha^{-1} in the first-year of production (Crews et al., 2022; Tautges et al., 2018). Intermediate wheatgrass tissue N concentrations at the time of grain harvest in Minnesota peaked above 10 g N kg^{-1} biomass and declined with stand age (Jungers et al., 2017). If tissue N concentrations were similar to previous studies in MN, removal rates could have been between 46 and 58 kg N ha^{-1} $year^{-1}$, thus less than the N applied as fertilizer (100 kg N ha^{-1}). However, total N demand may have been greater to support root biomass production. If root tissue N was similar to previously reported estimates between 9 and 11 g N kg^{-1} (Dobbratz, 2019), then there would be another pool of nearly 130 kg N ha^{-1} in belowground root tissues. It is not known what fraction of root N is recycled during root death and mineralization of root biomass from year to year in an IWG system, but our results suggest that the N fertilizer applied was needed to support above and belowground IWG biomass and that little N was likely lost *via* leaching or left in the soil.

Root biomass

Root biomass is considered an important trait of perennial crops for providing ecosystem services such as reduced nitrate leaching to groundwater. Intermediate wheatgrass root biomass averaged 13.7 Mg ha^{-1} after the third-year of production, while soybean root biomass was 2.5 Mg ha^{-1} when sampled from 0 to 60 cm. These values are similar to other reported values for these crops. For example, Intermediate wheatgrass fertilized at 80 kg N ha^{-1} had root biomass of 4.10, 7.32, and 9.51 Mg ha^{-1} (0–60 cm depth) in Years 1–3 of a 3-year study, while a soybean-corn-soybean rotation had root biomass of 2.22, 2.93, and 2.30 Mg ha^{-1} in Years 1–3 (Bergquist, 2019). Root biomass accumulation over time allows IWG to more effectively capture NO_3^--N before it reaches depths below the rooting zone where it is subject to leaching to groundwater. Nearly 63% of the IWG root biomass was found in the top 0–15 cm depth. Previous work has reported IWG belowground biomass to be 3.28 Mg ha^{-1} in the first 10 cm, on average, in Minnesota and Wisconsin (Sakiroglu et al., 2020). In an intra-annual study of root biomass beneath IWG, total root biomass from 0 to 20 cm peaked between 3.5 and 4 Mg ha^{-1} in June and July before declining to 1 Mg ha^{-1} at the end of the growing season (Pugliese et al., 2019). This concentration of root biomass at shallow depths also likely increases NO_3^--N capture and consequently reduce soil solution NO_3^--N below the rooting zone.

Soil water content

We found inconsistent differences in soil water content between annual crops and IWG. In the second-year of the study, soil water content was greater beneath the corn compared to the IWG in July, perhaps because IWG biomass would have been approaching peak biomass and thus been demanding more water than corn. A similar early-season pattern was found in Year 3 when soil water content was greater beneath the soybean compared to the IWG when measured in June. By the end of Year 2 (October), soil water content was greater in IWG compared to corn. Only in Year 3 did we observe any differences in soil water content by depth across treatments (Figure 2). In July, soil water content was greater beneath IWG compared to soybean at the deepest measured depth of 1,000 mm. This treatment effect was opposite at the 1,000 mm depth in September, where soil moisture content was greater for the soybean compared to IWG. Our results do match those from previous studies. In one comparison of perennial and annual systems, soil water content beneath *Miscanthus* and switchgrass was lower than a corn-soybean rotation earlier in the season, but the treatment effect flipped later in the season when switchgrass had higher soil water content (McIsaac et al., 2010). It has also been observed that soil water content tended to be higher under annuals than semi-perennials, and that there was less drainage from semi-perennials and perennials than annuals (Ferchaud and Mary, 2016). In studies with IWG, researchers have reported less in soil water content under IWG compared to annual wheat (Culman et al., 2013b) and corn (Jungers et al., 2019).

Soil water content can be used to make inferences on transpiration and drainage, the latter being an important component of nitrate leaching. The timing and frequency of our soil water content measurements precluded us from determining if both treatments had similar ET and drainage rates. Irrigation at our experiment could also have minimized our ability to detect differences in soil water content from plant ET. It is also established that greater root biomass increases water and nutrient uptake, which could reduce soil water content (Ehdaie et al., 2010; Matsunami et al., 2012; Carvalho et al., 2014). In our study, the similar soil moisture contents observed in the perennial and annual treatments may have been a function of the low water holding capacity of the sandy soil, which may have promoted drainage regardless of root biomass.

Grain and biomass yields

Intermediate wheatgrass grain yields at our sandy site were comparable to previous reports from sites with higher soil fertility levels. Under similar fertilizer treatments, reported first-year values range from 763 kg ha^{-1} (Zimbric et al., 2020) to 1,089 kg ha^{-1} at sites in Wisconsin (Favre et al., 2019) and from 893 kg ha^{-1} (Jungers et al., 2017) to 1,150 kg ha^{-1} (Fernandez et al., 2020) in Minnesota. Second- and third-year yields tend to be much lower, typically ranging from 150 kg ha^{-1} (Fernandez et al., 2020) to 630 kg ha^{-1} (Sakiroglu et al., 2020) in Year 2 and from 153 kg ha^{-1} (Jungers et al., 2017) to 371 kg ha^{-1} (Zimbric et al., 2020) in Year 3. Our yields suggest that this soil type and climate is appropriate for IWG grain and biomass production with irrigation.

Forage production is important for profitable IWG systems, since a major challenge of IWG grain production is the substantial yield declines in later years of production (Jungers et al., 2017; Pugliese et al., 2019; Hunter et al., 2020a). Intermediate wheatgrass biomass yields in this study included the stems and leaves that were remaining after grain harvest soon after peak productivity. Biomass harvested at this time, after physiological maturity, is relatively low in terms of forage quality compared to IWG biomass harvested at vegetative stages, but high compared to annual small grain biomass after grain harvest (Hunter et al., 2020b). Intermediate wheatgrass biomass yields were similar to those of other reports in Minnesota, though they were at the lower end of the range. Reported summer aboveground biomass values include 5,130 kg ha^{-1} in the second-year and 5,850 kg ha^{-1} in the third-year for IWG fertilized at 90 and 134 kg ha^{-1} in Wisconsin and 10,600 kg ha^{-1} for third-year stands in Minnesota (Sakiroglu et al., 2020). Similarly, summer yields of approximately 6,200 kg ha^{-1} were reported for first-year monocultures fertilized at 100 kg N ha^{-1} as urea (Favre et al., 2019). Biomass yields averaged 13,400 to 14,320 kg ha^{-1} for control treatments in a management study fertilized at 56 kg ha^{-1} the previous year (Pinto et al., 2021). Our results support that understanding that post-grain harvest biomass yields can be high enough for growers to consider harvesting for used as feed or straw on the farm or marketed for an additional revenue stream.

Conclusion

We found that soil solution NO_3^--N concentrations were 77–96% lower under IWG than the annual corn-soybean rotation, even in the unfertilized soybean phase of rotation, but soil water content was similar. This suggests that the IWG captured and utilized a greater proportion of soil solution NO_3^--N, which is also demonstrated by very low residual soil extractable NO_3^--N levels at the end of the experiment relative to the annual crops. The lower NO_3^--N concentrations in soil solution would be expected to translate to reductions in total leaching load of a similar magnitude. The increased uptake of N by IWG was likely facilitated by its greater root biomass, which was 5.4 times higher than that under the annual system. Despite the challenges associated with production of IWG on low-fertility sandy soils, grain yields were comparable to other locations and the system would likely be profitable in the first-year for grain alone. Biomass yields would support additional revenue streams in subsequent years to improve economic viability, and together our study provides evidence that IWG could be a good option for coarse textured soils that are prone to nitrate pollution.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Author contributions

ER: collected data, analyzed data, wrote the first draft of the manuscript, and contributed to the final draft of the manuscript. JG: oversaw soil sample processing and contributed to the final draft of the manuscript. CS: designed the field experiment and contributed to the final draft of the manuscript. JJ: acquired funding, designed the field experiment, oversaw field sampling and data collection, data visualization, and contributed to the final draft of the manuscript. All authors contributed to data interpretation, manuscript writing, and revision.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

References

Asbjornsen, H., Hernandez-Santana, V., Liebman, M., Bayala, J., Chen, J., Helmers, M., et al. (2014). Targeting perennial vegetation in agricultural landscapes for enhancing ecosystem services. *Renew. Agric. Food Syst.* 29, 101–125. doi: 10.1017/S1742170512000385

Bajgain, P., Zhang, X., Jungers, J. M., DeHaan, L. R., Heim, B., Sheaffer, C. C., et al. (2020). 'MN-Clearwater', the first food-grade intermediate wheatgrass (Kernza perennial grain) cultivar. *J. Plant Regist.* 14, 288–297. doi: 10.1002/plr2.20042

Bergquist, G. (2019). Biomass Yield and Soil Microbial Response to Management of Perennial Intermediate Wheatgrass (Thinopyrum *intermedium*) as Grain Crop and Carbon Sink. Master's Theses, University of Minnesota.

Brender, J. D., Weyer, P. J., Romitti, P. A., Mohanty, B. P., Shinde, M. U., Vuong, A. M., et al. (2013). Prenatal nitrate intake from drinking water and selected birth defects in offspring of participants in the national birth defects prevention study. *Environ. Health Perspect.* 121, 1083–1089. doi: 10.1289/ehp.1206249

Carvalho, P., Azam-Ali, S., and Foulkes, M. J. (2014). Quantifying relationships between rooting traits and water uptake under drought in Mediterranean barley and durum wheat: root traits and water uptake. *J. Integr. Plant Biol.* 56, 455–469. doi: 10.1111/jipb.12109

Crews, T. E., Kemp, L., Bowden, J. H., and Murrell, E. G. (2022). How the nitrogen economy of a perennial cereal-legume intercrop affects productivity: can synchrony be achieved? *Front. Sustain. Food Syst.* 6:755548. doi: 10.3389/fsufs.2022.755548

Crews, T. E., and Peoples, M. B. (2005). Can the synchrony of nitrogen supply and crop demand be improved in legume and fertilizer-based agroecosystems? A review. *Nutr. Cycl. Agroecosystems* 72, 101–120. doi: 10.1007/s10705-004-6480-1

Culman, S. W., Snapp, S. S., Green, J. M., and Gentry, L. E. (2013a). Short- and long-term labile soil carbon and nitrogen dynamics reflect management and predict corn agronomic performance. *Agron. J.* 105, 493–502. doi: 10.2134/agronj2012.0382

Culman, S. W., Snapp, S. S., Ollenburger, M., Basso, B., and DeHaan, L. R. (2013b). Soil and water quality rapidly responds to the perennial grain Kernza wheatgrass. *Agron. J.* 105, 735–744. doi: 10.2134/agronj2012.0273

DeHaan, L., Christians, M., Crain, J., and Poland, J. (2018). Development and evolution of an intermediate wheatgrass domestication program. *Sustainability* 10:1499. doi: 10.3390/su10051499

Delta-T Devices (2021). *PR2 Profile Probe - Analogue Version*. Cambridge, UK. Available online at: www.delta-t.co.uk/product/pr2/

Dinnes, D. L., Karlen, D. L., Jaynes, D. B., Kaspar, T. C., Hatfield, J. L., Colvin, T. S., et al. (2002). Review and interpretation: nitrogen management strategies to reduce nitrate leaching in tile-drained Midwestern soils. *Agron. J.* 94, 153–171. doi: 10.2134/agronj2002.1530

Dobbratz, M. (2019). *Perennial fuel, feed, and cereal: High diversity perennials for biofuel and intermediate wheatgrass for grain and forage*. PhD Dissertation retrieved from University of Minnesota Digital Conservancy. Available online at: https://hdl.handle.net/11299/211748

Ehdaie, B., Merhaut, D. J., Ahmadian, S., Hoops, A. C., Khuong, T., Layne, A. P., et al. (2010). Root system size influences water-nutrient uptake and nitrate leaching potential in wheat: root system and nutrient uptake in wheat. *J. Agron. Crop Sci.* 196, 455–466. doi: 10.1111/j.1439-037X.2010.00433.x

Erisman, J. W., Galloway, J. N., Seitzinger, S., Bleeker, A., Dise, N. B., Petrescu, A. M. R., et al. (2013). Consequences of human modification of the global nitrogen cycle. *Philos. Trans. R. Soc. B Biol. Sci.* 368, 20130116. doi: 10.1098/rstb.2013.0116

Favre, J. R., Castiblanco, T. M., Combs, D. K., Wattiaux, M. A., and Picasso, V. D. (2019). Forage nutritive value and predicted fiber digestibility of Kernza intermediate wheatgrass in monoculture and in mixture with red clover during the first production year. *Anim. Feed Sci. Technol.* 258, 114298. doi: 10.1016/j.anifeedsci.2019.114298

Ferchaud, F., and Mary, B. (2016). Drainage and nitrate leaching assessed during 7 years under perennial and annual bioenergy crops. *Bioenergy Res.* 9, 656–670. doi: 10.1007/s12155-015-9710-2

Fernandez, C. W., Ehlke, N., Sheaffer, C. C., and Jungers, J. M. (2020). Effects of nitrogen fertilization and planting density on intermediate wheatgrass yield. *Agron. J.* 112, 4159–4170. doi: 10.1002/agj2.20351

Feyereisen, G. W., Wilson, B. N., Sands, G. R., Strock, J. S., and Porter, P. M. (2006). Potential for a rye cover crop to reduce nitrate loss in Southwestern Minnesota. *Agron. J.* 98, 1416–1426. doi: 10.2134/agronj2005.0134

Hunter, M. C., Sheaffer, C. C., Culman, S. W., and Jungers, J. M. (2020a). Effects of defoliation and row spacing on intermediate wheatgrass I: Grain production. *Agron. J.* 112, 1748–1763. doi: 10.1002/agj2.20128

Hunter, M. C., Sheaffer, C. C., Culman, S. W., Lazarus, W. F., and Jungers, J. M. (2020b). Effects of defoliation and row spacing on intermediate wheatgrass II: forage yield and economics. *Agron. J.* 112, 1862–1880. doi: 10.1002/agj2.20124

Hupet, F., Bogaert, P., and Vanclooster, M. (2004). Quantifying the local-scale uncertainty of estimated actual evapotranspiration. *Hydrol. Process.* 18, 3415–3434. doi: 10.1002/hyp.1504

Jungers, J. M., DeHaan, L. H., Mulla, D. J., Sheaffer, C. C., and Wyse, D. L. (2019). Reduced nitrate leaching in a perennial grain crop compared to maize in the Upper Midwest, USA. *Agric. Ecosyst. Environ.* 272, 63–73. doi: 10.1016/j.agee.2018.11.007

Jungers, J. M., DeHaan, L. R., Betts, K. J., Sheaffer, C. C., and Wyse, D. L. (2017). Intermediate wheatgrass grain and forage yield responses to nitrogen fertilization. *Agron. J.* 109, 462–472. doi: 10.2134/agronj2016.07.0438

Keeler, B. L., Gourevitch, J. D., Polasky, S., Isbell, F., Tessum, C. W., Hill, J. D., et al. (2016). The social costs of nitrogen. *Sci. Adv.* 2, e1600219. doi: 10.1126/sciadv.1600219

Keeler, B. L., and Polasky, S. (2014). Land-use change and costs to rural households: a case study in groundwater nitrate contamination. *Environ. Res. Lett.* 9, 074002. doi: 10.1088/1748-9326/9/7/074002

Law, E. P., Wayman, S., Pelzer, C. J., Culman, S. W., Gómez, M. I., DiTommaso, A., et al. (2022). Multi-criteria assessment of the economic and environmental sustainability characteristics of intermediate wheatgrass grown as a dual-purpose grain and forage crop. *Sustainability.* 14, 3548. doi: 10.3390/su14063548

Length, R. (2019). *emmeans: Estimated Marginal Means, aka Least-Squares Means. R package version 1.3.3.* Available online at: https://CRAN.R-project.org/package=emmeans

Maeght, J.-L., Rewald, B., and Pierret, A. (2013). How to study deep roots—and why it matters. *Front. Plant Sci.* 4:299. doi: 10.3389/fpls.2013.00299

Matsunami, M., Matsunami, T., Ogawa, A., Toyofuku, K., Kodama, I., and Kokubun, M. (2012). Genotypic variation in biomass production at the early vegetative stage among rice cultivars subjected to deficient soil moisture regimes and its association with water uptake capacity. *Plant Prod. Sci.* 15, 82–91. doi: 10.1626/pps.15.82

McIsaac, G. F., David, M. B., and Mitchell, C. A. (2010). *Miscanthus* and switchgrass production in Central Illinois: impacts on hydrology and inorganic nitrogen leaching. *J. Environ. Qual.* 39, 1790–1799. doi: 10.2134/jeq2009.0497

Ochsner, T. E., Schumacher, T. W., Venterea, R. T., Feyereisen, G. W., and Baker, J. M. (2017). Soil water dynamics and nitrate leaching under corn–soybean rotation, continuous corn, and kura clover. *Vadose Zone J.* 17, 1–11. doi: 10.2136/vzj2017.01.0028

Pinheiro, J., Bates, D., DebRoy, S., Sarkar, D., and and, R., Core Team (2019). *nlme: Linear and Nonlinear Mixed Effects Models. R package version 3.1-139,*. Available online at: https://CRAN.R-project.org/package=nlme

Pinto, P., De Haan, L., and Picasso, V. (2021). Post-harvest management practices impact on light penetration and Kernza intermediate wheatgrass yield components. *Agronomy* 11, 442. doi: 10.3390/agronomy11030442

Pugesgaard, S., Schelde, K., Larsen, S. U., Laerke, P. E., and Jørgensen, U. (2015). Comparing annual and perennial crops for bioenergy production - influence on nitrate leaching and energy balance. *GCB Bioenergy* 7, 1136–1149. doi: 10.1111/gcbb.12215

Pugliese, J. Y., Culman, S. W., and Sprunger, C. D. (2019). Harvesting forage of the perennial grain crop Kernza (*Thinopyrum intermedium*) increases root biomass and soil nitrogen cycling. *Plant Soil* 437, 241–254. doi: 10.1007/s11104-019-03974-6

R Core Team (2018). *R: A Language and Environment for Statistical Computing*. Vienna: R Foundation for Statistical Computing Available online at: https://www.R-project.org/

Randall, G. W., Huggins, D. R., Russelle, M. P., Fuchs, D. J., Nelson, W. W., and Anderson, J. L. (1997). Nitrate losses through subsurface tile drainage in Conservation Reserve Program, Alfalfa, and row crop systems. *J. Environ. Qual.* 26, 1240–1247. doi: 10.2134/jeq1997.00472425002600050007x

Randall, G. W., and Mulla, D. J. (2001). Nitrate nitrogen in surface waters as influenced by climatic conditions and agricultural practices. *J. Environ. Qual.* 30, 337–344. doi: 10.2134/jeq2001.302337x

Sakiroglu, M., Dong, C., Hall, M. B., Jungers, J., and Picasso, V. (2020). How does nitrogen and forage harvest affect belowground biomass and nonstructural carbohydrates in dual-use Kernza intermediate wheatgrass? *Crop Sci.* 60, 2562–2573. doi: 10.1002/csc2.20239

Smucker, A. J. M., McBurney, S. L., and Srivastava, A. K. (1982). Quantitative separation of roots from compacted soil profiles by the hydropneumatic elutriation system. *Agron. J.* 74, 500–503. doi: 10.2134/agronj1982.00021962007400030023x

Struffert, A. M., Rubin, J. C., Fernández, F. G., and Lamb, J. A. (2016). Nitrogen management for corn and groundwater quality in Upper Midwest irrigated sands. *J. Environ. Qual.* 45.1557–1564. doi: 10.2134/jeq2016.03.0105

Tautges, N. E., Jungers, J. M., DeHaan, L. R., Wyse, D. L., and Sheaffer, C. C. (2018). Maintaining grain yields of the perennial cereal intermediate wheatgrass in monoculture v. bi-culture with alfalfa in the Upper Midwestern USA. *J. Agric. Sci.* 156, 758–773. doi: 10.1017/S0021859618000680

USDA–NRCS (2021). *Web Soil Survey. USDA – Natural Resources Conservation Service*. Available online at: https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm

Ward, M., Jones, R., Brender, J., de Kok, T., Weyer, P., Nolan, B., et al. (2018). Drinking water nitrate and human health: an updated review. *Int. J. Environ. Res. Public Health* 15, 1557. doi: 10.3390/ijerph15071557

Ward, M. H., Kilfoy, B. A., Weyer, P. J., Anderson, K. E., Folsom, A. R., and Cerhan, J. R. (2010). Nitrate intake and the risk of thyroid cancer and thyroid disease. *Epidemiology* 21, 389–395. doi: 10.1097/EDE.0b013e3181d6201d

Zimbric, J. W., Stoltenberg, D. E., and Picasso, V. D. (2020). Effective weed suppression in dual-use intermediate wheatgrass systems. *Agron. J.* 112, 2164–2175. doi: 10.1002/agj2.20194

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Financial comparison of seven nitrate reduction strategies for Midwestern agricultural drainage

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ABSTRACT

Much work has been invested in the development of practices and technologies that reduce nitrate losses from agricultural drainage in the US Midwest. While each individual practice can be valuable, the effectiveness will be site specific and the acceptability of each approach will differ between producers. To enhance decision making in terms of water quality practices, this work created average cost effectiveness parameters for seven nitrate management strategies (controlled drainage, wetlands, denitrification bioreactors, nitrogen management rate and timing, cover crops, and crop rotation). For each practice, available published cost information was used to develop a farm-level financial model that assessed establishment and maintenance costs as well as examined financial effects of potential yield impacts. Then, each practice's cost values were combined with literature review of N reduction (% N load reduction), which allowed comparison of these seven practices in terms of cost effectiveness (dollars per kg N removed). At $-\$14$ and $-\$1.60\ \text{kg N}^{-1}\ \text{yr}^{-1}$, springtime nitrogen application and nitrogen application rate reduction were the most cost effective practices. The in-field vegetative practices of cover crop and crop rotation were the least cost effective (means: \$55 and \$43 $\text{kg N}^{-1}\ \text{yr}^{-1}$, respectively). With means of less than \$3 $\text{kg N}^{-1}\ \text{yr}^{-1}$, controlled drainage, wetlands, and bioreactors were fairly comparable with each other. While no individual technology or management approach will be capable of addressing

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drainage water quality concerns in entirety, this analysis provides measures of average cost effectiveness across these seven strategies that allows direct comparison.

1. Introduction

Artificial subsurface drainage systems in the Midwestern "Corn Belt" region have allowed for increased productivity over the past century [1], but nitrate (NO_3^-) losses in drainage have caused significant multi-scale environmental concerns [2,3]. Much work has been done developing and advancing practices to reduce NO_3^- losses in subsurface agricultural drainage. Dinnes et al. [1] provide a comprehensive review of NO_3^- reducing technologies for the Midwest including in-field "preventative" N strategies (e.g., N management, cover crops, diversified rotations) and "remedial" strategies for N removal from drainage (e.g., controlled drainage, bioreactors, wetlands). While each strategy and individual practice can be valuable, the NO_3^- removal effectiveness will be site specific and the acceptability of each individual approach will differ between producers. Nevertheless, no individual technology or management approach will be capable of addressing drainage water quality concerns in entirety [1,4]; as such, a suite of approaches used across these landscapes will be required [5].

On an individual farmer basis, adoption of environmental management practices designed to mitigate or prevent issues such as NO_3^- losses through drainage to surface waters are motivationally different from production innovations largely because short-term economic advantages of adopting a mitigation technology are rare [6,7]. Farm level action involving use of technology is in large part influenced by owner and operator beliefs and attitudes (i.e., regarding environmental and financial risk) in combination with personal environmental goals and knowledge about technology [8]. Perceptions of a technology in turn are shaped by external factors such as cost, overall complexity and effectiveness of the available technology, and available technical/financial support [9,10]. As such, crop producers require comprehensive information about water quality technologies with regard to the context for use, operational parameters, performance efficacy, and the full range of financial parameters (e.g., upfront and long-term costs). Of particular and universal concern for farmers is the financial feasibility of a particular technology in the context of their production system, as well as comparative advantage across technology-based management options. Moreover, comprehensive financial information is needed to calibrate agricultural conservation cost-share programming and targeting and to better guide federal and state technical service provision at county levels [4].

To enhance land-use decision making, this work investigates and makes transparent the financial parameters of seven NO_3^- management strategies; three are remedial N strategies: controlled drainage, wetlands, denitrification bioreactors and four are preventative N strategies: N rate reduction, spring N application, cover crops, and crop rotation. It bears to note early-on; however, that the Midwest is a heterogeneous region where not every abatement strategy will be equally appropriate (i.e., costly or effective) in any given situation. Suitability, in addition to NO_3^- reduction effectiveness, can vary by soil type, topography, landscape position, and microclimate (e.g., rainfall patterns, winter severity) for each of the seven distinct practices investigated here. For example, winter cover crops may be more difficult to establish in northern Minnesota vs. southern Indiana, and controlled drainage will be most cost effective on flatter topographies. The assumed baseline cropping system for this work was a corn/soybean rotation, reflective of the Midwestern agricultural landscape [11], and because tillage generally has a relatively small impact upon tile drainage NO_3^- export [12], it was not included as a variable here.

Controlled drainage (also known as drainage water management) is a strategy that addresses agricultural NO_3^- loading through the use of a series of structures installed in drainage pipes or drainage ditches that allow control of the water table depth [13,14]. Though this practice can be used to achieve agronomic and/or environmental objectives [14], a major limitation is that controlled drainage becomes more expensive on slopes greater than 0.5–1% [1,15]. The second practice under consideration here, denitrification or woodchip bioreactors, uses control structures to regulate drainage water flowing through an excavation (typically >30 m long, >1 m wide) filled with a carbon source allowing enhanced denitrification of the NO_3^- in the drainage water [16,17]. These systems have been tested for treating drainage from “field-sized” areas of approximately 20 ha and usually require very little to no land to be removed from production by fitting in grassed edge-of-field areas [17]. The third of the remedial strategies, constructed wetlands, is a long-term NO_3^- reduction strategy intended for watershed-scale treatment [18,19]. A key consideration for N removal in wetlands is the wetland to treatment area ratio with increased N removal possible at increased wetland: watershed area ratios [18,20–22].

Regarding in-field, preventative practices, N fertilizer management, here in terms of rate and timing, is one of the farm operator-controlled factors to reduce N losses in agricultural drainage [1,12,23,24]. Water quality benefits of reduced application rates will be a function of the original and the modified rate [25,26]. Lawlor et al. [27] proposed that a corn (*Zea mays* L.) and soybean (*Glycine max* (L.) Merr.) rotations can be described with:

$$\text{N Concentration in Drainage} = 5.72 + 1.33e^{(0.0104 \times N\ Rate)} \tag{1}$$

where N concentration is in mg N L^{-1} and rate is in kg N applied ha^{-1} [27]. Spring N application in the U.S. Midwest more closely synchronizes the application with plant uptake [28,29], an outcome that is preferable from both water quality and agronomic perspectives [24]. Nevertheless, fall N applications are a way to manage risk associated with uncertain spring weather and spring-time field activities [30].

The “preventative” strategy of winter cover crops such as rye, oat, winter wheat, brassica, or winter-hardy legumes, utilizes plant uptake as the major water quality improvement mechanism [31,32]. Benefits of cover crops (as well as several of the other practices) extend beyond drainage water NO_3^- reduction (e.g., erosion control, pest control, enhancement of soil productivity) [29,33] but were not included here as this analysis focuses solely on NO_3^- reduction; see Table 1 for abbreviated comments and Christianson et al. [34] for a broad discussion of ecosystem services associated with the use of any of these seven practices. The main limitations of winter cover crops are that they need to grow well under non-ideal conditions [1,32], some need to be killed before planting the main crop, and a corn yield reduction following certain covers is possible [31,32]. The final practice, crop rotations that include perennials, similarly provides water quality benefits via N and water uptake [1,35] and additional benefits to the soil [36]. Although the main limitations for this sort of rotation include access to markets, crop storage, and additional machinery requirements, Dinnes [29] reported diversifying cropping systems in Iowa has the most potential to reduce NO_3^- loadings compared to any other best management practice.

The objectives of this exploratory financial assessment are two-fold: (1) characterize and quantify the financial (cost) parameters of the seven NO_3^- reduction strategies; and (2) explore and compare the average cost efficiency of each strategy (dollars per kg N removed) using published measures of N reduction effectiveness. The primary motivation of this work is that while cost assessment of this type is fairly straight-forward, cost comparison analysis across various agricultural best management practices is invariably challenged [37] by (1) limited availability of published cost information, (2) variable methodology in published financial assessments, (3) limited methodological transparency in published cost assessments, (4) variable discount rates, (5) inconsistent analysis horizons due to variable life spans or management horizons, and (6) many costs are often site specific and therefore can exhibit significant ranges. This analysis is therefore an attempt to make transparent the structure and timing of cost parameters associated with using any of these NO_3^- management strategies, and to develop comparable measures of average cost effectiveness across these seven NO_3^- management strategies. Nevertheless, we recognize an inherent limitation of this work arises from the site-specific nature of the practices being compared; their application at different sites and under different conditions will necessarily confound a comparison of their effectiveness in reducing N loads and hence their calculated cost efficiencies.

Table 1
Description of the scenarios, uncertainty ranges for the Total Present Value Costs, and the additional benefits and costs that were not quantified for seven nitrogen reduction practices for agricultural drainage; see Christianson et al. [34] for more specific discussion of ecosystem services of these practices.

Practice	Practicable lifespan (yr)	Specific scenario	Uncertainty of ranges for TPVC	Unquantified costs and benefits
Controlled drainage	40	1 structure per 4 ha–8 ha	Low uncertainty	Potential yield impacts Potential increase in soil erosion, soil compaction, or surface runoff
Bioreactor	40	20.2 ha field treated with a 0.1 ha bioreactor	Low uncertainty	None
Wetland	50	405 ha treated by a 4 ha wetland plus buffer	Moderate uncertainty due to predominance of land cost and the variability of this factor	Additional ecosystem services including pollination, wood fuel, ornamental resources, natural hazard regulation, and recreation
N rate reduction	1	168 kg N ha^{-1}–140 kg N ha^{-1}	Large uncertainty due to yield impact variability	Probabilistic variability of yields
N spring application	1	Apply N in spring instead of fall	Large uncertainty due to unquantified risk and yield impact variability	Cost of infrastructure potentially required for fertilizer storage, handling, etc. Probabilistic variability of yields Potential loss of yield by a delayed planting date
Cover crop	4	Rye drilled	Large uncertainty as this practice is primarily implemented for reasons other than N reduction and due to yield impact variability	Additional ecosystem services including pollination and erosion and pest regulation; Potential future yield enhancement due to cover crop-induced soil quality and organic matter enhancement
Rotation	10	3 years alfalfa, 2 years corn	Very large uncertainty due to rotation complexity and the variability of alfalfa-induced yield increase	Additional ecosystem services including pollination and erosion and pest regulation; Potential future yield enhancement due to perennial-induced soil quality and organic matter enhancement

2. Materials and methods

There is limited availability of published cost information regarding drainage NO_3^- reduction strategies, and the variable methodology and limited transparency for the studies that have been done in this area make comparison between published analyses difficult. The timing of costs particularly complicates comparisons of water quality practices. For example, controlled drainage, bioreactors, and wetlands all have large initial capital outlays and intermittent management costs, while N management, cover crops, and crop rotations largely involve variable annual costs. Cost assessments have been carefully constructed for all seven practices with itemized cost parameters and unit cost data for each strategy collected from various secondary sources (e.g., published literature, published custom rate surveys, and when necessary personal communication with knowledgeable individuals). Total present value costs (TPVCs) were assessed with a discounted cost model that aggregates total fixed and variable costs.

$$\mathrm{TPVC}_{\mathrm{practice}} = C_{\mathrm{est,practice}} \text{ in year } 1 + C_{\mathrm{main}} \text{ occuring over n years} \tag{2}$$

where $\mathrm{TPVC}_{\mathrm{Practice}}$ is the total present value of the cost of a practice, $C_{\mathrm{est,Practice}}$ is the full establishment cost, and C_{main} involves all annual and/or periodic maintenance costs of the practice applicable for and discounted over n years. The specific variations of this general model for each individual technology are presented in Supplemental material.

To develop a range of costs for each practice, minimum and maximum values for each individual cost category were summed to develop a minimum and maximum TPVC, respectively (Tables 2–7). If only a single value (i.e., mean) was available for a cost, this value was used in both the minimum and maximum TPVC calculation for that practice. As is appropriate for this type of cost comparison assessment (e.g., [38–41]), the minimum and maximum TPVCs for each practice were then used to develop a range of equal annual costs (EACs) for the strategies (Table 9). The EAC approach involves determining the equal annual payment (in present value terms) that would be made at the end of each year to fully cover costs over a planning horizon, and allows for the direct comparison of total present value costs from practices that have different practicable life spans [42]. More pragmatically, the EAC format allows farm-level decision makers to consider environmental best management practice costs essentially on a similar basis that they consider typical farm-level production costs [43].

Following Burdick et al. [44] and Tyndall and Grala [45], conversion to EACs was done using a capital recovery factor (CRF):

$$\mathrm{EAC} = \mathrm{TPVC} \times \mathrm{CRF} \tag{3}$$

where TPVC is the total present value of the cost of the practice and the CRF is calculated using:

$$\mathrm{CRF} = \frac{i(1+i)^n}{(1+i)^n - 1} \tag{4}$$

where i is the annual real discount rate and n is the number of years in the evaluation (i.e., planning horizon). The analysis was carried out using a 4% real discount rate, and the n was set to each practice's individual practicable lifespan (Table 1). A 4% discount rate represented the average real interest rate on Iowa farmland loans during 2008–2010 and was very similar to the 2011 rate for federal water projects (4.125%) [46].

Calculated EACs were combined with published measures of NO_3^- removal efficacy (% load reduction; Table 8) to develop an average efficiency parameter of dollars per kg N removed. This literature review-based approach (as opposed to a more site-specific modeling approach, which was outside the scope of this financial parameterization work) allowed capture of some inherent variability as the literature contains observations across sites and conditions. Dividing the EAC of each strategy by the amount of NO_3^--N removed is a standard way to present total costs per unit e.g., [44,47]. To do so, a Midwestern-representative load of 31.4 kg N ha^{-1} was developed from an average of Jaynes et al. [48] tile and drain N loads and Lawlor et al. [49] drainage N loads at their 168 kg N ha^{-1} application rate. Then, the minimum and maximum EAC for each practice were each applied to that practices' range for N load reduction (mean, median, 25th, and 75th percentiles from Table 8 and Fig. 1

Table 2
Itemized costs and Total Present Value Costs for controlled drainage in the U.S. Midwest at real discount rate of 4 % and analysis horizon of 40 years.

Item	Cost timing (yr)	Minimum cost ($ ha^{-1})	Mean cost ($ ha^{-1})	Maximum cost ($ ha^{-1})	Notes and assumptions	Reference
Structure cost	1	$61.78		$247.11	New drainage system: 1 structure per 8 ha at $500–$2000 per ea.	[15]
	1	$123.55		$494.21	Existing drainage system: 1 structure per 4 ha at $500–$2000 per ea.	
Transport structures	–				Assumed included above	Assumption
Design cost	1		$80.63		For new drainage systems but also included as design cost of existing	[100]
Contractor fees	1	$4.32	$9.47	$15.44	Structure installation: Back hoeing at $35.00 h^{-1}, $76.65 h^{-1}, $125.00 h^{-1} for 8 h to treat 65 ha	[81]
Total cost of establishment		**$146.73**		**$343.18**	**New (TPVC)**	
		$208.51		**$590.29**	**Existing (TPVC)**	
Time to raise/lower	$1-n$	$0.99		$4.94	Four hours × two to four times a year; labor at $8–$20 h^{-1}, 65 ha treatment area	[81]
Stop log/gate replacement	8, 16, 24, …	$17.67		$35.34	Summation of single sum TPV every eight years for 5 gates per structure at original cost of $14.17–$15.32 per ea. for 15 cm structures, 1 structure per 4 (Existing) or 8.1 (New) ha	[101]
Total cost of establishment, maintenance, and replacement		**$183.96**		**$723.44**	**TPVC**	

Table 3
Itemized costs and Total Present Value Costs for a denitrification bioreactor in the U.S. Midwest at real discount rate of 4 % and analysis horizon of 40 years.

Item	Cost timing (yr)	Minimum cost ($ ha^{-1})	Mean cost ($ ha^{-1})	Maximum cost ($ ha^{-1})	Notes	Reference
Both control structures	1	$49.42		$197.68	Two control structures at $500–$2000 ea.; 20.2 ha treatment area	[101]
Structure transport	–				Assumed included above	Assumption
Woodchip cost	1		$116.14		Two semi loads at $975 chips + $200 transport ea.; 20.2 ha treatment area	[102]
Woodchip transport to farm	–				Included above	
Design cost	1	$0.00		$31.63	Assumed: $40 h^{-1} for 2 days of work or NRCS service provider; 20.2 ha treatment	Assumption
Contractor fees	1	$27.68	$60.61	$98.84	Back hoeing at $35.00 h^{-1}, $76.65 h^{-1}, $125.00 h^{-1} for 16 h to treat 20.2 ha	[81]; Assumptions
Seeding bioreactor surface	1	$0.05	$0.11	$0.15	Seeding grass, broadcast with tractor; for 20.2 ha treatment and 0.10 ha bioreactor at $9.88, $22.61, and $29.65 h^{-1}	[81]
Seed cost	1		$1.11		Seed costs from dealer: $222.27 ha^{-1} for CRP Mix (CP23) Diversified mix; bioreactor surface 0.005 of treatment area	[82]
Misc. materials	1		$8.80		6″ tile $890 per 305 m(1000 ft); Assume 61 m needed for control structure connections for 20.20 ha treatment area	[101]
Total cost of establishment		**$203.19**		**$454.35**	**TPVC**	
Time to raise/lower	$1-n$	$1.19		$2.97	Three hours per yr with farm labor wages at $8–$20 h^{-1}, 20.2 ha treatment area	[81]; Assumption
Mowing/maintenance	$1-n$	$0.12		$0.62	Spot mowing bioreactor at $24.71–$123.55 ha^{-1} for 20.2 ha treatment	[83]
Replacement year 20	20	$65.66		$98.18	Single sum TPVC at 20 years: woodchips, contractor, seeding	Assumption
Gate replacement	8, 16, 24,…		$14.14		Summation of single sum TPV every eight years for 5 gates per structure ($14.17–$15.32 per ea. for 15 cm structure) 2 structures per 20.2 ha	[101]
Total cost of establishment, maintenance, and replacement		**$308.91**		**$637.59**	**TPVC**	

Table 4
Itemized costs and Total Present Value Costs for a wetland in the U.S. Midwest at real discount rate of 4 % and analysis horizon of 50 years.

Item	Cost timing (yr)	Minimum cost ($ ha^{-1})	Mean cost ($ ha^{-1})	Maximum cost ($ ha^{-1})	Notes	Reference
Design cost	1		$71.17		Assumed: $40 h^{-1} for 90 days of work (8 h d^{-1}) for 405 ha site	Assumption
Contractor fees	1	$28.17	$34.43	$41.51	Building ponds at 8 h d^{-1} for 15 days with Custom Rate Survey $ h^{-1} for 405 ha wetland , not including seeding time	[81]
Seeding buffer	1	$0.35	$0.79	$1.04	Tractor broadcasting at $9.88, $22.61, or $29.65 ha^{-1} for 14 ha wetland buffer for 405 ha treatment	[81]
Seed cost	1	$7.43		$95.38	Seed costs from dealer: $212.39 ha^{-1} for CRP wetland program mix to $162.09 kg^{-1} for "wetland seed mix" at needed 16.8 kg ha^{-1}	[82,84]
Weir plate	1		$14.83		$30 per sq ft. for 40 ft width × 5 ft sheet pile plate, for 405 ha site	Assumption
Control structure	1	$3.26		$7.25	One large control structure ($1320–$2935 per ea.), for 405 ha site	[101]
Land acquisition	1	$529.08		$679.31	$11,757–$15,095 ha^{-1} for 4 ha wetland plus 14 ha buffer treating 405 ha; 2010 state-wide Iowa average for high and medium grade lands	[85]
Total cost of establishment		**$654.28**		**$910.48**	**TPVC**	
Time to manage	$1-n$	$0.09		$0.43	Spot mowing 10% of buffer area at $24.71–$123.55 ha^{-1}	[83]
Control structure and weir replacement	40	$4.55		$5.75	Single sum TPVC at year 40 includes costs of a new structure and weir and 16 hrs of earth work	Assumption
Total cost of establishment, maintenance, and replacement		**$660.69**		**$925.52**	**TPVC**	

Table 5
Itemized costs and Total Present Value Costs for N management for corn in the U.S. Midwest at real discount rate of 4 % and analysis horizon of 1 year.

Item	Cost timing (yr)	Minimum cost ($ ha^{-1})	Mean cost ($ ha^{-1})	Maximum cost ($ ha^{-1})	Notes	Reference
Fertilizer application	$1-n$	$14.83	$24.09	$42.01	Anhydrous-injecting, w/tool bar	[81]
Diesel for equipment	–				Included above	
Fertilizer cost	$1-n$		$156.40		North Central US mean 2008–2010 anhydrous ammonia price paid: $762.80 metric ton^{-1}; 168 kg N ha^{-1}; AA:82-0-0 (82%)	[56]
Total cost of establishment for baseline application		$171.23		$198.41	Using Fertilizer cost: $156.40 ha^{-1} considering application of 168 kg N ha^{-1} in Fall	[56]
Total cost of establishment at a lower rate (from 168 kg N ha^{-1} to 140 kg N ha^{-1})		**$145.16**		**$172.34**	Using Fertilizer cost: $130.33 ha^{-1} for application of 140 kg N ha^{-1} rather than $156.40 ha^{-1} for 168 kg N ha^{-1}	[56]
Total cost of establishment of Spring application		**$178.42**		**$205.60**	Spring price of $798 metric ton^{-1} at 168 kg N ha^{-1} application rate ($163.59 ha^{-1})	[56,58]
Annual baseline revenue	$1-n$		$1850.12		Iowa mean 2008–2010 yield of 10.84 metric ton ha^{-1} and 2008–2010 mean corn price received of $0.17 kg^{-1}; at 99% yield for 168 kg N ha^{-1}	[55,56]
Annual revenue from changed yields due to N management (Lower rate)	$1-n$		$1831.44		Iowa mean 2008–2010 yield of 10.84 metric ton ha^{-1} and 2008–2010 mean corn price received of $0.17 kg^{-1}; at 98% yield for 140 kg N ha^{-1}	[55,56]
Annual revenue from changed yields due to N management (Spring application)	$1-n$		$1947.30		Iowa mean 2008–2010 yield of 10.84 metric ton ha^{-1} and 2008–2010 mean corn price received of $0.17 kg^{-1}; with 4.2% yield boost for spring application	[56]
Total cost of establishment and revenue impacts for baseline application		−$1614.32		−$1588.19	TPVC (negative represents a revenue)	
Total cost of establishment and revenue impacts at a lower application rate		**−$1621.42**		**−$1595.28**	**TPVC (negative represents a revenue)**	
Total cost of establishment and revenue impacts for Spring application		**−$1700.85**		**−$1674.71**	**TPVC (negative represents a revenue)**	
N Rate Marginal Cost		**−$7.09**		**−$7.09**	**Marginal TPVC**	
Spring N Marginal Cost		**−$86.52**		**−$86.52**	**Marginal TPVC**	

Table 6
Itemized costs and Total Present Value Costs for a cover crop in the U.S. Midwest at real discount rate of 4 % and analysis horizon of 4 years.

Item	Cost timing (yr)	Minimum cost ($ ha^{-1})	Mean cost ($ ha^{-1})	Maximum cost ($ ha^{-1})	Notes	Reference
Seed costs	$1-n$	$14.83		$29.65	Planted at 63 kg ha^{-1}; cereal rye	[32,103]
Planting Drill	$1-n$	$18.53	$32.12	$49.42	Custom cost to have small grains drilled	[81]
Diesel for equipment	–				Included above	
Spraying	$1-n$	$11.12	$15.07	$21.99	Ground, broadcast, tractor	[81]
Herbicide cost	$1-n$		$14.09		Herbicides, Glyphosate, 480 kg m^{-3}, Price paid, US Total, 2010: $6023 m^{-3} ; 0.0023 m^3 ha^{-1}	[32,56]
Total cost of establishment		**$58.56**		**$115.15**	**TPVC**	
Annual baseline revenue (no cover crop)	$1-n$		$1868.81		Iowa mean 2008–2010 yield of 10.84 metric ton ha^{-1} and 2008–2010 mean corn price received of $0.17 kg^{-1}; at 100% yield	[56]
Annual revenue from changed yields due to cover crop	$1-n$		$1752.95		Iowa mean 2008–2010 yield of 10.84 metric ton ha^{-1} and 2008–2010 mean corn price received of $0.17 kg^{-1}; at 6.2% yield reduction for corn following rye	[56]
Difference in annual revenue from baseline			$115.87		Considered a cost of cover crop with corn grown in every other year	
Total cost of establishment and revenue impacts		**$594.98**		**$800.39**	**TPVC**	

Table 7
Itemized costs and Total Present Value Costs for a diversified crop rotation in the U.S. Midwest at real discount rate of 4 % and analysis horizon of 10 years.

Item	Cost timing (yr)	Minimum cost ($ ha^{-1})	Mean cost ($ ha^{-1})	Maximum cost ($ ha^{-1})	Notes	Reference
Seed costs	Year 3 of every 5	$101.19		$140.48	Legume, alfalfa, public and common seed or proprietary seed, price paid, National, 2010: $273–$379 cwt^{-1}; planted 16.8 kg ha^{-1}	[56]
Planting drill	Year 3 of every 5	$18.53	$32.12	$49.42	Custom cost to have small grains drilled	[81]
Diesel for equipment	–				Included above	Assumption
Soil preparation	Year 3 of every 5		$34.10		Disking, harrow: Default values from ISU Ag Decision Maker	[72] (alfalfa)
Herbicide	Year 3 of every 5		$37.81		Default values from ISU Ag Decision Maker (machinery and chemical)	[72] (alfalfa)
Labor	3–5 of every 5		$81.54		Pre-harvest labor: 7.4 h ha^{-1} at $11.00 h^{-1}	[72] (alfalfa)
Fertilizer	3–5 of every 5	$307.15		$481.36	Default values from ISU Ag Decision Maker for establishment year (min) and production year (max); machinery and chemical	[72] (alfalfa)
Harvesting – mowing	3–5 of every 5	$19.77	$30.64	$37.07	Mowing/conditioning	[81]
Harvesting – baling	3–5 of every 5	$74.13	$123.55	$172.97	Haying baling - small square: $0.30–$0.70 bale^{-1}; 12.4 ton ha^{-1} at 45.4 kg bale^{-1}	[81]; Assumption
Total cost of alfalfa establishment	Year 3 of every 5	**$674.23**		**$860.55**		
Total cost of alfalfa maintenance	Year 4 and 5	$656.81		$772.95	Labor, fertilizer and harvesting costs from above	
Corn in year 1	YEAR 1 of 5		$1183.64		Cost of corn establishment (corn following soybean to be more accurate for years 6, etc.); land rent removed, 10.84 metric ton ha^{-1} yield	[72] (corn following soybean)
Corn in year 2	Year 2 of 5		$1312.13		Cost of corn establishment (corn following corn); land rent removed, 10.84 metric ton ha^{-1}	[72] (corn following corn); [49]
Total costs for five year diversified rotation		**$4214.00**		**$4588.79**	**TPVC: Corn in years 1 and 2 with alfalfa establishment in year 3 and alfalfa maintenance in years 4–5**	
Alfalfa revenue	4–5 of every 5		$1511.46		Alfalfa average yield 12.4 ton ha^{-1} (assuming 3 cuttings); Iowa mean 2008–2010 alfalfa hay price received: $134.85 metric ton^{-1}	[56,72]
Corn revenue			$1868.81			[56]

	1–2 of every 5				Iowa mean 2008–20109 corn yield: 10.84 metric ton ha^{-1} and 2008–2010 mean corn price received of \$0.17 kg^{-1}	
Total revenue for five year diversified rotation			**\$6850.51**		**TPV: Corn revenue in year 1 plus 4.5% yield boost, corn revenue in year 2, alfalfa revenue divided by 3 (only 1 cutting) in alfalfa establishment year, and alfalfa revenue in year 4–5**	[73]
Total costs and revenue for diversified crop rotation for 10 yr horizon		**−\$10,456.91**		**−\$8970.43**	**TPVC (negative represents a revenue)**	
Cost of corn and soybean five year rotation			\$4469.53		TPVC: Five year cost of corn soybean rotation; starting with corn (ISU Decision Maker, corn following soy, yield 10.8 metric ton ha^{-1}); soybean cost: \$637.53 ha^{-1} ISU Ag Decision Maker for herbicide tolerant soybeans following corn, yield 3.33 metric ton^{-1}; land rent removed	[72]
Revenue of corn and soybean five year rotation			\$7564.77		TPV: Five year revenue of corn soybean rotation, starting with corn; corn revenue described above; soybean revenue: Iowa mean 2008–2010 yield of 3.33 metric ton ha^{-1} and mean price \$0.38 kg^{-1} yields \$1281.05 ha^{-1}	[56]
Total costs and revenue for corn and soybean rotation for 10 yr horizon			**−\$12,276.31**		**TPVC (negative represents a revenue)**	
Marginal cost		**\$1819.40**		**\$3305.87**	**Marginal TPVC**	

Table 8
Review of nitrogen load reduction effectiveness for seven drainage water quality practices in the U.S. Midwest.

Practices and references	N load reduction			Notes
	Minimum (%)	Mean (%)	Maximum (%)	
Controlled drainage				
[86]	30		40	Overview of this N management practice
[15]	15		75	Controlled drainage factsheet
[87]	48	75	100	Load reduction for mean loads from six months of free drainage vs. controlled water tables at 0.25 m and 0.5 m above the drain; Ontario, Canada
[14]		30		Overview of this N management practice
[13]	10		20	An original paper on drainage control
[88]		43		Controlled drainage/sub-irrigation system, Canada
[29]	0		50	N technology comparison
[89]	31	44	51	Simulation of Midwestern region with Root Zone Water Quality Model-Decision Support System for Agrotechnology Transfer (RZWQM –DSSAT)
[90]		26		Mean of DRAINMOD-NII simulated N losses for drain spacing 18 m–36 m for conventional vs. controlled drainage; Waseca, Minnesota
Bioreactor				
[76]	11		13	Bioreactor in Iowa
[76]	47		57	Bioreactor in Iowa
[76]	27		33	Bioreactor in Iowa
[91]	40	55	65	Denitrification trenches surrounding tile drain, Iowa
[92]	23	33	50	Bioreactor in Illinois
[93]		47		Bioreactor in Illinois, slug of NO_3^- injected
[94]	18		47	Bioreactor in Minnesota
[94]	35		36	Bioreactor in Minnesota
Wetland				
[21]	25		78	Review table
[18]	33	40	55	Annual N load reduction for three wetlands, three years of data; Champaign County, Illinois
[95]		33		Wetland in Illinois
[20]	9		15	Mean N load reduction for two years from wetland with area treatment ratio of 1046:1; Iowa
[20]	34		44	Mean N load reduction for two years from wetland with area treatment ratio of 349:1; Iowa
[20]	55		74	Mean N load reduction for two years from wetland with area treatment ratio of 116:1; Iowa
[29]	20		40	N technology comparison
[54]	40		90	Summary of CREP wetlands in Iowa
Spring N application				
[96]	−67	6.4	44	Load difference between fall and spring (corn phase)
[97]	0	27	41	Load difference between fall and spring (corn phase)
[23]	24		30	6-yr period at Waseca, Minnesota

[29]	−10		30	N technology comparison
[59]	14	35	52	Simulation with Environmental Policy Integrated Climate (EPIC) for central Illinois; Fall vs. spring application at five rates ranging from 112 kg N ha^{-1} to 224 kg N ha^{-1} for Drummer soil
[49]	−62	−23	7.4	N load difference between spring and fall applied at 168 and 252 kg N ha^{-1}; Iowa
N rate reduction				
[23]	21		28	6-yr period at Waseca, Minnesota; 134 kg ha^{-1} vs. 202 kg ha^{-1} application
[29]	20		70	N technology comparison
[98]	17		40	Central Iowa; loadings of 48 kg N ha^{-1}, 35 kg N ha^{-1}, and 29 kg N ha^{-1} for high, medium and low N application rates, respectively
Cover crops				
[66]		13		Southwestern Minnesota, three year study
[100]		40		Based on review
[71]	−13.5	−3.3	7.6	Four year loads and mean for corn treatment vs. corn with rye cover; Gilmore City, Iowa
[31]		61		Four year average; Boone County, Iowa
[29]	10		70	N technology comparison
Crop rotation				
[36]	14		77	Review
[99]	11		14	Six year average losses from corn/soybean or soybean/corn vs. rotation with three years alfalfa followed by corn, soybean, oats; Nashua, Iowa
[35]	18	48	80	Conversion from alfalfa pasture; three year study, compared with corn and soybean and continuous corn rotations; Lamberton, Minnesota
[29]	−50		95	N technology comparison

Table 9
Nitrogen load reduction effectiveness and Equal Annual Costs in terms of treatment area or nitrogen removal for seven drainage water quality practices in the U.S. Midwest (without government payments).

	EAC (area-based)		Load reduction from Fig. 2				EAC (N-based)			
	Minimum ($ ha^{-1} yr^{-1})	Maximum ($ ha^{-1} yr^{-1})	25th (%)	75th (%)	Mean (%)	Median (%)	Mean (Standard Deviation, $ kg N removed^{-1} yr^{-1})	Median ($ kg N removed^{-1} yr^{-1})	Minimum [a] ($ kg N removed^{-1} yr^{-1})	Maximum [a] ($ kg N removed^{-1} yr^{-1})
Controlled Drainage	$9.30	$37.00	26.0	50.0	40.5	40.0	$2.00 ($1.40)	$1.70	$0.60	$4.50
Bioreactors	$16.00	$32.00	27.0	47.0	37.5	36.0	$2.10 ($0.90)	$2.00	$1.10	$3.80
Wetland	$31.00	$43.00	30.9	55.0	42.8	40.0	$2.90 ($0.80)	$2.80	$1.80	$4.40
N rate reduction	−$7.40	−$7.40	—	—	14.5	—	−$1.60 ($0.00)	−$1.60	−$1.60	−$1.60
Spring N application [b]	−$90.00	−$90.00	−2.5	31.3	9.3	19.0	−$14.00 ($12.00)	−$12.00	−$31.00	−$0.07
Cover crop	$164.00	$221.00	4.9	45.3	23.1	11.5	$55.00 ($48.00)	$38.00	$12.00	$144.00
Crop rotation	$224.00	$408.00	14.0	77.0	34.1	18.0	$43.00 ($29.00)	$39.00	$9.30	$93.00

[a] Minimum and maximum calculated using the minimum EAC and the 75th percentile load reduction and the maximum EAC and the 25th percentile load reduction, respectively.
[b] Due to confounding effects of negative EAC and negative 25th percentile load reduction (indicating a contribution to the N load), the maximum value for Spring N application was calculated using the marginal increase to the baseline load based on the 25th percentile and the minimum value was calculated from the mean load reduction.

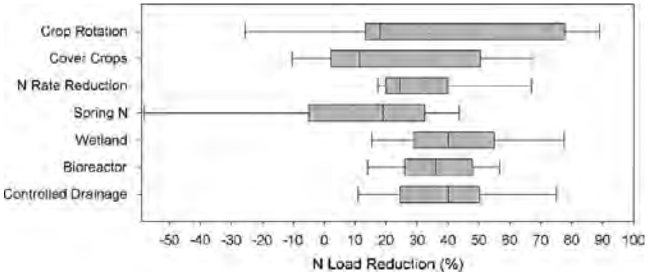

Fig. 1. Comparison of nitrogen load reductions obtained from literature for seven water quality improvement strategies in the U.S. Midwest; the box boundaries represent the 25th and 75th percentiles, the solid line represents the median, the dotted line represents the mean, and the whiskers show the 10th and 90th percentiles.

are shown in Table 9).

$$\frac{\text{EAC \$}}{\text{kg N yr}} = \frac{\text{minimum or maximum EAC \$}}{ha\ yr} \div \left(\frac{\text{31.4 kg N lost baseline}}{\text{ha}} \times \text{Load removal percentage mean, median, 25th, or 75th}\right) \quad (5)$$

In the case of modified N application rate, rather than use load reduction values from literature, a correlation from Lawlor et al. [27] was used (Eq. (1)). For this practice, literature values proved to be too variable as they were not for the specific rates used in this comparison. After drainage NO_3^-–N concentrations were developed via Eq. (1) for the two application rates, a constant drainage volume was assumed to develop a percent N load reduction. While, Eq. (1) was specifically applicable to the database and site from which it was developed (northwestern Iowa), and does not account for other factors that affect N leaching losses (e.g., soil mineralizable N, the time of N application relative to crop N uptake, soil moisture content, weather conditions), it provided a straight forward approach to estimate approximate concentrations based upon N fertilizer application rates.

Finally, because cost-share has been shown to be an important incentive for operators to make environmental mitigation decisions, the impact of existing government cost-share and incentive programming was assessed. In Iowa, USDA environmental quality incentive program (EQIP) payments were available for each of the practices evaluated here except for modification of fertilizer rate [50] (Table 10). EQIP cost rates used were standard rate, not the higher rates available for historically underserved groups. Incentives for controlled drainage, bioreactors, wetlands, and N management were treated as one time, present value payments (year 1), while the others occurred in years $1-n$ with time limits set by EQIP payment schedules. Though EQIP funding is available for wetlands, cost share payments from the Iowa Department of Agriculture and Land Stewardship's Conservation Reserve Enhancement Program (IDALS CREP) are more appropriate because the wetland in this analysis was sized based upon Iowa CREP guidelines. For a CREP 30 year easement agreement, compensation included 15 annual rental payments of 150% the soil rental rate, cost-share for 100% of the wetland installation (90% federal, 10% state), and a one-time incentive payment ($247 ha^{-1}) [19,51]. The soil rental rate was assumed to be the average cash rental rate for 2008–2010 for the state of Iowa ($447 ha^{-1}) [52].

2.1. Controlled drainage

The major cost of controlled drainage is the capital expense of the structures and their installation. Because of this expense, land slope limitations are an important factor as more structures are needed at steeper sites. Another important consideration is the cost difference between implementing controlled drainage in existing vs. newly designed drainage systems [14].

For this evaluation of controlled drainage, the costs to retrofit an existing drainage system and the cost to implement a new drainage system designed for controlled drainage are considered. To reflect

Table 10
Environmental Quality Incentives Program (EQIP) payment schedule rates for Iowa for seven nitrogen reduction practices [50] and calculated total present value ($TPVC_{Govt}$) of this government cost-share for this evaluation.

	EQIP practice name	Practice code	Payment schedule cost	Payment unit	Minimum life (yr)	Year of payment	Payment ($ ha treated $^{-1}$)	$TPVC_{Govt}$ ($ ha^{-1})
Controlled drainage [a]	Drainage water management	554	$364.08	Per number of water control zones	1	1	$44.98	$44.98
Bioreactors [b]	Denitrifying bioreactor	747	$3999.50	Per bioreactor	10	1	$197.66	$197.66
Wetland [c]	Wetland creation	658	$680.00	Per acre	15	1	$16.80	$16.80
N rate reduction [d]	—	—	—	—	—	—	$0.00	$0.00
Spring N application [d, f]	Nutrient management	590	$11.00	Per acre	1	1	$27.18	$27.18
Cover crop [e, f]	Cover crop (and green manure)	340	$53.26	Per acre	1	1–3	$131.61	$379.83
Crop rotation [f]	Conservation crop Rotation	328	$52.00	Per acre	1	1–3	$128.50	$370.85

[a] Used scenario of 65 ha, requiring eight zones.
[b] EQIP specifies treatment of drainage from 12.1 ha which was less than the treatment area assumed here of 20.2 ha; EQIP cost-share was not used in replacement years for bioreactors or controlled drainage.
[c] Based on CREP 30 yr contract incentives rather than EQIP cost share shown here (see Section 2).
[d] Based on a mid-range payment rate requiring only two additional enhancement practices.
[e] Based on "cover crop winter hardy" rate for a winter cover of rye.
[f] EQIP funding for N management, cover crop and crop rotation practices has three year payment time limits; payments for cover crop and crop rotation were assumed to happen in the first three years of the analysis period and because N management had a planning horizon of $n=1$, only 1 year of EQIP was included.

the marginal cost of water quality improvement and not just the cost of new drainage systems, contractor tiling and materials expenses for new systems are not included. Full cost components are described in Table 2. Regarding more long-term costs, the cost of maintenance for this practice includes landowner time to manipulate the control structures; this would vary based on the number of structures, distance between them, and management intensity a landowner chose. The control structure stop logs/gates need to be replaced every eight years. Because the structures themselves would need to be replaced in year 40, this determined the practicable lifespan of this practice ($n=40$).

2.2. Bioreactors

As with controlled drainage, bioreactor establishment costs include design, contractor and structure fees. However, unlike controlled drainage, bioreactor treatment area differs from the surface area of the technology. Here, the $ ha^{-1} values referred to the treatment area not the bioreactor surface footprint. On an itemized basis, a maximum value for engineering fees of $40 h^{-1} for 16 h of work is assumed, though if the bioreactor is designed by a technical service provider, these fees may not apply. Although no land is typically removed from production for bioreactors, seeding the surface is important to prevent erosion of the soil cap. Bioreactors are typically less than 0.5% of the drainage treatment area, so this area ratio is used for the seeding and mowing costs. Bioreactor full cost components are described in Table 3.

Farmer time for adjusting the control structures is minimal compared to the controlled drainage practice due to fewer structures here. In addition to annual maintenance, the bioreactor material is replaced once in year 20 (involving costs associated with new woodchips, seeding and contractor fees) before the structures' lifespan is exhausted in year 40 (bioreactor practicable lifetime, $n=40$). Similar to controlled drainage, the stop logs/gates are replaced every eight years.

2.3. Wetlands

Wetlands are unique in that their capital expense can be very high, but they are capable of treating drainage from far larger areas than the other strategies considered here. Design and construction are important components of wetland establishment but the largest single expense is the land acquisition cost. Longer-term economic considerations sometimes include the opportunity cost of lost crop income (e.g., Prato et al. [53] and Crumpton et al. [22]), as well as maintenance and mowing expense and potential income streams.

For the purposes of this comparison, a 405 ha treatment area is assumed with a wetland occupying 1% of this area (4 ha) consistent with the conservation reserve enhancement program (CREP) guidelines for Iowa which specify a wetland size of 0.5–2% of the treatment area (not including associated wetland buffer) [19,54]. Accordingly, in addition to the wetland basin, a grass buffer is required. The wetland buffer has a 3.5:1 area ratio with the wetland (i.e., 3.5% of the treatment area in buffer, 14 ha) (Iowa Department of Ag. and Land Stewardship, personal communication, 2011). Because land acquisition costs are the largest portion of CREP wetland expense, this is included here; however, land for the other practices (e.g., edge-of-field area for the bioreactor or fields for the in-field practices) is assumed to be owned. Alternatively, forgone annual land rent would be another way to account for land costs. The cost per area for this practice reflected the area treated, not the area of the wetland and associated buffer. Wetland cost components are shown in Table 4.

Structural components include a water control structure and a weir plate, which are used to control wetland flow. The annual maintenance cost involves mowing 10% of the buffer area. Replacement costs of the control structure and sheet pile weir in year 40 are included within the 50 year wetland planning horizon ($n=50$). Also, over the life of a wetland, sediment removal and earthwork maintenance would be required, though those costs are not incorporated in this analysis because their timing would be difficult to estimate and may occur at greater than the 50 year planning horizon.

2.4. N rate reduction (168–140 kg N ha^{-1})

The establishment costs for both N management practices (rate reduction and timing) are similar and include custom rates for application machinery usage and fertilizer costs as described in Table 5. Because an N management practice is an annual occurrence, there are no long-term maintenance costs but, rather, establishment cost and revenue impacts occur every year (practicable lifespan, $n=1$). For these N management strategies, a baseline scenario of fall applied 168 kg N ha^{-1} is developed for comparison. The marginal difference in TPVC between the baseline and the rate/timing alternative is used in the analysis rather than the absolute value of the rate/timing TPVC themselves. Using these marginal costs of the lower rate practice and of the spring timing practice allows evaluation of their cost solely due to water quality improvement.

Financial analysis of lowering the N application rate consists of less fertilizer expense in addition to the cost of potential yield loss depending upon the initial and final application rates [25]. This analysis is complicated by the variability of the impacts of initial and revised fertilizer rates. In practice, challenges to N fertilizer rate reduction include the fact that the optimum rate is indeterminable at application time (though soil testing can help) and is highly variable year to year. Sawyer and Randall [25] provide a detailed explanation of these variable negative and positive returns based on initial and final fertilizer rates.

In analyzing the costs of reduced fertilizer rate here, “establishment” cost consists of less fertilizer purchased (i.e., a cost savings) as well as the effect of potentially reduced yield. The Iowa State University N-Rate Calculator [55] is used to estimate the yield impact from changing the fertilizer rate. Using a three-yr average (2008–2010) anhydrous ammonia price of \$763 metric ton^{-1} [56] and a three-yr average (2008–2010) Iowa corn price of \$0.17 kg^{-1} [56], the calculated percent of maximum yield is 99% at an N application rate of 168 kg N ha^{-1} and is approximately 98% at 140 kg N ha^{-1} (corn following soybean rotation). However, it is worth noting that shifting to this lower rate permanently may not be sustainable over long periods if soil N pools become depleted [57].

2.5. Spring N application

The cost of shifting application from the fall to the spring is affected by differences in both fall/spring fertilizer price and yield. Because current fall vs. spring fertilizer prices are no longer published by USDA, the average historical difference in the fall and spring fertilizer prices, on a percentage basis, is used to calculate the average increase in expense for spring anhydrous application. Between 1960 and 1994, the average prices for September/October were \$184 metric ton^{-1} and for April/May were \$193 metric ton^{-1} [58], thus an increase of 4.6% over the average 2008–2010 anhydrous price of \$763 metric ton^{-1} is used for spring (spring: \$798 metric ton^{-1}).

Multiple authors have reported lower drainage NO_3^- loadings with corresponding higher corn yields for spring vs. fall N applications [23,59,60]. Spring N fertilizer applications may increase yield by 8–14% compared to fall applications [23,60], though this may not always be the case. For example, there was no corn yield difference between fall and spring applications at two different application rates during a study in Iowa [49]. Despite this variability, an overall 4.2% corn yield boost is included for the practice of spring application (site year average from Refs. [49,61–64]).

2.6. Cover crops (cereal rye)

For the purposes of this evaluation, cereal rye (*Secale cereale* L.) is studied as a cover crop because this crop has good potential to improve water quality in cool Midwestern climates [31] and is popular in this region [65]. First year costs of a cover crop (Table 6) (assuming a no-till system in this analysis) include planting as well as herbicide application because cereal rye overwinters [32]. Cover cropping is an annual practice, thus there are no long-term maintenance costs but rather annual establishment costs. A yield reduction for corn following rye is also an important part of the analysis. A 6.2% corn yield reduction is assumed compared to a baseline where no cover crop was used (site year average from Refs. [31,66–71]). This corn revenue reduction is assumed to occur every other year during the planning horizon (i.e., a corn/soybean rotation; cover crop practice period, $t=2$; cover crop planning horizon, $n=4$).

2.7. Crop rotation (multiple years of alfalfa)

The number of possible rotation combinations is quite large, and to simplify this work, a multi-year incorporation of alfalfa (*Medicago sativa* L.) into a corn rotation is investigated. Only one year of alfalfa in a rotation may not be as beneficial as several years considering high seed cost and potential low alfalfa yield in the establishment year [36]. Therefore, this diversified crop rotation consists of two years of corn (years 1–2) followed by three years of alfalfa (years 3–5). The major costs for such a crop rotation are the seed, planting, and harvesting. The cost components of this rotation are shown in Table 7, with the rotation practice period (t) equal to five years and the planning horizon, n, equal to 10 years.

Within the rotation, enterprise budget information published by Iowa State University is used to specifically estimate the costs of corn following soybean (for years 1, 6, etc.; most applicable for corn following alfalfa) and for corn following corn (in years 2, 7, etc.) [72]. Default Iowa State University Ag Decision Maker [72] values were used after removing land rent costs (i.e., assumed land owned) and substitution of average Iowa 2010 corn yield from USDA NASS [56].

A multiple year alfalfa rotation may provide monetary benefit via reduced fertilizer requirements, reduced tillage and other field trips, and revenue from the alfalfa harvest. Here only direct revenue streams are considered with alfalfa revenue in years 3–5 and corn revenue in years 1–2. The establishment year of alfalfa is assumed to only have one cutting rather than the three as in the maintenance years (i.e., establishment years had one third of the yield experienced in maintenance years). Corn following alfalfa may have an increased yield of 19–84% compared to corn after corn according to a review by Olmstead and Brummer [36], but Liebman et al. [73] showed more moderate corn yield increases averaging 4.5% which was used here for the first year of corn.

Additionally, the TPVCs for this crop rotation scenario are compared against TPVCs for traditional corn/soybean rotations. Similarly to the N management practices, this allowed evaluation of the cost of this water quality practice (i.e., marginal cost of the practice). The corn/soybean baseline scenario is evaluated using the same five year framework as the extended rotation with cost values taken from ISU Ag Decision maker for corn following soybeans and herbicide tolerant soybeans following corn with default values except for removal of land rent costs and use of average yields (2008–2010, USDA NASS data) (Table 7) [72].

3. Results and discussion

3.1. Equal annualized costs

The TPVCs from the seven practices ranged from a cost savings of approximately \$90 ha^{-1} for spring applied N fertilizer to a cost of \$3306 ha^{-1} for a diversified crop rotation (Tables 2–7), and the resulting EACs ranged from −\$90 ha^{-1} yr^{-1} (Spring N, representing cost savings) to \$408 ha^{-1} yr^{-1} (crop rotation) (Table 9). The highest EACs were associated with the two in-field vegetated practices, cover crops and crop rotations, and the lowest were associated with the N management strategies. However, the high EACs developed for the cover and diversified cropping practices were associated with large uncertainties (Tables 1 and 9).

With regard to spring N applications, Randall and Sawyer [24] also noted long-term economic gains of \$46–\$126 ha^{-1} yr^{-1} (seven and fifteen year averages). However, a complete shift from fall fertilization could be expensive for individual producers in terms of both additional infrastructure required for spring applications (storage, equipment, labor, handling, application, etc.) and in the potential loss of yield by a delayed planting date [74]. Additionally, when lower N rates are applied, the risk of a yield loss is increased compared to higher application rates if it is a year where corn is more responsive to N inputs (depending upon the soil mineralizable N). In these years, the probability of obtaining a certain yield percentage declines when lower rates are applied; this probabilistic variability was not reflected here. Any such potential increased risk for either of these N management practices is an important factor in terms of producer decision-making.

Along with the relatively high EACs for the rye cover crop (\$164–\$221 ha^{-1} yr^{-1}; Table 9), several comments should be noted. First, costs to kill the cover are contingent upon producer actions. For example, in a no-till system as assumed here, an early burn-down application of herbicide may be done regardless if a cover crop was present; likewise, in a tilled system, a producer may do a second tillage pass in the spring regardless of a cover crop. Second, rye cover crop implementation costs can be \$10–\$15 ha^{-1} lower if a landowner chooses not to use a custom operator [75]. Next, potential negative yield impacts will likely be reduced or minimized through several years of experience with cover crop management. This increased experience also likely means a more effective cover, though returns to farm management can improve under highly skilled managers regardless of the production practice. Finally, some of the N taken up by a cover crop will be returned to future crops. It is difficult to place an economic value on this, but it is worth noting the multiple benefits to the soil provided by cover crops [33]. Because cover crops are typically done for reasons other than drainage water quality improvement, it has been suggested that only a portion of the cost should be attributed to N. However, because this work was solely focused on N reduction cost effectiveness, see Table 1 or Christianson et al. [34] for discussion of the ecosystem services provided by these practices.

The EAC for the diversified rotation was \$224–\$408 ha^{-1} yr^{-1} (Table 9). The values developed here were contrary to values from Olmstead and Brummer [36] who showed a diversified rotation was more profitable than a conventional rotation. One major caveat worth noting is the potential for large scale market effects if this rotation were done by a large numbers of producers in a limited area; if this practice became widespread, the alfalfa price could markedly decline.

The two field-scale constructed practices, controlled drainage and bioreactors, had similar EAC ranges at \$9.30–\$37 ha^{-1} yr^{-1} (spanning both existing and new drainage systems) and \$16–\$32 ha^{-1} yr^{-1}, respectively. For reference of installation costs, bioreactor TPVC estimates (Table 3) were within the range of five bioreactor installations in Iowa (total costs of \$4400–\$11,800 to treat drainage from 12 ha to over 40 ha [76]), and overall TPVCs estimated for constructed wetlands (\$661–\$926 ha^{-1}, Table 4) compared well with cost assessments from IDALS CREP wetlands constructed in Iowa. CREP wetlands average approximately \$880 ha^{-1} including land acquisition (\$513 ha^{-1}), establishment and maintenance costs (\$297 ha^{-1}), and engineering costs (\$69 ha^{-1}). As of 2011, 72 wetlands had been installed under the CREP wetland program in Iowa with an average treatment area of 505 ha (Iowa Department of Ag. and Land Stewardship, personal communication, 2011).

3.2. Comparative average cost effectiveness of nitrogen mitigation

In addition to variation between practices in TPVCs and EACs, the practices also varied widely in terms of N removal effectiveness (Fig. 1). For example, modification of fertilizer timing had comparatively low N removal, ranging notably into the potential for negative water quality impacts, while the constructed practices tended to have relatively better water quality performance. Bioreactors had the smallest range of N load reduction between the 25th and 75th percentiles with mean and median values above 35% load reduction. The other two constructed practices, controlled drainage and wetlands, had similarly high load reduction potential (means and medians $\geq 40\%$). Note, because the 25th percentile for spring N application was a negative value (-2.5%), indicating a contribution to the N load, the resulting marginal increase to the baseline load was used to calculate the \$ kg N^{-1} yr^{-1} for this value.

When these N removal performances were combined with the cost data, spring N application timing was the most cost effective option for removing N from drainage (mean \$14 kg N^{-1} yr^{-1} cost savings or revenue) and cover crop the least (mean \$55 kg N^{-1} yr^{-1}) (Table 9, Fig. 2). Both N management practices yielded negative average cost efficiencies indicating a savings or increased profitability. However, it's important to note nutrient management practices alone may not be sufficient to meet all N water quality goals in the Midwestern Region. In addition to the highest mean values, the cover crop and the diversified rotation had the largest standard deviations (pre-government payment), which highlighted the variability of these two in-field vegetative practices both in terms of costs and N removal potential. The more constructed practices of controlled drainage, bioreactors and wetlands had fairly comparable average cost efficiencies with mean values between \$2 and \$3 kg N^{-1} yr^{-1} (Table 9, Fig. 2).

To put these average cost efficiencies in context of other reported values is difficult in light of the variable methodology and limited transparency of other assessments. Nevertheless several practices were in the range of literature, while others were distinctly different. For example, the cost efficiency of controlled drainage in this analysis was \$2.00 ± \$1.40 kg N^{-1} yr^{-1}, which was similar to reports which are often in the range of \$2–\$4 kg N^{-1} [77,78]. Moreover, the average cost efficiency of wetlands is often reported at approximately \$3–\$4 kg N^{-1} [51,54,77,79]; the value reported in our study was \$2.90 ± \$0.80 kg N^{-1} yr^{-1}. Only one report was available for bioreactors; in a multi-year cost analysis of a theoretical denitrification system, Schipper et al. [80] calculated costs of \$2.39–\$15.17 kg N^{-1}. This range was higher than what was estimated for a bioreactor in our study (\$2.10 ± \$0.90 kg N^{-1} yr^{-1}). Finally, cover crops have been reported to be less expensive per kg N removed than calculated in this analysis (mean \$55 ± \$48 kg N^{-1} yr^{-1}). Values from cover crop literature have ranged from \$1.26 kg N^{-1} to \$11.06 kg N^{-1} [32,75,77], though these previous reports may not have included corn yield impacts.

Inclusion of EQIP or CREP payments generally increased the average cost effectiveness of the practices from a farmer's perspective (Table 9 vs. Table 11) with the largest percentage change

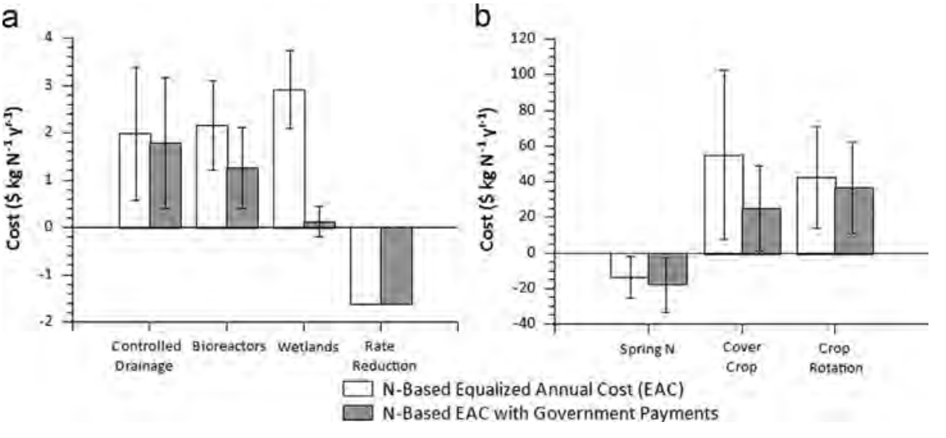

Fig. 2. Equal Annual Costs (\$ kg N^{-1} yr^{-1}) on a nitrogen removal basis for seven agricultural practices in the U.S. Midwest with and without government payments at real discount rate of 4% and analysis horizons of practicable lifespans by practice; note y-axis scales differ for figure parts (a) and (b).

Table 11
Nitrogen removal-based Equal Annual Costs for seven drainage water quality practices in the U.S. Midwest including government payments and additional revenue at real discount rate of 4 % and analysis horizons of practicable lifespan by practice.

	Equal annual costs	
	Mean (standard deviation, \$ kg N^{-1} yr^{-1})	Median (\$ kg N^{-1} yr^{-1})
Controlled drainage	\$1.80 (\$1.40)	\$1.50
Bioreactors	\$1.30 (\$0.86)	\$1.10
Wetland	\$0.12 (\$0.32)	\$0.09
N rate reduction	−\$1.60 (\$0.00)	−\$1.60
Spring N application	−\$18.00 (\$16.00)	−\$16.00
Cover crop	\$25.00 (\$24.00)	\$16.00
Crop rotation	\$36.00 (\$26.00)	\$33.00

occurring for the wetland practice. Without government payments, the practices in order of average cost effectiveness were (based on mean value): Spring N application, N application rate reduction, controlled drainage, bioreactors, wetlands, crop rotation and cover crops. When government payments were included, wetlands and bioreactors became the third and fourth most cost effective practices, respectively, and diversified crop rotations became the least cost effective (from the farmer's perspective) (Fig. 2).

4. Conclusions

Each drainage N reduction strategy provides landowners an additional distinct option for drainage water quality improvement and different strategies or combinations of such will be applicable in different locations. In this work, the N management practices were the most cost effective as both lowering the application rate (from 168 to 140 kg N ha^{-1}) and moving applications to spring resulted in negative costs. Of course, the scenarios here were limited in scope, and there is a wide range of N management and application possibilities that could yield different results. Importantly, a complete ban of fall fertilization could have large-scale economic effects, which were not investigated in this farm-level analysis. The least cost effective practices were the in-field vegetative practices of cover crop and crop rotation though these average cost efficiencies had wide standard deviations. Moreover, benefits like soil productivity, erosion protection, and management or reduction of multiple contaminants were not quantified. The three constructed practices were comparable in terms of pre-cost share \$ kg N^{-1} yr^{-1} although wetlands were very cost effective when CREP incentives were included. A final important note is that while this study focused on water quality NO_3^- mitigation, several of these practices provide significant additional ecosystem services not quantified here.

In an applied sense, these average cost efficencies need to be considered in context of the multiple agricultural and environmental objectives that will differ for each farm and for each farmer. Though the N management practices had the most attractive cost efficiencies, sole focus on N management either on farm or in policies will likely be insufficient to meet water quality goals in entirety. And while improved N management may be “low hanging fruit” for farmers aiming to improve water quality, there are important large scale impacts (e.g., infrastructure requirements for a complete fall fertilizer ban) that were not investgated in this farm level study. At the other end of the cost efficiency spectrum, the in-field vegetative practices were the least attractive in this analysis. However, with this work defined narrowly by reduction of N in drainage water, several potential additional agronomic and environmental benefits of these practices were excluded. Reduction of erosion and improved soil qualities potentially provided by these practices may be important considerations for farm decision makers. These strategies should certainly not be overlooked as Dinnes [29] reported that diversifying cropping systems in Iowa has the most potential to reduce NO_3^- loadings compared with any other best management practice.

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Appendix A. Supplementary information

Supplementary data associated with this article can be found in the online version at http://dx.doi.org/10.1016/j.wre.2013.09.001.

References

[1] D.L. Dinnes, D.L. Karlen, D.B. Jaynes, T.C. Kaspar, J.L. Hatfield, T.S. Colvin, C.A. Cambardella, Nitrogen management strategies to reduce nitrate leaching in tile-drained midwestern soils, Agronomy Journal 94 (2002) 153–171.
[2] United States Geological Survey, Nitrogen in the Mississippi Basin—Estimating Sources and Predicting Flux to the Gulf of Mexico. ⟨http://ks.water.usgs.gov/pubs/fact-sheets/fs.135-00.pdf⟩, 2000 (accessed 08.08.12).
[3] J.A. Delgado, R.F. Follett, Advances in nitrogen management for water quality, Journal of Soil and Water Conservation 66 (2011) 25A–26A.
[4] D.W. Lemke, D.P. McKenna, Final Report: Gulf Hypoxia and Local Water Quality Concerns Workshop, ASABE, St. Joseph, MI vii–ix.
[5] L. Christianson, J. Tyndall, Seeking a dialog: a targeted technology for sustainable agricultural systems in the US Corn Belt, Sustainability: Science Practice and Policy 7 (2011) 70–77.
[6] R.D. Battel, D.E. Krueger, Barriers to change: farmers' willingness to adopt sustainable manure management practices, Journal of Extension 43 (2005). ⟨http://www.joe.org/joe/2005august/a7.shtml⟩.
[7] J.M Gillespie, S.A. Kim, K. Paudel, Why don't producers adopt best management practices? An analysis of the beef cattle industry, Agricultural Economics 36 (2007) 89–102.
[8] R.L. McCown, New thinking about farmer decision makers, in: J.L. Hatfield (Ed.), The Farmer's Decision, Soil and Water Conservation Society, Ankeny, Iowa 2005, pp. 11–44.
[9] L.S. Prokopy, K. Floress, D. Klotthor-Weinkauf, A. Baumgart-Getz, Determinants of agricultural best management practice adoption: evidence from the literature, Journal of Soil and Water Conservation 63 (2008) 300–311.
[10] A.M. Lemke, T.T. Lindenbaum, W.L. Perry, M.E. Herbert, T.H. Tear, J.R. Herkert, Effects of outreach on the awareness and adoption of conservation practices by farmers in two agricultural watersheds of the Mackinaw River, Illinois, Journal of Soil and Water Conservation 65 (2010) 304–315.
[11] USDA ARMS, Agricultural Resource Management Survey USDA. ⟨http://www.ers.usda.gov/data-products/arms-farm-financial-and-crop-production-practices/tailored-reports.aspx#.Ua3Y9EC1GCk⟩, 2012 (accessed 05.06.13).
[12] G.W. Randall, M.J. Goss, Nitrate losses to surface water through subsurface, tile drainage, in: R.F. Follett, J.L. Hatfield (Eds.), Nitrogen in the Environment: Sources, Problems, and Management, Elsevier Science, 2001. (Chapter 5).
[13] J.W. Gilliam, R.W. Skaggs, S.B. Weed, Drainage control to diminish nitrate loss from agricultural fields, Journal of Environmental Quality 8 (1979) 137–142.
[14] R.A. Cooke, G.R. Sands, L.C. Brown, Drainage Water Management: A Practice for Reducing Nitrate Loads from Subsurface Drainage Systems. http://water.epa.gov/type/watersheds/named/msbasin/upload/2006_8_24_msbasin_symposia_ia_session2.pdf, (accessed 08.08.12).
[15] J. Frankenberger, E. Kladivko, G. Sands, D. Jaynes, N. Fausey, M. Helmers, R. Cooke, J. Strock, K. Nelson, L. Brown, Drainage Water Management for the Midwest: Questions and Answers About Drainage Water Management for the Midwest, Purdue Agriculture. ⟨http://www.extension.purdue.edu/extmedia/wq/wq-44.pdf⟩, 2006 (accessed 08.08.12).
[16] R.A. Cooke, A.M. Doheny, M.C. Hirschi, Bio-reactors for Edge of Field Treatment of Tile Outflow, Paper Number 012018, in: Proceedings of the 2001 ASAE Annual International Meeting, ASABE, St. Joseph, MI, 2001.
[17] L. Christianson, A. Bhandari, M. Helmers, Emerging technology: denitrification bioreactors for nitrate reduction in agricultural waters, Journal of Soil and Water Conservation 64 (2009) 139A–141A.
[18] D.A. Kovacic, M.B. David, L.E. Gentry, K.M. Starks, R.A. Cooke, Effectiveness of constructed wetlands in reducing nitrogen and phosphorus export from agricultural tile drainage, Journal of Environmental Quality 29 (2000) 1262–1274.
[19] Iowa Department of Agriculture & Land Stewardship, ⟨http://www.agriculture.state.ia.us/waterResources/pdf/LandownerGuide.pdf⟩, (accessed 08.08.12).
[20] J.L. Baker, W.G. Crumpton, Use of Constructed/Reconstructed Wetlands to Reduce Nitrate–Nitrogen Transported with Subsurface Drainage, in: Proceedings of the 1st Agricultural Drainage Field Day, Lamberton, MN, 2002. ⟨http://swroc.cfans.umn.edu/prod/groups/cfans/@pub/@cfans/@swroc/documents/content/cfans_content_290197.pdf⟩, (accessed 08.08.12).
[21] W.G. Crumpton, G.A. Stenback, B.A. Miller, M.J. Helmers, Potential Benefits of Wetland Filters for Tile Drainage Systems: Impact on Nitrate Loads to Mississippi River Subbasins, Final Project Report to U.S. (Proj. No. IOW06682), Department of Agriculture, 2006 ⟨http://www.fsa.usda.gov/Internet/FSA_File/fsa_final_report_crumpton_rhd.pdf⟩ (accessed 08.08.12).
[22] W.G. Crumpton, D.A. Kovacic, D.L. Hey, J.A. Kostel, Potential of Restored and Constructed Wetlands to Reduce Nutrient Export from Agricultural Watersheds in the Corn Belt, in: Final Report: Gulf Hypoxia and Local Water Quality Concerns Workshop, ASABE, St. Joseph, MI29–42 (Chapter 3).
[23] G.W. Randall, D.J. Mulla, Nitrate nitrogen in surface waters as influenced by climatic conditions and agricultural practices, Journal of Environmental Quality 30 (2001) 337–344.
[24] G.W. Randall, J.E. Sawyer, Nitrogen Application Timing, Forms, and Additives, in: Final Report: Gulf Hypoxia and Local Water Quality Concerns Workshop, ASABE, St. Joseph, MI73–85 (Chapter 6).
[25] J.E. Sawyer, G.W. Randall, Nitrogen Rates, in: Final Report: Gulf Hypoxia and Local Water Quality Concerns Workshop, ASABE, St. Joseph, MI59–72 (Chapter 5).
[26] M.J. Helmers, J.L. Baker, Strategies for Nitrate Reduction: The Cedar River case study, in: Proceedings of 22st Annual Integrated Crop Management Conference, Iowa State University, Ames, IA, 2010.
[27] P.A. Lawlor, M.J. Helmers, J.L. Baker, S.W. Melvin, D.W. Lemke, Nitrogen application rate effect on nitrate-nitrogen concentration and loss in subsurface drainage for a corn-soybean rotation, Transactions of the ASABE 51 (2008) 83–94.
[28] K.G. Cassman, A. Dobermann, D.T. Walters, Agroecosystems, nitrogen-use efficiency, and nitrogen management, Ambio 31 (2002) 132–140.
[29] D.L. Dinnes, Assessments of Practices to Reduce Nitrogen and Phosphorus Nonpoint Source Pollution of Iowa's Surface Waters, Report for the Iowa, Department of Natural Resources in cooperation with the USDA-ARS National Soil Tilth Laboratory, 2004 ⟨http://www.iowadnr.gov/portals/idnr/uploads/water/nutrients/files/nps_assessments.pdf⟩ (accessed 08.08.12).
[30] United States Department of Agriculture Economic Research Service, Agricultural Resources and Environmental Indicators Publication, 4.5 Nutrient Management, 1997. ⟨http://www.ers.usda.gov/publications/arei/ah712/AH7124-5.PDF⟩, (accessed 08.08.12).

[31] T.C. Kaspar, D.B. Jaynes, T.B. Parkin, T.B. Moorman, Rye cover crop and gamagrass strip effects on NO_3 concentration and load in tile drainage, Journal of Environmental Quality 36 (2007) 1503–1511.
[32] T.C. Kaspar, E.J. Kladivko, J.W. Singer, S. Morse, D. Mutch, Potential and Limitations of Cover Crops, Living Mulches, and Perennials to Reduce Nutrient Losses to Water Sources from Agricultural Fields, in: Final Report: Gulf Hypoxia and Local Water Quality Concerns Workshop, ASABE, St. Joseph, MI129–147 (Chapter 10).
[33] T.C. Kaspar, J.W. Singer, The use of cover crops to manage soil, in: J.L. Hatfield, T.J. Sauer (Eds.), Soil Management: Building a Stable Base for Agriculture, American Society of Agronomy and Soil Science Society of America, Madison, WI 2011, pp. 321–337.
[34] L. Christianson, T. Knoot, D. Larsen, J. Tyndall, M. Helmers, Adoption potential of nitrate mitigation practices: an ecosystem services approach, International Journal of Agricultural Sustainability (2013)http://dx.doi.org/ 10.1080/14735903.2013.835604. in press.
[35] D.R. Huggins, G.W. Randall, M.P. Russelle, Subsurface drain losses of water and nitrate following conversion of perennials to row crops, Agronomy Journal 93 (2001) 477–486.
[36] J. Olmstead, E.C. Brummer, Benefits and barriers to perennial forage crops in Iowa corn and soybean rotations, Renewable Agriculture andFood Systems 23 (2008) 97–107.
[37] V. Afari-Sefa, E.K. Yiridoe, R. Gordon, D. Hebb, Decision considerations and cost analysis of Beneficial Management Practice implementation in Thomas Brook Watershed, Nova Scotia, Journal of International Farm Management 4 (2008) 1–32.
[38] N.S. Rao, Z.M. Easton, D.R. Lee, T.S. Steenhuis, Economic analysis of best management practices to reduce watershed phosphorus losses, Journal of Environmental Quality 41 (2012) 855–864.
[39] Y. Yuan, S.M. Dabney, R.L. Bingner, Cost effectiveness of agricultural BMPs for sediment reduction in the Mississippi Delta, Journal of Soil and Water Conservation 57 (2002) 259–267.
[40] X. Zhou, M.J. Helmers, M. Al-Kaisi, H.M. Hanna, Cost-effectiveness and cost-benefit analysis of conservation management practices for sediment reduction in an Iowa agricultural watershed, Journal of Soil and Water Conservation 64 (2009) 314–323.
[41] J.R. Williams, P.M. Clark, P.G. Balch, Streambank stabilization: An economic analysis from the landowner's perspective, Journal of Soil and Water Conservation 59 (2004) 252–259.
[42] J. Canada, W. Sullivan, D. Kulonda, J. White, Capital Investment Analysis for Engineering and Management, 3rd ed., Prentice Hall, New Jersey624.
[43] R.D. Kay, W.M. Edwards, P.A. Duffy, Investment Analysis, in: Farm Management, McGraw-Hill, New York, NY 308–329 (Chapter 17).
[44] C.R. Burdick, D.R. Refling, H.D. Stensel, Advanced biological treatment to achieve nutrient removal, Journal of the Water Pollution Control Fed 54 (1982) 1078–1086.
[45] J.C. Tyndall, R.C. Grala, Financial feasibility of using shelterbelts for swine odor mitigation, Agroforestry Systems 76 (2009) 237–250.
[46] United States Department of Agriculture Natural Resources Conservation Service, Rate for federal water projects. ⟨http://www.nrcs.usda.gov/wps/portal/nrcs/detail/national/technical/econ/references/?&cid=nrcs143_009685⟩, 2012 (accessed 08.08.12).
[47] R.H. Van Note, P.V. Hebert, R.M. Patel, C. Chupek, L. Feldman, A Guide to the Selection of Cost-effective Wastewater Treatment System. ⟨http://nepis.epa.gov⟩, 1975 (accessed 08.08.12).
[48] D.B. Jaynes, J.L. Hatfield, D.W. Meek, Water quality in Walnut Creek Watershed: herbicides and nitrate in surface waters, Journal of Environmental Quality 28 (1999) 45–59.
[49] P.A. Lawlor, M.J. Helmers, J.L. Baker, S.W. Melvin, D.W. Lemke, Comparison of liquid swine manure and ammonia nitrogen application timing on subsurface drainage water quality in Iowa, Transactions of the ASABE 54 (2011) 973–981.
[50] United States Department of Agriculture Natural Resources Conservation Service (Iowa), Iowa Environmental Quality Incentives Program (EQIP) list of eligible practices and payment schedule FY2011. ⟨http://www.ia.nrcs.usda.gov/programs/eqip/FY2011%20Iowa%20EQIP%20Practice%20Descriptions%20and%20Payment%20Rates.pdf⟩, 2010 (accessed 08.08.12).
[51] S. Hyberg, Economics of CREP/CRP Treatment Wetlands for the Tile Drained Cropland in the Corn Belt. ⟨http://www.fsa.usda.gov/Internet/FSA_File/hyberg_iowa_wetlands.pdf⟩, 2007 (accessed 08.08.12).
[52] Iowa State University Extension, Cash rental rates for Iowa 2012 Survey File C2-10. http://www.extension.iastate.edu/agdm/wholefarm/pdf/c2-10.pdf, 2012 (accessed 08.08.12).
[53] T. Prato, Y. Wang, T. Haithcoat, C. Barnett, C. Fulcher, Converting hydric cropland to wetland in Missouri: a geoeconomic analysis, Journal of Soil and Water Conservation 50 (1995) 101–106.
[54] R. Iovanna, S. Hyberg, W. Crumpton, Treatment wetlands: cost-effective practice for intercepting nitrate before it reaches and adversely impacts surface waters, Journal of Soil and Water Conservation 63 (2008) 14A–15A.
[55] J. Sawyer, E. Nafziger, G. Randall, L. Bundy, G. Rehm, B. Joern, 2006. Concepts and Rationale for Regional Nitrogen Rate Guidelines for Corn (PM 2015), Iowa State University Extension.
[56] United States Department of Agriculture National Agricultural Statistics Service, Quick Stats 2.0. ⟨http://quickstats.nass.usda.gov/⟩, 2011 (accessed 08.08.12).
[57] D.B. Jaynes, D. Karlen, Sustaining Soil Resources While Managing Nutrients, in: Final Report: Gulf Hypoxia and Local Water Quality Concerns Workshop, ASABE, St. Joseph, MI149–158 (Chapter 11).
[58] United States Department of Agriculture Economic Research Service, Data Sets: Fertilizer use and Price. ⟨http://www.ers.usda.gov/Data/FertilizerUse/⟩, 2012 (accessed 08.08.12).
[59] R.M. Rejesus, R.H. Hornbaker, Economic and environmental evaluation of alternative pollution-reducing nitrogen management practices in central Illinois, Agriculture, Ecosystems and Environment 75 (1999) 41–53.
[60] G. Randall, 2008. Managing Nitrogen for Optimum Profit and Minimum Environmental Loss, in: Proceedings of Annual Integrated Crop Management Conference, Iowa State University, Ames, IA.
[61] G.W. Randall, J.A. Vetsch, J.R. Huffman, Corn production on a subsurface-drained mollisol as affected by time of nitrogen application and Nitrapyrin, Agronomy Journal 95 (2003) 1213–1219.
[62] J.A. Vetsch, G.W. Randall, Corn production as affected by nitrogen application timing and tillage, Agronomy Journal 96 (2004) 502–509.

[63] M.W. Clover, Impact of nitrogen management on corn grain yield and nitrogen loss on a tile drained field (M.S. thesis), University of Illinois at Urbana-Champaign, Urbana-Champaign, IL, 2005.
[64] G.W. Randall, J.A. Vetsch, Corn production on a subsurface-drained mollisol as affected by fall versus spring application of nitrogen and Nitrapyrin, Agronomy Journal 97 (2005) 472–478.
[65] J.W. Singer, Corn Belt assessment of cover crop management and preferences, Agronomy Journal 100 (2008) 1670–1672.
[66] J.S. Strock, P.M. Porter, M.P. Russelle, Cover cropping to reduce nitrate loss through subsurface drainage in the Northern U. S. Corn Belt, Journal of Environmental Quality 33 (2004) 1010–1016.
[67] J. Sawyer, J. Pantoja, D. Barker, Nitrogen fertilization of corn grown with a cover crop, Iowa State University Research Farm Report, , 2009 ⟨http://www.agronext.iastate.edu/soilfertility/info/2009CoverCrop-NFertilization.pdf⟩ (accessed 08.08.12).
[68] C. Pederson, R. Kanwar, M. Helmers, A. Mallarino, Impact of liquid swine manure application and cover crops on ground water quality, Iowa State University Northeast Research and Demonstration Farm Annual Report (RFR-A10111), 2010 ⟨http://www.ag.iastate.edu/farms/10reports/Northeast/ImpactLiquidSwine.pdf⟩ (accessed 08.08.12).
[69] J. Sawyer, J. Pantoja, D. Barker, Nitrogen fertilization of corn grown with a cover crop, Iowa State University Research Farm Report (RFR-A1064), 2010 ⟨http://www.ag.iastate.edu/farms/10reports/Northeast/ImpactLiquidSwine.pdf⟩ (accessed 08.08.12).
[70] Practical Farmers of Iowa, Cover Crop Effect on Cash Crop Yield: Year 2. ⟨http://www.practicalfarmers.org/assets/files/field_crops/cropping-systems/Cover_Crop_Effect_on_Yield.pdf⟩, 2011 (accessed 08.08.12).
[71] Z. Qi, M.J. Helmers, R.D. Christianson, C.H. Pederson, Nitrate-Nitrogen losses through subsurface drainage under various agricultural land covers, Journal of Environmental Quality 40 (2011) 1578–1585.
[72] Iowa State University Extension, Estimated costs of crop production in Iowa—2011 (including corn following corn, corn following soybeans, herbicide tolerant soybeans following corn, and alfalfa or alfalfa-grass hay). http://www.extension.iastate.edu/agdm/crops/html/a1-20.html, 2011 (accessed October 2011).
[73] M. Liebman, L.R. Gibson, D.N. Sundberg, A.H. Heggenstaller, P.R. Westerman, C.A. Chase, R.G. Hartzler, F.D. Menalled, A. S. Davis, P.M. Dixon, Agronomic and economic performance characteristics of conventional and low-external-input cropping systems in the central Corn Belt, Agronomy Journal 100 (2008) 600–610.
[74] D. Otto, Economic impacts of fall commercial nutrient regulation, Iowa State University Department of Economics. ⟨https://www.econ.iastate.edu/sites/default/files/publications/papers/p11215-2008-03-01.pdf⟩, 2008 (accessed 08.08.12).
[75] A. Saleh, E. Osei, D.B. Jaynes, B. Du, J.G. Arnold, Economic and environmental impacts of LSNT and cover crops for nitrate-nitrogen reduction in Walnut Creek watershed, Iowa, using FEM and enhanced SWAT models, Transactions of the ASABE 50 (2007) 1251–1259.
[76] L. Christianson, Design and performance of denitrification bioreactors for agricultural drainage (Ph.D. dissertation), Iowa State University, Ames, IA, 2011.
[77] J. Baker, 2009. The UMRSHNC Workshop: the Basis for the Cedar River Watershed Case Study, in: Proceedings of the Science to Solutions: Reducing Nutrient Export to the Gulf of Mexico, a Workshop for Managers, Policy Makers, and Scientists, Soil and Water Conservation Society, Ankeny, IA.
[78] D.B. Jaynes, K.R. Thorp, D.E. James, 2010. Potential Water Quality Impact of Drainage Water Management in the Midwest USA, Paper Number IDS-CSBE100084, in: Proceedings of the 9th International Drainage Symposium of the ASABE, ASABE, St. Joseph, MI.
[79] M.O. Ribaudo, R. Heimlich, R. Claassen, M. Peters, Least-cost management of nonpoint source pollution: source reduction versus interception strategies for controlling nitrogen loss in the Mississippi Basin, Ecological Economics 37 (2001) 183–197.
[80] L.A. Schipper, W.D. Robertson, A.J. Gold, D.B. Jaynes, S.C. Cameron, Denitrifying bioreactors—an approach for reducing nitrate loads to receiving waters, Ecological Engineering 36 (2010) 1532–1543.
[81] Iowa State University Extension, 2010 Iowa Farm Custom Rate Survey Ag Decision Maker. ⟨http://www.extension.iastate.edu/publications/fm1698.pdf⟩, 2010 (accessed October 2011).
[82] Prairie Land Management, CRP Mix—Seed Mix Pricing. http://www.habitatnow.com/store/shop/shop.php?pn_selected_category=37, 2005 (accessed 08.08.12).
[83] Iowa State University Extension, Natural Resources Custom Rate Survey Ag Decision Maker. http://www.extension.iastate.edu/agdm/crops/pdf/a3-11.pdf, 2009 (accessed 08.08.12).
[84] Ernst Conservation Seed, Seed mixes. ⟨http://www.ernstseed.com/seed-mixes/⟩, 2011 (accessed October 2011).
[85] Iowa State University Extension, 2010 Farmland value survey. ⟨http://www.extension.iastate.edu/agdm/wholefarm/html/c2-70.html⟩, 2011 (accessed October 2011).
[86] R.A. Cooke, G.R. Sands, L.C. Brown, Drainage water management: A practice for reducing nitrate loads from subsurface drainage systems, in: Final Report: Gulf Hypoxia and Local Water Quality Concerns Workshop, ASABE, St. Joseph, MI 19–28 (Chapter 2).
[87] V. Lalonde, C.A. Madramootoo, L. Trenholm, R.S. Broughton, Effects of controlled drainage on nitrate concentrations in subsurface drain discharge, Ag, Water Management 29 (1996) 187–199.
[88] C.F. Drury, C.S. Tan, J.D. Gaynor, T.O. Oloya, T.W. Welacky, Influence of controlled drainage-subirrigation on surface and tile drainage nitrate loss, Journal of Environmental Quality 25 (1996) 317–324.
[89] K.R. Thorp, D.B. Jaynes, R.W. Malone, Simulating the long-term performance of drainage water management across the Midwestern United States, Transactions of the ASABE 51 (2008) 961–976.
[90] W. Luo, G.R. Sands, M. Youssef, J.S. Strock, I. Song, D. Canelon, Modeling the impact of alternative drainage practices in the northern Corn-belt with DRAINMOD-NII, Ag, Water Management 97 (2010) 389–398.
[91] D.B. Jaynes, T.C. Kaspar, T.B. Moorman, T.B. Parkin, In situ bioreactors and deep drain-pipe installation to reduce nitrate losses in artificially drained fields, Journal of Environmental Quality 37 (2008) 429–436.
[92] K.P. Woli, M.B. David, R.A. Cooke, G.F. McIsaac, C.A. Mitchell, Nitrogen balance in and export from agricultural fields associated with controlled drainage systems and denitrifying bioreactors, Ecological Engineering 36 (2010) 1558–1566.
[93] J.A. Chun, R.A. Cooke, J.W. Eheart, J. Cho, Estimation of flow and transport parameters for woodchip-based bioreactors: II. field-scale bioreactor, Biosystems Engineering 105 (2010) 95–102.

[94] A. Ranaivoson, J. Moncrief, R. Venterea, M. Dittrich, Y. Chander, P. Rice, Bioreactor Performance In Minnesota. ⟨http://www.extension.umn.edu/AgDrainage/components/Ranaivoson.pdf⟩, 2010 (accessed 08.08.12).
[95] P.S. Miller, J.K. Mitchell, R.A. Cooke, B.A. Engel, A wetland to improve agricultural subsurface drainage water quality, Transactions of the ASAE 45 (2002) 1305–1317.
[96] G.W. Randall, J.A. Vetsch, J.R. Huffman, Nitrate losses in subsurface drainage from a corn–soybean rotation as affected by time of nitrogen application and use of Nitrapyrin, Journal of Environmental Quality 32 (2003) 1764–1772.
[97] G.W. Randall, J.A. Vetsch, Nitrate losses in subsurface drainage from a corn–soybean rotation as affected by fall and spring application of nitrogen and Nitrapyrin,, Journal of Environmental Quality 34 (2005) 590–597.
[98] D.B. Jaynes, T.S. Colvin, D.L. Karlen, C.A. Cambardella, D.W. Meek, Nitrate loss in subsurface drainage as affected by nitrogen fertilizer rate, Journal of Environmental Quality 30 (2001) 1305–1314.
[99] R.S. Kanwar, R.M. Cruse, M. Ghaffarzadeh, A. Bakhsh, D.L. Karlen, T.B. Bailey, Corn-soybean and alternative cropping systems effects on NO_3–N leaching losses in subsurface drainage water, Applied Engineering in Agriculture 21 (2005) 181–188.
[100] D.B. Jaynes, Personal communication, USDA ARS National Laboratory for Agriculture and the Environment, Ames, IA, USA (2011).
[101] Agri Drain Corp., Personal communication, Adair, IA, USA (2011).
[102] Iowa Soybean Association, Personal communication, Ankeny, IA, USA (2011).
[103] T. Kaspar, Personal communication, USDA ARS National Laboratory for Agriculture and the Environment, Ames, IA, USA (2011).

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Title: Subsurface drain losses of water and nitrate following conversion of alfalfa and conservation reserve land to row crops

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Interpretive Summary: The conversion of annual row crops to alfalfa (ALF) and perennial grasses achieved with Conservation Reserve Program (CRP) plantings has reduced losses of nitrate nitrogen through subsurface tile drains in the Upper Midwest. Conversion of alfalfa or CRP back to row crops could have rapid, adverse affects on water quality of tile drainage. Our objectives were to evaluate how prior perennial crops affect water and N use efficiency of annual row crops, and losses of water and nitrate to subsurface tile drains. Tile flow volumes increased to levels similar to row-crops during the first season following conversion of ALF and CRP to corn. Residual soil nitrate (RSN) in the root zone increased by 125% in first year corn following CRP and was 32% greater than continuous corn (CC) after 3 years. High N uptake efficiencies of corn following ALF helped to slow buildup of RSN, but levels were equal to row crop systems after two years. Nitrate losses and concentrations in tile drainage remained low during the initial year of conversion, but were similar to row crop systems during the subsequent two years. Thus, low tile flows and nitrate losses will likely require a rotation of perennial and annual crops in the Upper Midwest.

Technical Abstract: Nitrate losses through subsurface tile drains pose a serious threat to surface water quality. Large reductions in drainage losses of nitrate can be achieved with alfalfa (Medicago sativa L.)or perennial grasses often used in Conservation Reserve Program (CRP). Conversion of alfalfa or CRP back to row crops could have rapid, adverse affects on water quality. Our objectives were to evaluate how prior perennial crops affect water and N use efficiency of annual row crops, and losses of water and nitrate to subsurface tile drains. Four cropping systems [continuous corn (Zea mays L.), corn-soybean [Glycine max (L.) Merr.], alfalfa (ALF), and CRP] were established in 1988. ALF and CRP were converted to a corn-corn-soybean sequence from 1994 through 1996 while continuous corn (CC) and corn-soybean (CS) rotations were maintained. Beneficial rotation effects occurred following CRP including a 14% increase in corn yield and a 20% increase in water use efficiency (WUE) as compared to CC. Yield was 19% and WUE 21% greater for soybean following corn in CRP and ALF as compared to CS. Tile flow volumes were correlated to water supplies (Ws) and drainage differences were small following conversion of CRP and ALF to row crops. Residual soil nitrate(RSN) in the top 1.5 m increased by 125% in first year corn following CRP and was 32% greater than CC by 1996. High N uptake efficiencies of corn following alfalfa helped to slow buildup of RSN, but levels were equal to row crop systems after two years. Nitrate losses and

concentrations in tile drainage remained low during the initial year of conversion, but were similar to row crop systems during the subsequent two years. Thus, low tile flows and nitrate losses will likely require a rotation of perennial and annual crops in the Upper Midwest.

Manure applied on frozen soil or snow - what will happen to my nitrogen?

blog-crop-news.extension.umn.edu/2019/01/manure-applied-on-frozen-soil-or-snow.html

By Melissa Wilson, manure management and water quality Extension specialist

It was a tough fall for manure application. In many places of the state it was wet and harvest was delayed. On top of that, winter arrived earlier than it has in the past couple of years. Many people were forced to apply manure on top of frozen soils or even snow. We've gotten a lot of questions about how the nitrogen in the manure will be impacted.

When manure is applied on the surface of frozen soils or on top of snow, we have two concerns. First, it cannot seep into the ground, so if there is any runoff in your fields, it can carry the manure to low spots or away from the field entirely which may cause environmental issues. We have already seen widespread rain in December across southern Minnesota and snow melt in January in many parts of the state. Fields with higher amounts of residue are less likely to have as much runoff as fields with low residue, so this problem may be worse in some fields and not others.

The second problem we have to consider is the ammonia losses. Remember that manure has two main forms of nitrogen: organic-nitrogen and ammonium-nitrogen. When ammonium-nitrogen is on the soil surface instead of being mixed in with the soil, it can volatilize and be lost as ammonia gas. This is mainly driven by chemical and physical factors. While the freezing temperatures slow the reaction down, research suggests it doesn't stop it entirely. Plus, with the freeze thaw cycles we have seen this year, it is difficult to pinpoint how much will be lost as the manure sitting on the surface freezes and thaws, too. This problem is likely to impact all manure types, but especially swine manure since the total nitrogen content is roughly 60 to 80 percent ammonium-nitrogen when applied.

The good news is that with the cooler temperatures, the conversion of ammonium-nitrogen in manure to nitrate-nitrogen form is minimal. We do not expect nitrate leaching or denitrification to be increased because of the conditions in which manure was applied this year. This is because bacteria are responsible for the conversion, and the freezing temperatures minimize their activity in the winter. This could change depending on the kind of spring we have, however.

Unfortunately, we cannot predict exactly how much nitrogen was lost this year if it was applied on frozen soil or snow. Manure nutrient release can vary depending on specific circumstances. Our best guess is to use our guidelines in Table 1. This will help determine the percent of nitrogen available the first year when broadcasting manure with no incorporation (see the second column). The actual amount available may be more or less, however.

My best advice is to keep an eye on your crop this upcoming year and be prepared to sidedress additional nitrogen if the crop is looking deficient. The Minnesota Pollution Control Agency says you can apply an additional 20 percent of total crop N needs above UMN nitrogen guidelines (PDF) if soil conditions or cool weather warrants additional nitrogen application.

Table 1. Nitrogen availability and loss as affected by method of manure application and animal type.

Percent of total nitrogen available for first year crop after application

Animal type	Broadcast incorporated later than 96 hours or not incorporated	Broadcast incorporated in 12-96 hours	Broadcast incorporated in less than 12 hours	Inject - sweep	Inject - knife
Beef	25%	45%	60%	60%	50%
Dairy	20%	40%	55%	55%	50%
Swine	35%	55%	75%	80%	70%
Poultry	45%	55%	70%	--	--

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RESEARCH ARTICLE

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Livestock manure driving stream nitrate

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Keith E. Schilling, Calvin F. Wolter**

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Abstract Growth and consolidation in the livestock industry in the past 30 years have resulted in more total farm animals being raised on fewer Iowa farms. The effects of this on stream water quality at the landscape scale have largely gone unexplored. The main objective of this work was to quantify the effects on stream nitrate levels of livestock concentration in two western Iowa watersheds relative to seven other nearby watersheds. To achieve this objective, we used data on high-frequency nitrate concentration and stream discharge, commercial nitrogen fertilizer use, and manure-generated nitrogen in each watershed. Our analysis shows much higher stream nitrate in the two watersheds where livestock concentration has been greatest, and little difference in commercial fertilizer inputs with the widespread availability of manure N. Reducing N inputs and better management of manure N, including analysis of crop N availability in soil and manure, can reduce uncertainty regarding fertilization while improving water quality.

Keywords Concentrated livestock · Commercial fertilizer · Flow weighted average · Manure · Nitrate-nitrogen

INTRODUCTION

The state of Iowa, located in the U.S. Midwest, has long been one of the country's leading producers of hogs, cattle, poultry, and eggs. Currently Iowa exceeds all other states in egg and pork production and is fourth in production of feeder cattle (USDA 2018). Iowa has also been a leading producer of both corn (*Zea mays* L.) and soybeans (*Glycine max* [L.] Merr.), frequently topping all other U.S. states in harvested totals of these commodities (Jones et al. 2018a). Co-locating crop production and livestock within the state has created efficiencies of production, transportation, and fertilization.

High yield agriculture, such as that conducted on nearly 70% of Iowa's area (USDA 2018), depends on addition of nitrogen fertilizers. Various forms of fertilizer nitrogen are used throughout the state to enhance crop yields, especially those of corn. Most of this nitrogen is applied as formulations of ammonia/ammonium (NH_3/NH_4^+) and nitrate (NO_3–N) generated from industrial processes, but also animal manures where available. The use of industrially produced nitrogen fertilizers emerged as an important component of U.S. and Iowa agriculture following World War II (Commoner 1977). Before 1945, nearly all nitrogen inputs used to fertilize Iowa corn fields came from legumes such as alfalfa and clovers, and animal waste. However, after this time, the use of inorganic nitrogen fertilizers increased 13-fold from 1945 to 1972 as they quickly became affordable and widely available (Commoner 1977). Livestock, especially cattle, consumed the alfalfa and clover, but commercial fertilizer allowed farmers to forgo hay crops and cattle. This enabled many Iowa farmers to specialize on corn and soybean production (Hendrickson and James 2005). The demand for animal protein, however, continued to increase with world population and increased income levels (Delgado et al. 2001). With fewer farmers wanting or needing livestock, those that continued with livestock production were able to greatly enlarge their operations. This is especially evident in Iowa with hog production. In 1980, 65 000 Iowa farmers raised a total of 13 million hogs; by 2002, the number of hog farmers had dwindled to 10 000, but total hog numbers increased to 14 million (Herriges et al. 2005). This dramatic shift in production resulted in many hogs being concentrated in certain areas of the state and a geographical alignment with buyers, packing houses, feed and equipment suppliers, and haulers (Honeyman and Duffy 2006). Similar scenarios have also played out with cattle and poultry. This agricultural specialization that has occurred in Iowa is consistent with changes that are still occurring worldwide (Liu et al. 2017).

This transition from diverse, multi-species farms to ones specializing in corn and soybean production with a subset of the latter raising concentrated livestock has produced both efficiencies and negative environmental consequences. It has long been known that nitrogen fertilization correlates with stream nitrate in the U.S. Cornbelt (Klepper 1974) with impacts on municipal water supply (Hatfield et al. 2009) and Gulf of Mexico Hypoxia (Rabalais et al. 2002). However, because nitrogen inputs cycle through plant biomass and into and out of soil organic matter (Jackson et al. 2000), and because of the time lag of pollutant transport to streams via groundwater pathways (Van Meter et al. 2017), it is nearly impossible to trace stream nitrate back to commercial fertilizer, animal manure, legumes, or soil organic matter. Hence, many have attempted to gain insights on nitrate sources and pathways using nitrogen budgeting (David et al. 1997; Libra et al. 2004; Jones et al. 2016).

The intensity of crop and livestock production in Iowa has made the state a major contributor to Mississippi River basin nitrate loads (David et al. 2010; Jones et al. 2018a, b). Nitrate loading from Iowa appears to be increasing (Jones et al. 2018a), especially in the Missouri River and its Iowa tributaries (Sprague et al. 2011; Li et al. 2013), and Iowa contributes up to 89% of the annual Missouri River nitrate load even though Iowa areas draining to the Missouri comprise only 3% of the total watershed area (Jones et al. 2018a). Northwest Iowa, which drains to the Missouri River, is an area where livestock production has been concentrated in recent years (Andersen and Pepple 2017). The overall objective of our research was to assess whether the manure generated from high animal densities drives stream nitrate levels in the region. Using high-frequency river monitoring data collected from nine western Iowa watersheds draining to the Missouri River, two of which have a much larger animal density than the others, and comparing the water quality data to crop area, fertilization, and livestock populations, we show that river nitrate levels are linked to agricultural and livestock management.

MATERIALS AND METHODS

Study area

The nine western Iowa watersheds selected for study are shown in Fig. 1 and Table 1. These nine watersheds were selected because they all drain to the Missouri River and were instrumented with real-time, continuous nitrate sensors co-located with a discharge measurement station. Areas upstream of the water quality and discharge monitoring locations constitute 23% of Iowa's area and 74% of the state's area that drains to the Missouri River. Agricultural land use dominates each catchment and large point source discharges are absent, with no cities greater than 10 000 population draining into any of the watersheds.

Agricultural data

County-level data for the latest available (2012) commercial nitrogen fertilizer were obtained from the US Geological Survey National Water Quality Assessment project (Gronberg and Spahr 2012). County-level manure data were obtained from Gronberg and Arnold (2017). There is reason to believe that the 2012 commercial fertilizer data are relevant in the present day because changes in crop areas from 2012 to 2017 were small in the nine watersheds, e.g., − 6.2, + 5.4, and − 1.3% for corn, soybean, and total corn plus soybean, respectively, and statewide commercial fertilization rates have not changed appreciably since 1990 (Hatfield et al. 2009).

Data for animal populations were collected from two sources. Recent (2018) data for animal numbers were obtained from the Iowa Department of Natural Resources (IDNR) Animal Feeding Operations (AFO) database (IDNR 2018a). The IDNR's database is mostly limited to regulated facilities; therefore, numbers obtained from this source are likely to represent less than the actual number of animals raised in these areas. When calculating total animal units (AU) in a watershed, the population of a species is multiplied by the equivalence factor shown in Table 2 (IAC 2018). Historical county-level hog (1980–2012) and cattle (2002–2012) population data were obtained from USDA (2018) and adjusted to each watershed area based on the portion of the county that lies within the individual watershed. Watershed-level hog and cattle populations for 2018 were obtained from IDNR (2018a). The county-level areas planted with corn and soybeans in 2012 and 2017 were obtained from USDA (2018) and adjusted to the county's area portion within each watershed.

For the purposes of constructing a rough agronomic N budget for each watershed, inputs included commercial N (CN), N generated by manure (MN), fixation N (FN) from the previous year's soybean crop while outputs included N harvested in the grain (GN) (Eq. 1).

$$\mathrm{CN} + \mathrm{MN} + \mathrm{FN} - \mathrm{GN} = \text{N surplus or deficit.} \quad (1)$$

Biological N fixation of soybean in 2016 was calculated according to Barry et al. (1993) using county-level crop areas and soybean yields adjusted to the area portion lying

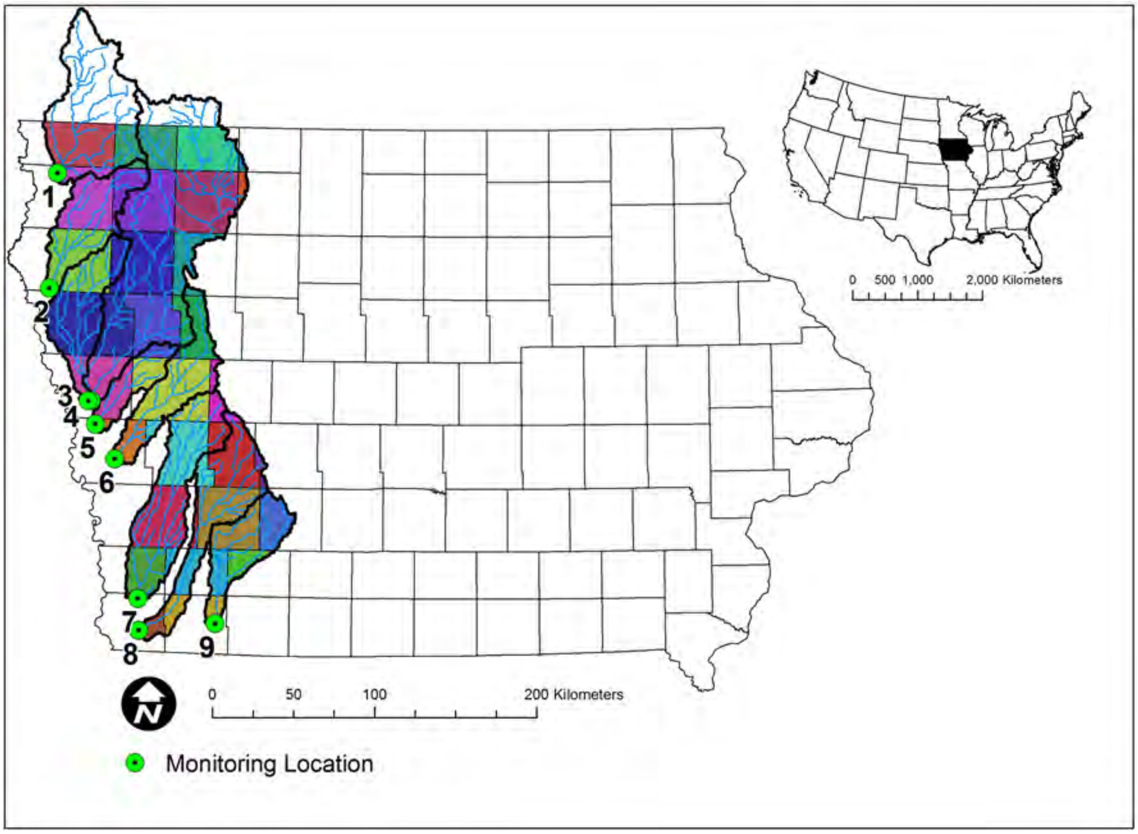

Fig. 1 Nine western Iowa watersheds are evaluated here. The number corresponds to the watershed number shown in Table 1. The green circle designates monitoring location near the outlet

within each watershed. Nitrogen harvested in corn grain was calculated using watershed crop yields and the measured average for Iowa corn reported by Blesh and Drinkwater (2013). Export of N in the harvested soybeans was calculated assuming 6.4% N in soybean seeds according to the USDA protocols using the Crop Nutrient Tool (2009).

Hydrology

Watershed precipitation totals for 2017 were estimated based on data collected at 22 stations within the individual watersheds and averaging data from each watershed location. These data were obtained from the Iowa State University Mesonet network (2017). Discharge data for all the sites were generated by the U.S. Geological Survey (USGS 2018). These 15-min interval data were aggregated into daily averages and the water yield was calculated by dividing total annual discharge by watershed area.

Water quality

High frequency (15 min) 2017 NO_3–N concentration data were obtained from the University of Iowa's Water Quality Information System (Jones et al. 2018b). This network of real-time water quality sensors measures NO_3–N concentrations at about 65 sites throughout Iowa including those shown in Fig. 1. Data quality for the network is governed by a QA/QC plan adopted from USEPA and USGS protocols. Basic QA protocols include systematic monitoring of incoming water quality data, remote monitoring of field sensor/system health (e.g., battery voltage and signal strength), automatic data review through the use of data thresholds and limits, and use of data descriptors for denoting state of data review. Measurements are generated by the Hach Nitratax sc plus (Loveland, CO, US) nitrate sensor and accuracy is verified through regular collection of grab samples that are lab-analyzed. Extensive details about measurement and quality control protocols can be found at Jones et al. (2018b). Data from the IDNR ambient monitoring program were used (IDNR 2018b) for periods when high-frequency data were missing (i.e., equipment malfunction and Dec–Feb). Linear interpolation was used to estimate NO_3–N concentrations on days with no NO_3–N data. Daily average NO_3–N concentrations were multiplied by daily average discharges and then summed to obtain annual NO_3–N loads and yields (load per watershed area). Flow weighted average (FWA) NO_3–N concentrations

Table 1 Watersheds in the study area along with crop area, livestock densities, commercial N fertilizer application rates, and nitrogen generated from animal manure

Figure 1 Map No.	Name	Iowa area (km^2)	Area fractions 2012			2017			Animal Units (AU) ha^{-1} 2017	kg ha^{-1} Corn + soybean area			Corn area only
			Corn	Soybean	Total corn–soybean	Corn	Soybean	Total corn–Soybean		Commercial N application rate (2012)	Manure N generated	Commercial N + generated manure N	Commercial N + generated manure N
1	Rock River	1748	0.50	0.33	0.81	0.44	0.34	0.78	5.00	116	111	227	369
2	Floyd River	2295	0.48	0.34	0.82	0.47	0.35	0.82	3.53	112	117	229	379
3	Monona-Harrison Ditch	2331	0.42	0.31	0.73	0.38	0.33	0.71	1.31	122	37	159	261
4	Little Sioux R.	8350	0.45	0.34	0.79	0.42	0.35	0.77	1.04	119	40	159	262
5	Soldier River	1049	0.46	0.31	0.76	0.42	0.33	0.75	0.76	128	22	150	240
6	Boyer River	2202	0.49	0.31	0.81	0.45	0.34	0.79	1.13	138	38	176	235
7	W. Nishnabotna R.	3434	0.44	0.32	0.76	0.40	0.35	0.75	0.68	121	23	144	241
8	E. Nishnabotna R.	2862	0.39	0.31	0.69	0.36	0.33	0.69	0.53	106	32	138	233
9	W. Nodaway R.	1974	0.33	0.29	0.63	0.32	0.32	0.64	0.45	91	24	115	201

Table 2 Factors used to calculate total animal units (AU). Populations are multiplied by the factors shown to quantify total AU

Animal species	Factor
Horses	2.0
Mature dairy cattle	1.4
Slaughter or feeder cattle	1.0
Immature dairy cattle	1.0
Hogs > 25 kg	0.4
Hogs 7–25 kg	0.1
Turkeys > 3 kg	0.018
Chickens > 1.4 kg	0.01
Turkeys < 3 kg	0.0085
Chickens < 1.4 kg	0.0025
Fish	0.001

were calculated by dividing total load by total discharge. Minnesota areas draining to the Rock and Little Sioux Rivers were used when calculating yields.

RESULTS

Agricultural

Current density of animals ranged from 0.45 (West Nodaway) to 5.00 AU ha^{-1} (Table 1). The Floyd (3.53 AU ha^{-1}) and Rock (5.00 AU ha^{-1}) watersheds had much higher animal densities than the other seven watersheds (average 0.84 AU ha^{-1}). Cattle and hogs are by far the largest contributors to AU units in all watersheds, and historical data for these species are shown in Fig. 2, illustrating how the concentration of hogs has risen since 1980 and cattle since 2002. Hog densities have increased since 1980 in the Rock, Floyd, Monona-Harrison Ditch, and Little Sioux watersheds and declined in the others, with the decline especially pronounced in the West Nodaway (− 80%) and increases largest in the Floyd (+ 126%) and Rock watersheds (+ 269%). Overall, hog populations increased 41% since 1980, but when the Floyd and Rock watersheds are excluded, the increase is only 4.2%. The Floyd and Rock watersheds also have the highest current cattle densities at 1.14 and 1.70 per ha, respectively. Since 2002, the average cattle population grew by 37%, but increased only 0.01% when the Rock and Floyd watersheds are excluded. Large declines in cattle populations occurred in the Soldier (− 46%) and West Nodaway (− 74%) watersheds.

Areas planted with corn and soybean were obtained for 2012 and 2017 (Table 1) for comparison with available fertilization and water quality data. Overall in the nine watersheds, the total corn–soybean area was 1.3% lower in

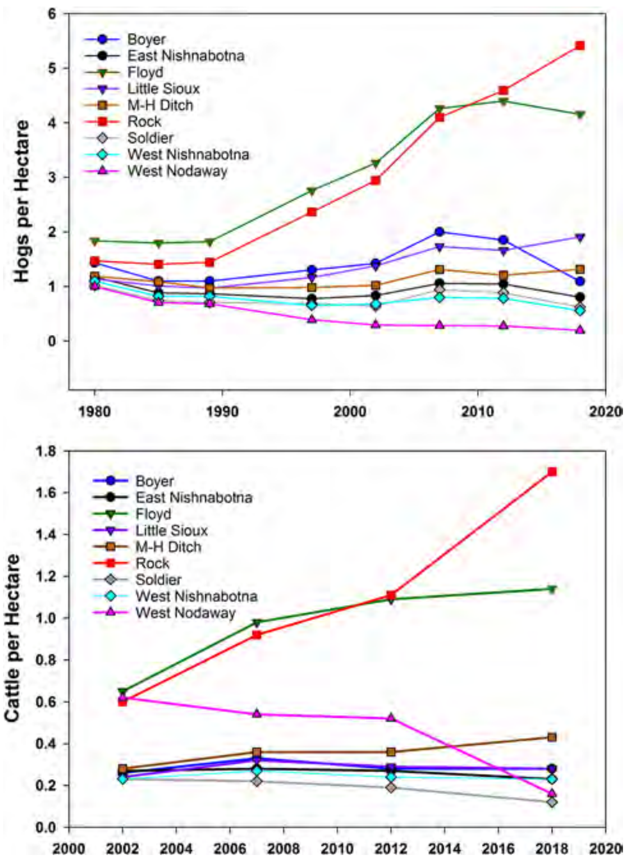

Fig. 2 Hog and cattle densities in the nine studied watersheds

2017 compared to 2012, with 6.2% less corn area and 5.4% more soybean area. Between watersheds, the biggest increase from 2012 to 2017 was in the West Nodaway (+ 1.6%) while the largest decrease was in the Monona-Harrison Ditch watershed (– 2.7%). Total corn–soybean area declined from 2012 to 2017 in all watersheds except the Floyd and West Nodaway. The cropped portion of each watershed ranged from 0.64 (West Nodaway) to 0.82 (Floyd) with an overall average of 0.74 in 2017.

The latest available fertilization data are from 2012 and are listed in Table 1. The commercial rates plus generated manure are based on 2012 crop areas and vary from 115 (West Nodaway) to 229 kg ha^{-1} of combined corn and soybean area. However, soybeans usually do not receive much nitrogen fertilizer in Iowa, with a statewide average of 15.7 kg ha^{-1} (Jones et al. 2016). Considering this, amounts per corn area alone ranged from 201 kg ha^{-1} (West Nodaway) to 379 kg ha^{-1} (Floyd) and averaged 269 kg ha^{-1} across all watersheds. Interestingly, the commercial N rates in the Rock watershed (116 kg ha^{-1} to all corn–soybean area) and the Floyd watershed (112 kg ha^{-1}) were similar to the nine-watershed average (117 kg ha^{-1}), this even with abundance of manure N generated by livestock (111 and 117 kg ha^{-1}, respectively). The commercial N rates in the West Nodaway watershed (91 kg ha^{-1} to all corn–soybean area) were lowest of the nine watersheds, even though the generated manure N was also quite low at 24 kg ha^{-1}, second lowest of the group.

Water quality and hydrology

The annual nitrate (NO_3–N), precipitation, and discharge data for 2017 are shown in Table 3. The precipitation recorded in the Rock (804 mm) and Floyd (759 mm) watersheds was substantially less than the other seven watersheds where the average was 917 mm. Despite lower amounts of rainfall, the Rock and Floyd each had the highest annual NO_3–N yields (24.7 and 30.5 kg ha^{-1}, respectively) and FWA NO_3–N concentration (11.5 and 16.2 mg L^{-1}, respectively) (Fig. 3). The averages for the other seven watersheds were 20.0 kg ha^{-1} (yield) and 7.3 mg L^{-1} (FWA concentration). The Monona-Harrison Ditch watershed had the lowest yield of NO_3-N (11.1 kg ha^{-1}) and the West Nodaway River had the lowest FWA concentration (4.9 mg L^{-1}).

Nitrogen budget

An estimated 2017 nitrogen budget was constructed assuming the fertilization rates from 2012 were relevant to 2017, using commercial N and manure data, crop yield data from 2017, and soybean area and yield from 2016 to calculate contributions from nitrogen fixation. This is shown in Table 4 along with the FWA NO_3–N concentrations for comparison. The surplus nitrogen, i.e., the amount applied as commercial fertilizer plus the amount generated by livestock plus the amount fixed by soybeans the previous year minus the amount harvested in the grain, ranged from 55 kg ha^{-1} (West Nodaway) to 161 kg ha^{-1} (Floyd) and averaged 99 kg ha^{-1} across the nine watersheds. The watersheds with the three largest surplus N values (Floyd, Rock, and Boyer) also had the three highest FWA concentrations while the watersheds with the two smallest surpluses also had the two smallest FWA concentrations. The average surplus for the Rock and Floyd (155 kg ha^{-1}) was nearly double the average of the other seven watersheds (83 kg ha^{-1}).

The FWA concentrations were well correlated with fertilization and crop area (Fig. 4). These concentrations correlated significantly ($p < 0.01$) with surplus nitrogen (fertilizer + manure + fixation-grain N), commercial + manure + fixation N, commercial + manure N, and manure N, and less significantly with area portion in corn and soybean ($p < 0.05$). The FWA concentrations did not correlate with commercial N ($p > 0.10$).

Table 3 2017 hydrology and stream NO_3–N data

Watershed	Annual precipitation (mm)	Discharge[a]	NO_3–N measurement days (N)	NO_3–N yield ($kg\ ha^{-1}$)	NO_3–N yield/precipitation ($g\ ha^{-1}\ mm^{-1}$)	FWA[b] NO_3–N ($mg\ L^{-1}$)
Rock River	804	215	115	24.7	30.7	11.5
Floyd River	759	188	284	30.5	40.2	16.2
Monona-Harrison Ditch	942	172	171	11.1	11.8	7.2
Little Sioux River	816	241	181	17.1	20.9	7.1
Soldier River	846	259	233	21.9	25.9	8.5
Boyer River	1056	312	249	27.1	25.7	8.7
West Nishnabotna River	846	291	293	23.9	28.3	8.2
East Nishnabotna River	974	430	193	23.7	24.3	5.5
West Nodaway River	963	282	288	13.9	14.4	4.9
Average	890	266	223	21.5	24.7	8.6

[a]Discharge calculated by dividing total discharge volume at the outlet by watershed area draining to the site

[b]FWA is Flow Weighted Average concentration, which is obtained by dividing total river NO_3–N load by total discharge

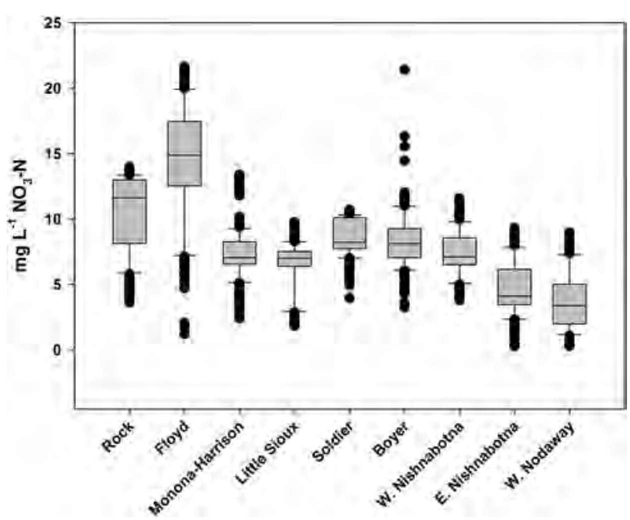

Fig. 3 Box plots of 2017 daily average NO_3–N concentrations. The boxes bracket the 25th–75th percentiles; the line in the box indicates the median; the whiskers the 10th and 90th percentiles, and the dots are data points less than (greater than) the 10th (90th) percentiles

DISCUSSION

Iowa State University (ISU) Extension guidelines for N application rates ($kg\ ha^{-1}$) range from 135 to 165 (average 150) for corn following soybean, and 193–221 (average 206) for corn following corn under the current price structure for commercial nitrogen fertilizer and corn grain (Sawyer 2016). When we adjust for statewide N rates to soybeans (15.7 $kg\ ha^{-1}$, Jones et al. 2016), commercial fertilizer data for 2012 show average annual commercial N rate to corn in these nine watersheds is 189 $kg\ ha^{-1}$, generally in-line-to-slightly-above ISU guidelines. However, these rates do not account for the substantial amounts of manure N generated in the nine watersheds, and especially in the Floyd and Rock watersheds, where the generated manure N is roughly equivalent to commercial N sales. After the generated manure N is added to commercial N, then the amount of N per corn-hectare exceeds ISU guidelines in all watersheds except the West Nodaway, where coincidentally the lowest FWA NO_3-N was recorded in 2017. In the Floyd and Rock watersheds, the commercial N plus N generated from manure sources is ~ 370–380 $kg\ ha^{-1}$ of corn (accounting for average N application to soybean), which is about double ISU recommendations. In these two watersheds, the "surplus" N (i.e., commercial + manure + fixation − grain) actually exceeds the ISU recommendations for corn grown after soybeans. It should be pointed out that this is based on 2012 animal populations and that hog and cattle numbers increased substantially in the Rock watershed since then (Fig. 2). The fate of all manure N applied to agricultural fields is not well understood. Some amount of the N in fresh animal manure is lost to volatilization (Kirchmann and Witter 1989) and never becomes available for crop uptake. There is evidence, however, that much of this volatilized N is deposited within 1 km of the confinement (Loubet et al. 2009) and McGinn et al. (2016) reported a 50% decline in deposition 200 m from a cattle confinement. Thus, much of this volatilized N is not lost from the watershed. Additionally, some portion of manure N is often in organic forms and not immediately available to plants after field application, a condition informed by testing the manure and soil for available N (NO_3–N and NH_4–N) (Paul and Beauchamp 1993). This organic N must eventually become available to crops and/or leach into the stream

Table 4 Estimated 2017 nitrogen budget for using commercial N rates, generated livestock manure, soybean fixation from previous year, N harvested in the grain, and stream NO_3–N for comparison

Watershed	Commercial N + generated manure N (Kg NO_3–N ha^{-1} $year^{-1}$)	Fixation from 2016 soybean crop	Fixation from 2016 soybean crop	Commercial N + manure N + fixation N-grain N	FWA NO_3–N (mg L^{-1})
Rock River	226	100	178	148	11.5
Floyd River	229	107	175	161	16.2
Monona-Harrison Ditch	159	110	169	100	7.2
Little Sioux River	158	111	172	97	7.1
Soldier River	150	96	171	74	8.5
Boyer River	176	98	171	103	8.7
West Nishnabotna River	145	97	159	83	8.2
East Nishnabotna River	138	95	163	70	5.5
West Nodaway River	115	98	159	55	4.9

network, and thus it must be considered in watershed N budgets. Finally, it is likely some of the generated manures are being transported beyond watershed boundaries for application elsewhere. Long-range hauling (more than ~ 8 km), however, becomes economically problematic (Fleming et al. 1998) and there is evidence that farmers tend to apply manure on fields nearby confinements (Innes 2000; Jackson et al. 2000). Thus, the majority of manure generated within watersheds of the size studied here is likely to remain in that watershed. All things considered, the amount of purchased (commercial) N plus the amount of N generated by manure is far beyond crop nutrient requirements in some of these watersheds, and this surplus N will accumulate as decaying plant matter, soil organic matter and organisms, and soil water NO_3–N, creating a growing pool of mobile N (Jackson et al. 2000).

When 2017 water quality data are considered alongside these estimates of fertilization and generated manure, the Floyd and Rock watersheds stand out not only for their level of fertilization, but also for stream NO_3–N concentration levels. Despite the relative dryness in these two watersheds compared to the others, their FWA NO_3–N concentrations are nearly double those of the other seven when considered in aggregate (13.9 vs. 7.3 mg L^{-1}). Likewise, the commercial plus manure N in the West Nodaway and East Nishnabotna watersheds is only 60% of that in the Rock and Floyd, and this is reflected in stream water quality where NO_3–N concentrations are only 37% as high as in the Rock and Floyd watersheds. Howarth et al. (2012) estimated when net anthropogenic N inputs (NANI), similar to the surplus N described here, exceeded 1070 kg N km^{-2} $year^{-1}$, 25% of this amount on average was exported to rivers worldwide. The average surplus N for our nine watersheds was 4489 kg N km^{-2} during 2017, and an all-watershed average of 33% of this amount exited in the stream network. Our simple N budgets, which do not incorporate pathways such as atmospheric deposition of N and N returned to livestock in animal feed, still produce a value not that different from the Howarth et al. (2012) analysis, and our stream export values could be expected to exceed those of Howarth et al. (2012) because our surplus N is 4 times as large as the threshold in that study.

It is notable that the Rock watershed, with higher livestock densities than the Floyd watershed (Fig. 2), actually has lower levels of stream NO_3–N (Fig. 3). It is important to note that 58% of the Rock River watershed lies outside of the state of Iowa in Minnesota. The state of Minnesota Pollution Control Agency (MPCA) conducts NO_3–N water monitoring on the Rock River at a site about 18 stream-km north of the Iowa border (MPCA 2018). In 2017, six samples were collected by MPCA from April 26 to September 27 and averaged 8.48 mg L^{-1} NO_3–N. The concentrations downstream at Rock Valley, Iowa, the site of the monitoring conducted for this study, were 10.04 mg L^{-1} during that period. Thus, we suspect that lower concentrations of NO_3–N in water from Minnesota are diluting higher concentrations of NO_3–N in water contributed by Iowa portions of the Rock watershed.

Recently, the metric NO_3–N yield per unit of precipitation (g NO_3–N ha^{-1} mm P^{-1}) was used to compare NO_3–N delivery in seven Iowa watersheds (Jones et al. 2018c). In the second 15 years of that study (2002–2016), an average of 22 g NO_3–N ha^{-1} was mobilized to streams per mm of precipitation. For the 2017 water quality and hydrology data presented here, the nitrogen yield from the Floyd (40.2 g NO_3–N ha^{-1} mm P^{-1}) and Rock (30.7 g NO_3–N ha^{-1} mm P^{-1}) watersheds were considerably higher than the other seven, where the aggregated average was 22.0. The West Nodaway watershed received 204 mm more precipitation than the Floyd (27% more) but the NO_3–N yields were less than half, a clear indicator that the

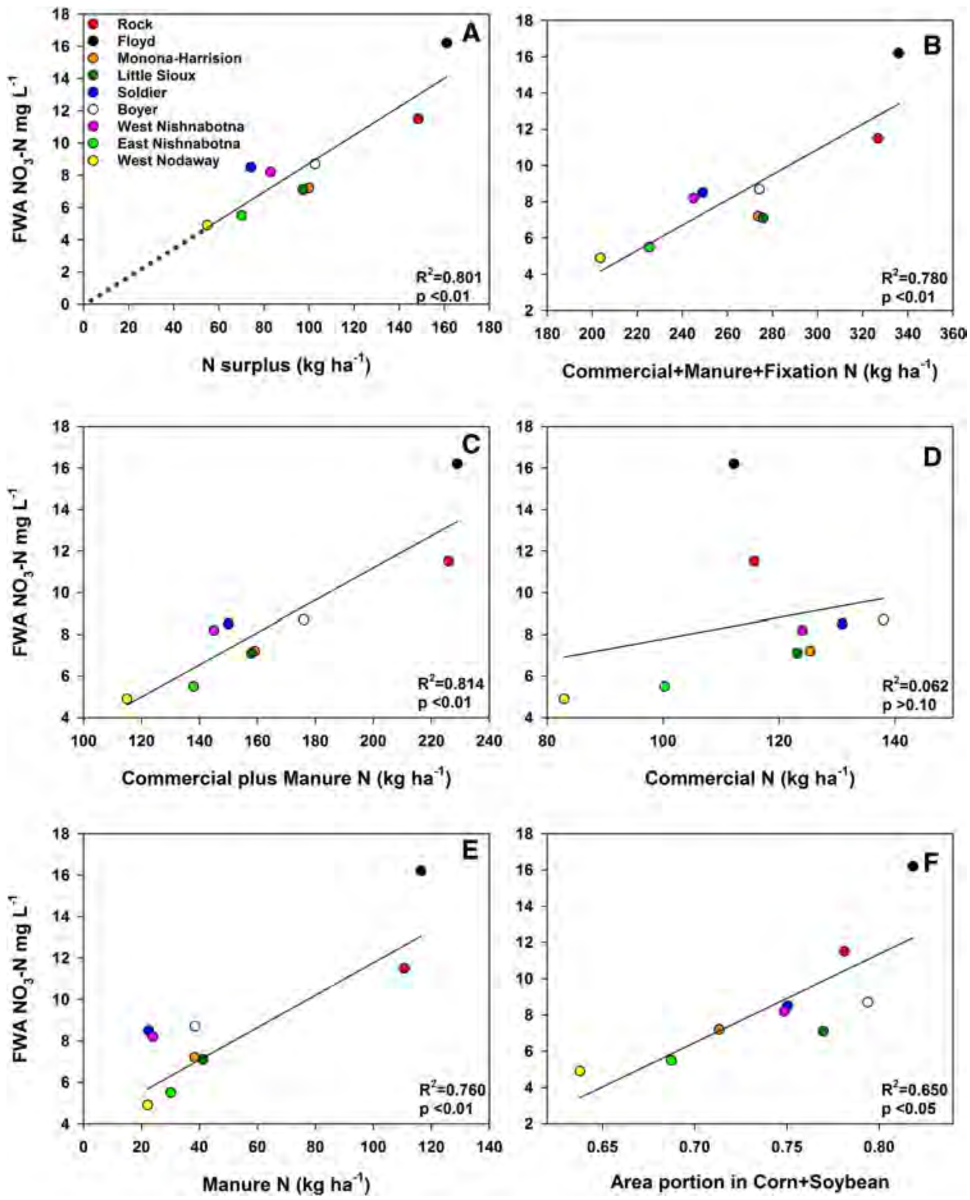

Fig. 4 Correlations of 2017 watershed Flow Weighted Average (FWA) NO_3–N concentrations with N surplus (**a**), sum of commercial, manure and fixation nitrogen (**b**), sum of commercial and manure nitrogen (**c**), commercial nitrogen (**d**), generated manure nitrogen (**e**), and area portion in corn and soybean (**f**). The dotted portion of the regression line in **a** is an extrapolation backward to a zero surplus condition. FWA is defined as total NO_3–N load divided by total discharge for 2017

supply of loss-vulnerable N was far higher in the Floyd watershed compared to the West Nodaway.

Li et al. (2013) evaluated NO_3–N concentrations and trends for Iowa streams from 1998 to 2012. Of the 48 Iowa streams in that study that had sufficiently long data records for trend analysis, the Rock and Floyd Rivers had the largest positive trends for NO_3–N concentration (0.33 and 0.29 mg L^{-1} $year^{-1}$, respectively) during a time when hog and cattle populations in the two watersheds were doubling (Fig. 2). The statistical significance of those trends was strong ($p < 0.01$). The other sites in that study that were also evaluated here included the West Nodaway River (increasing trend of 0.17 mg L^{-1} $year^{-1}$), Boyer River (0.16 mg L^{-1} $year^{-1}$), West Nishnabotna River (0.06 mg L^{-1} $year^{-1}$), Soldier River (0.03 mg L^{-1} $year^{-1}$), and Little Sioux River (0.03 mg L^{-1} $year^{-1}$). Without detailed information about manure nitrogen quantities, Li et al. (2013) speculated that manure applications associated with increasing hog populations were a driving factor for the upward NO_3–N trends in western Iowa, and we believe the data presented herein are consistent with that.

There are examples in the literature linking livestock concentration with surplus stream nutrients and degraded water quality in other parts of the world. For example, the northwestern Black Sea was seriously degraded from the 1960s to the 1980s by nutrient runoff from the Danube River, but rapidly improved after 1989 with the closure of many large animal farms as a result of the fall of communist regimes (Mee 2006). Considering that the average animal unit density in our study was 1.60 ha^{-1}, the average magnitude of N surplus we report (99 kg ha^{-1}) is consistent with research from other agricultural regions. For example, Wang et al. (2018) reported average N surpluses of 75-306 kg ha^{-1} when AU density exceeded 1 ha^{-1} for several countries in Europe, Asia, and the Americas. Oenema et al. (2007) reported highest levels of NO_3–N leaching in Europe to be in the northwest where livestock densities were highest. Leaching rates 20 to over 50 kg ha^{-1} were reported in that study, compared to 30.5 and 24.7 kg ha^{-1} for the Floyd and Rock watersheds, the two highest-density livestock watersheds of the nine assessed here. When considering the NO_3–N transported by these streams, and especially the Rock and Floyd Rivers, it is relevant to consider how this pollutant links to various processes that control stream amounts. At the landscape scale in the U.S. cornbelt, the NO_3–N loading is clearly transport-limited (Sprague et al. 2011; Jones et al. 2017). However, there are years within individual watersheds where supply limitations are controlling (Jones et al. 2017). Furthermore, fertilizer nitrogen has been shown to be a strong predictor and regulator of stream NO_3–N concentrations (David et al. 2010; Li et al. 2013). The Floyd and Rock were the two driest watersheds evaluated here, but still had by far the highest NO_3–N delivery of these nine western Iowa basins. The fact that in the Floyd and Rock watersheds, the commercial N inputs combined with generated manure N were nearly double the other watersheds illustrates the importance of N supply management for water quality improvement. There is ample evidence that U.S. Cornbelt farmers over-apply nitrogen, often in manure forms (Yadav et al. 1997; Jackson et al. 2000; Sheriff 2005; Khanal et al. 2014). This is not necessarily wasteful; rather, the economics of nitrogen can make it more profitable for farmers to concentrate manure applications on nearby fields and purchase chemical fertilizer for the rest of the farm (Letson et al. 1998). In fact, Jackson et al. (2000) concluded that in some scenarios it makes clear economic sense for large livestock confinements to maximize N volatilization losses. In these circumstances, manure becomes a waste product and the practice of squandering manure nutrients itself is not necessarily economically wasteful (Fleming et al. 1998; Sheriff 2005), i.e., the farmer may benefit financially by not fully taking advantage of the fertility benefits available in the generated manure. Many farmers may also manage manure application rates based not on N, but rather phosphorus and/or potassium. Farmers also may apply manure in the fall, followed by commercial fertilizer applications the following spring.

Interestingly, the N inputs in the West Nodaway watershed are in line with ISU recommendations for corn cultivation, and the FWA NO_3–N concentration was a relatively modest 4.9 mg L^{-1} and the daily concentration never exceeded the safe drinking water standard of 10 mg L^{-1}. This watershed illustrates the obvious opportunity for farmers and policy makers to make progress towards Iowa's water quality goal of a 45% NO_3–N load reduction (Iowa Nutrient Reduction Strategy 2013). Figure 4a indicates that reducing surplus N by better balancing inputs relative to expected crop needs would reduce stream NO_3–N levels. When considering Fig. 4a, extrapolating the regression backward to a zero surplus N condition results in a FWA NO_3–N concentration of < 1 mg L^{-1}. We acknowledge that legacy N (Van Meter et al. 2017) may elevate stream NO_3–N for prolonged periods after inputs are balanced with crop requirements and that the extrapolation in 4(A) is somewhat speculative. Nonetheless, it is apparent that better management and accounting of manure inputs could generate significant and rapid progress towards Iowa's water quality objective for stream N. The surplus N relates much more strongly to generated manure N ($R^2 = 0.83$) than commercial N inputs ($R^2 = 0.14$) among the nine watersheds and therefore this suggests a starting place when assessing inputs on the watershed scale. These findings are consistent with Khanal et al. (2014), who determined that manure-fertilized rotations had a higher net N (i.e., difference between inflows and outflows) statewide in Iowa. While the amount of N generated in livestock manure is not a precise estimate of what will be available to the receiving crop, methods exist to help reduce this uncertainty (Paul and Beauchamp 1993) and integration of commercial fertilizer and manure recommendation systems that account for soil fertility, crop needs, and availability of manure N is needed (Liu et al. 2017). With commercial fertilizer sales seemingly unrelated to the availability of manure N in these watersheds, refinements in planning and manure management hold great potential for producing water quality improvement in areas where livestock has been concentrated. Several policy recommendations were proposed by Jackson et al. (2000) to address similar issues in Central Iowa. These included alternative livestock housing, increased regulatory scrutiny of manure management plans, modification of land zoning rules, and incentivizing extended crop rotations that include small grains and forage legumes. Although now nearly 20 years old, we wish to emphasize that while these recommendations have mostly gone unheeded, they continue to hold potential for more efficient nitrogen use and water quality improvement.

CONCLUSIONS

While commercial fertilizer nitrogen input rates are similar among these nine western Iowa watersheds, generated manure N is far higher in two, the Floyd and Rock River watersheds, and the FWA NO_3–N concentrations at the outlets of these watersheds are approximately double that of the other seven. The commercial N inputs plus the generated manure N in these two watersheds total 370-380 kg corn ha^{-1}, which is about double the recommended application rates. The FWA NO_3–N concentration was significantly correlated with total N inputs and generated manure but not with commercial N fertilizer amounts. The only watershed where commercial fertilizer N inputs plus generated manure was consistent with the rate recommendations was the West Nodaway watershed, where the FWA NO_3–N concentrations were lowest and never exceeded 10 mg L^{-1}. Overall, the results from this study strongly suggest that better management of manure holds promise for producing significant water quality improvements at a watershed scale.

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REFERENCES

Andersen, D.S., and L.M. Pepple. 2017. A County-Level Assessment of Manure Nutrient Availability Relative to Crop Nutrient Capacity in Iowa: Spatial and Temporal Trends. *Transactions of the ASABE* 60: 1669–1680.

Barry, D.A.J., D. Goorahoo, and M.J. Goss. 1993. Estimation of Nitrate Concentrations in Groundwater Using a Whole Farm Nitrogen Budget. *Journal of Environmental Quality* 22: 767–775.

Blesh, J., and L.E. Drinkwater. 2013. The Impact of Nitrogen Source and Crop Rotation on Nitrogen Mass Balances in the Mississippi River Basin. *Ecological Applications* 23: 1017–1035.

Commoner, B. 1977. Cost-Risk-Benefit Analysis of Nitrogen Fertilization: A Case History. *Ambio* 6: 157–161.

David, M.B., L.E. Drinkwater, and G.F. McIsaac. 2010. Sources of Nitrate Yields in the Mississippi River Basin. *Journal of Environmental Quality* 39: 1657–1667.

David, M.B., L.E. Gentry, D.A. Kovacic, and K.M. Smith. 1997. Nitrogen Balance in and Export from an Agricultural Watershed. *Journal of Environmental Quality* 26: 1038–1048.

Delgado, C., M. Rosegrant, H. Steinfeld, S. Ehui, and C. Courbois. 2001. Livestock to 2020: The Next Food Revolution. *Outlook on Agriculture* 30: 27–29.

Fleming, R.A., B. Babcock, and E. Wang. 1998. Resource or Waste? The Economics of Swine Manure Storage and Management. *Review of Agricultural Economics* 20: 96–113.

Gronberg, J.M., and N.E. Spahr. 2012. County-level estimates of nitrogen and phosphorus from commercial fertilizer for the Conterminous United States, 1987–2006: U.S. Geological Survey Scientific Investigations Report 2012-5207. https://pubs.usgs.gov/sir/2012/5207/.

Gronberg, J.M., and T.L. Arnold. 2017. County-level estimates of nitrogen and phosphorus from animal manure for the conterminous United States, 2007 and 2012, U.S. Geological Survey Open-File Report 2017-1021, https://doi.org/10.3133/ofr20171021.

Hatfield, J.L., L.D. McMullen, and C.S. Jones. 2009. Nitrate–Nitrogen Patterns in the Raccoon River Basin Related to Agricultural Practices. *Journal of Soil and Water Conservation* 64: 190–199.

Hendrickson, M.K., and H.S. James. 2005. The Ethics of Constrained Choice: How the Industrialization of Agriculture Impacts Farming and Farmer Behavior. *Journal of Agricultural and Environmental Ethics* 18: 269–291.

Herriges, J.A., S. Secchi, and B.A. Babcock. 2005. Living with Hogs in Iowa: The Impact of Livestock Facilities on Rural Residential Property Values. *Land Economics* 81: 530–545.

Honeyman, M.S., and M.D. Duffy. 2006. Iowa's Changing Swine Industry. *Animal Industry Report* 652: 64.

Howarth, R., D. Swaney, G. Billen, J. Garnier, B. Hong, C. Humborg, P. Johnes, C.M. Mörth, and R. Marino. 2012. Nitrogen Fluxes from the Landscape are Controlled by Net Anthropogenic Nitrogen Inputs and by Climate. *Frontiers in Ecology and the Environment* 10: 37–43.

IAC (Iowa Administrative Code) 2018. Chapter 65.1. https://www.legis.iowa.gov/docs/iac/rule/11-09-2016.567.65.1.pdf.

IDNR, Iowa Department of Natural Resources, 2018a. Iowa DNR Animal Feeding Operation Database. https://programs.iowadnr.gov/animalfeedingoperations/.

Innes, R. 2000. The Economics of Livestock Waste and Its Regulation. *American Journal of Agricultural Economics* 82: 97–117.

Iowa DNR, Iowa Department of Natural Resources 2018b. Iowa's Ambient Water Quality Monitoring and Assessment Program. http://www.iowadnr.gov/Environmental-Protection/Water-Quality/Water-Monitoring.

Iowa Nutrient Reduction Strategy. 2013. A Science-and Technology-Based Framework to Assess and Reduce Nutrients to Iowa Waters and the Gulf of Mexico. http://publications.iowa.gov/23225/.

Iowa State University, College of Agriculture, Department of Agronomy. 2017. Iowa Environmental Mesonet, IEM Climodat Reports. From: http://mesonet.agron.iastate.edu/climodat/index.phtml.

Jackson, L.L., D.R. Keeney, and E.M. Gilbert. 2000. Swine Manure Management Plans in North-central Iowa: Nutrient Loading and Policy Implications. *Journal of Soil and Water Conservation* 55: 205–212.

Jones, C.S., C.A. Davis, C.W. Drake, K.E. Schilling, S.H. Debionne, D.W. Gilles, I. Demir, and L.J. Weber. 2018a. Iowa Statewide Stream Nitrate Load Calculated Using In Situ Sensor Network. *JAWRA Journal of the American Water Resources Association* 54: 471–486.

Jones, C.S., K.E. Schilling, I.M. Simpson, and C.F. Wolter. 2018b. Iowa stream nitrate, discharge and precipitation: 30 year perspective. *Environmental Management*. https://doi.org/10.1007/s00267-018-1074-x.

Jones, C.S., J.K. Nielsen, K.E. Schilling, and L.J. Weber. 2018c. Iowa Stream Nitrate and the Gulf of Mexico. *PLoS ONE* 13: e0195930.

Jones, C.S., A. Seeman, P.M. Kyveryga, K.E. Schilling, A. Kiel, K.-S. Chan, and C.F. Wolter. 2016. Crop Rotation and Raccoon River Nitrate. *Journal of Soil and Water Conservation* 71: 206–219.

Jones, C.S., B. Wang, K.E. Schilling, and K.S. Chan. 2017. Nitrate Transport and Supply Limitations Quantified Using High-Frequency Stream Monitoring and Turning Point Analysis. *Journal of Hydrology* 549: 581–591.

Khanal, S., R.P. Anex, B.K. Gelder, and C.F. Wolter. 2014. Nitrogen Balance in Iowa and the Implications of Corn-Stover Harvesting. *Agriculture, Ecosystems & Environment* 183: 21–30.

Kirchmann, H., and E. Witter. 1989. Ammonia Volatilization During Aerobic and Anaerobic Manure Decomposition. *Plant and Soil* 115: 35–41.

Klepper, R., 1974. Fertilizer application rates and nitrate concentrations in Illinois surface waters. National Agricultural Library. http://agris.fao.org/agris-search/search.do?recordID=US201300533223.

Letson, D., N. Gollehon, C. Kascak, V. Breneman, and C. Mose. 1998. Confined Animal Production and Groundwater Protection. *Review of Agricultural Economics* 20: 348–364.

Li, D., K.-S. Chan, and K.E. Schilling. 2013. Nitrate Concentration Trends in Iowa's Rivers, 1998 to 2012: What Challenges Await Nutrient Reduction Initiatives? *Journal of Environmental Quality* 42: 1822–1828.

Libra, R.D., C.F. Wolter, and R.J. Langel. 2004. Nitrogen and phosphorus budgets for Iowa and Iowa watersheds. https://ir.uiowa.edu/cgi/viewcontent.cgi?article=1046&context=igs_tis.

Liu, Q., J. Wang, Z. Bai, L. Ma, and O. Oenema. 2017. Global Animal Production and Nitrogen and Phosphorus Flows. *Soil Research* 55: 451–462.

Loubet, B., W.A. Asman, M.R. Theobald, O. Hertel, Y.S. Tang, P. Robin, M. Hassouna, U. Dämmgen, S. Genermont, P. Cellier, and M.A. Sutton. 2009. Ammonia deposition near hot spots: processes, models and monitoring methods. *Atmospheric Ammonia*, 205–267. Dordrecht: Springer.

McGinn, S.M., H.H. Janzen, T.W. Coates, K.A. Beauchemin, and T.K. Flesch. 2016. Ammonia Emission from a Beef Cattle Feedlot and Its Local Dry Deposition and Re-emission. *Journal of Environmental Quality* 45: 1178–1185.

Mee, L. 2006. Reviving Dead Zones. *Scientific American* 295: 78–85.

MPCA, Minnesota Pollution Control Agency, Environmental Data Access. 2018. https://cf.pca.state.mn.us/eda/stationInfo.php?ID=S000-687&ORG=MNPCA&wdip=2.

Oenema, O., D. Oudendag, and G.L. Velthof. 2007. Nutrient Losses from Manure Management in the European Union. *Livestock Science* 112: 261–272.

Paul, J.W., and E.G. Beauchamp. 1993. Nitrogen Availability for Corn in Soils Amended with Urea, Cattle Slurry, and Solid and Composted Manures. *Canadian Journal of Soil Science* 73: 253–266.

Rabalais, N.N., R.E. Turner, and W.J. Wiseman Jr. 2002. Gulf of Mexico Hypoxia, Aka "The dead zone". *Annual Review of Ecology and Systematics* 33: 235–263.

Sawyer, J.E., 2016. Iowa State University, Extension and Outreach Publications 5-2016. Nitrogen use in Iowa corn production. https://lib.dr.iastate.edu/cgi/viewcontent.cgi?article=1081&context=extension_pubs.

Sheriff, G. 2005. Efficient Waste? Why Farmers Over-apply Nutrients and the Implications for Policy Design. *Review of Agricultural Economics* 27: 542–557.

Sprague, L.A., R.M. Hirsch, and B.T. Aulenbach. 2011. Nitrate in the Mississippi River and Its Tributaries, 1980 to 2008: Are We Making Progress? *Environmental Science and Technology* 45: 7209–7216.

USDA, 2009. Natural Resources Conservation Service, Crop Nutrient Tool, Plants Database. A tool for calculating the approximate amount of nitrogen, phosphorus, and potassium that is removed by the harvest of agricultural crops. https://plants.usda.gov/npk/main.

USDA. National agricultural statistics service quick stats. 2018. https://quickstats.nass.usda.gov/.

USGS, 2018. National Water Information System, Web Interface, Current Conditions for Iowa: Streamflow. https://waterdata.usgs.gov/ia/nwis/current/?type=flow.

Van Meter, K.J., N.B. Basu, and P. Van Cappellen. 2017. Two Centuries of Nitrogen Dynamics: Legacy Sources and Sinks in the Mississippi and Susquehanna River Basins. *Global Biogeochemical Cycles* 31: 2–23.

Wang, J., Q. Liu, Y. Hou, W. Qin, J.P. Lesschen, F. Zhang, and O. Oenema. 2018. International Trade of Animal Feed: Its Relationships with Livestock Density and N and P Balances at Country Level. *Nutrient Cycling in Agroecosystems* 110: 197–211.

Yadav, S.N., W. Peterson, and K.W. Easter. 1997. Do Farmers Overuse Nitrogen Fertilizer to the Detriment of the Environment? *Environmental & Resource Economics* 93: 323–340.

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September 3, 2024
Clean Water Organizations Comments Exhibit 42

University of Minnesota Extension
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Reduce water quality issues from manure

Minnesotans know how precious clean surface and groundwater is to recreation and wildlife habitat in the state. Access to clean water is something that many take for granted, but protecting it from harm needs to be a top priority.

Pollution from towns and farms harm both surface and groundwater. Nitrogen, phosphorus, and pathogens are the most common water pollutants from manure on farms.

Nitrogen

Nitrogen – in the form of nitrate – is of most concern in groundwater since that is where 3 out of 4 Minnesotans get their drinking water.

- The nitrate threshold for safe drinking water is only 10 ppm. Above that level, infants may develop a condition that limits the supply of oxygen to the blood.
- Nitrates that leave Minnesota through the Mississippi River add to the Gulf of Mexico dead zone. Added nitrates cause an excess of ocean plants and algae to grow.
- When the plants and algae die, they are decomposed by bacteria that use up dissolved oxygen. This causes areas of low oxygen to form where ocean plants and animals cannot live.

Phosphorus

Phosphorus is a major concern because it causes excessive plant and algae growth in lakes and rivers. This causes an oxygen-depleting reaction similar to what happens in the Gulf of Mexico dead zone.

Fish kills and loss of habitat are caused by the decreased oxygen content. Certain types of algae growth caused by phosphorus (called harmful algal blooms) can harm the health of humans and animals that come in contact with them.

Pathogens

Pathogens such as harmful bacteria and viruses in manure become an issue when they enter waterways and groundwater.

E. coli, Cryptosporidium, and Giardia are just a few pathogens that can cause serious health problems in people and animals that come in contact with contaminated water.

Tips to reduce water quality impacts of manure:

Though farms are not the only source of water contamination, farmers still have the responsibility to do their part in protecting water quality. These recommendations can help farmers manage manure to reduce the amount of pollutants leaving their farm or field.

1. Manage runoff and leaching from stockpiled manure. Stacking solid manure on a concrete pad will reduce leaching of nutrients through the soil. Also, placing the stockpile in an open-sided shed, on a level surface, and above the seasonal high-water table will reduce runoff risk. A catch basin can also be placed nearby to hold any runoff before it reaches a waterway.
2. Manage runoff and leaching from open lots. Catch basins and grass buffer strips can be used to hold and filter runoff from open lots before it reaches a waterway.
3. Manage leaching from storage pits. Impermeable concrete, synthetic, or clay soil liners should be used in manure pits to keep nutrients from leaching downward. Pits should also be monitored closely and pumped before overflowing.
4. Use clean-water diversion system. Berms, ditches, and gutters can be used to divert upslope and rain water from areas with manure so that it does not carry nutrients and pathogens to waterways.
5. Use correct manure application techniques on fields. Apply nutrients only as needed in accordance with the University of Minnesota and Minnesota Pollution Control Agency's guidelines. Whenever possible, incorporate manure into the soil to reduce risk of surface runoff. Do not apply on saturated or frozen soils as this will increase runoff.

Chryseis Modderman, Extension educator

Reviewed in 2020

Please scan the above QR code to visit the live webpage for links.

https://extension.umn.edu/manure-management/reduce-water-quality-issues

REGION 5
CHICAGO, IL 60604

May 9, 2024

Lisa M. Scheirer, Supervisor
Watershed Division
Minnesota Pollution Control Agency
714 Lake Avenue
Detroit Lakes, MN 56501
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Re: U.S. Environmental Protection Agency Review of Pre-Public Notice Draft Feedlot NPDES General Permit (MNG440000)

Dear Ms. Scheirer:

The U.S. Environmental Protection Agency has reviewed the Pre-Public Notice Draft Feedlot NPDES General Permit (Permit), fact sheet, and supporting documents that were submitted to EPA on February 29 and March 1, 2024. Based on our review to date, EPA provides the following comments:[1]

1. EPA has direct implementation for the NPDES program in Indian Country. The Permit should contain language excluding concentrated animal feeding operations (CAFOs) located within Indian Country from coverage under the Permit.

2. The Permit needs to specify the required contents of the notice of intent for coverage under the Permit. 40 C.F.R. § 122.28(b)(2)(ii).

3. The Permit needs to specify the deadlines for submitting notices of intent for coverage under the Permit. 40 C.F.R. § 122.28(b)(2)(iii).

4. Permit Part 1.4 allows for suspension of the Permit in accordance with Minn. R. 7001.0170 through 7001.0190; however, the referenced state rules do not include suspension of permits. Federal regulations do not recognize suspension of permits; federal regulations recognize modification, revocation and reissuance, or termination of permits. The word "suspended" needs to be removed. 40 C.F.R. §§ 122.62 and 124.5.

[1] All cited federal regulations are made applicable to states by 33 U.S.C. §§ 1314(i) and 1342(c)(2) and 40 C.F.R. § 123.25.

5. Permit Part 2.5 contains requirements regarding the change of ownership or control of the facility. Minn. R. 7020.0405 only allows a change of ownership or control of an animal feeding operation or manure storage area through a permit modification. Therefore, Part 2.5 needs to be revised to conform with 40 C.F.R. § 122.63, by requiring that a permit modification request include a written agreement with a specific date for transfer of permit responsibility, coverage, and liability between the current and new permittees.

6. When manure is transferred, Permit Part 9.4 requires that the permittee provide to the manure recipient, at the time of transfer of ownership, a "Manure Transfer Tracking" form that is generated by the Nutrient Management Tool. This form does not include the date of manure transfer but should. 40 C.F.R. § 122.42(e)(3).

7. Permit Part 10.2 requires the CAFO to use Minnesota's Nutrient Management Tool to develop and maintain the Manure Management Plan (MMP). The Minnesota Nutrient Management Tool does not conform with the following requirements of 40 C.F.R. § 122.42(e)(1) nor does the Permit include specific conditions that conform with these federal requirements. Conditions addressing these federal requirements need to be included in the Permit or the Minnesota Nutrient Management Tool could be updated to include these federal requirements.

    a. The Permit does not specifically prohibit the disposal of mortalities in storm water storage systems. 40 C.F.R. § 122.42(e)(1)(ii).
    b. The Permit does not specifically require that clean water be diverted, as appropriate, from the production area., 40 C.F.R. § 122.42(e)(1)(iii).
    c. The Permit does not specifically prohibit the disposal of chemicals and other contaminants handled on-site into storm water storage systems. 40 C.F.R. § 122.42(e)(1)(iv).

8. Permit Part 15.1 contains land application setback requirements. Federal regulations require that manure, litter, and process wastewater not be applied closer than 100-foot to any down-gradient surface waters, open tile intake structures, sinkholes, agricultural well heads, or other conduits to surface waters unless a compliance alternative is exercised. Part 15.1 includes setbacks for several land features; however, Part 15.1 does not include a setback for the broader term "other conduits to surface waters" which would ensure setback requirements apply to all conduits to surface waters rather than just those identified in the Permit. 40 C.F.R. § 412.4(c)(5).

9. Permit Parts 16.2 and 16.3 require "that the production area is designed, constructed, operated, and maintained to contain all manure, manure-contaminated runoff, ***or*** process wastewater, and all direct precipitation" (Emphasis added). To conform with federal regulations, the word "or" needs to be removed from Parts 16.2 and 16.3. Federal regulations require that production areas are designed, constructed, operated and maintained to contain all manure, litter, ***and*** process wastewater (Emphasis added). 40 C.F.R. Part 412.

10. Permit Part 26.5 does not conform to the federal requirements because it does not identify an overflow as a discharge. In order to conform with federal regulations, Part 26.5 needs to be revised to read "... unless the ***discharge is an*** overflow of manure or process wastewater ***that*** is caused by a precipitation event ..." (Emphasis added). 40 C.F.R. Part 412.

11. Federal regulations require that each NPDES permit (1) include monitoring requirements to ensure compliance with permit limitations and (2) specify required monitoring including type, intervals, and frequency sufficient to yield data which are representative of the monitored activity. 40 C.F.R. §§ 122.44(i) and 122.48. Permit Part 27.5 requires the permittee to ensure that all discharges, spills, or overflows associated with the facility do not cause or contribute to non-attainment of water quality standards. The Permit needs to require monitoring of discharges, spills, or overflows to ensure compliance with Part 27.5. In order to assess compliance with the reference to water quality standards in Part 27.5, monitoring of discharges to surface waters from a production area for volume, duration, pH, phosphorus, NH_3-N, BOD, TSS, dissolved oxygen, and *E.coli* should be required.

12. The federal definition of "production area" includes bedding material in the raw materials description, while the definition of "Production Area" in Permit Part 30.47 does not include "bedding materials" in the raw materials description. Part 30.47 definition of "Production Area" needs to be revised to conform with the federal definition. 40 C.F.R. § 122.23(b)(8) and 40 C.F.R. § 412.2(h).

13. The Standard Conditions of 40 C.F.R. § 122.41 are not incorporated by reference into the Permit. The Permit does not contain the following standard conditions or words used to describe particular conditions do not adequately conform with the following federal standard conditions:

    a. Duty to Comply § 122.41(a);
    b. Permit Actions § 122.41(f);
    c. Duty to Provide Information § 122.41(h);
    d. Monitoring and Records § 122.41(j);
    e. Signatory Requirement § 122.41(k);
    f. Reporting Requirement - Permit Transfers § 122.41(l)(3);
    g. Reporting Requirement - Compliance Schedules § 122.41(l)(5);
    h. Reporting Requirement - Twenty-Four Hour Reporting § 122.41(l)(6);
    i. Reporting Requirement - Other Information § 122.41(l)(8);
    j. Reporting Requirement - Identification of the initial recipient for NPDES electronic reporting data § 122.41(l)(9);
    k. Bypass § 122.41(m); and
    l. Upset § 122.41(n).

In addition to the comments listed above, EPA recommends you consider and address the comments identified in Enclosure A in order to improve the overall Permit.

When the proposed permit is prepared, please forward one copy and Minnesota's response to any significant comments received during any public notice period to this office at r5NPDES@epa.gov. Please include the permit name and permit number in the subject line and cc kuss.michael@epa.gov. If you have any technical questions related to EPA's review, please contact Michael Kuss of my staff. He can be reached at 312-886-5482 or kuss.michael@epa.gov.

Thank you for your cooperation during the review process and your thoughtful consideration of our comments.

Sincerely,

STEPHEN JANN

Digitally signed by STEPHEN JANN
Date: 2024.05.09 13:00:18 -05'00'

Stephen M. Jann
Manager, Permits Branch
Water Division

Enclosure

cc: George Schwint, Principal Feedlot Engineer, MPCA

Please consider the following comments and recommendations to clarify and improve the draft permit:

1. It is recommended that the Permit include a requirement to identify, in the MMP, subsurface drain tiles on all fields where manure or process wastewater is land applied, and to require observation of subsurface drain tile outlets prior to, during and following land application of manure or process wastewater for volume/rate of flow and color, turbidity, foam, and odor to identify any discharges that may violate effluent limitations.

2. Permit Part 1.2 authorizes the Permittee to operate the facility in compliance with the requirements of Minn. R. 7020, and Minn R. 7020.2015 prohibits animals from entering waters of the State. The Permit could be improved by including a requirement that specifically prohibits the direct contact of confined animals with waters of the United States. 40 C.F.R. § 122.42(e)(1)(iii).

3. Federal regulations require that manure, litter, and process wastewater not be applied closer than 100-foot to any down-gradient surface waters, open tile intake structures, sinkholes, agricultural well heads, or other conduits to surface waters unless a compliance alternative is exercised. 40 C.F.R. § 412.4(c)(5)(ii) provides that a CAFO may demonstrate that an alternative conservation practice or field-specific conditions will provide pollutant reductions equivalent or better than the reductions achieved by a 100-foot setback. Permit Parts 15.4 through 15.7 include alternative conservation practices. Permit Part 10.2 requires that the manure management plan developed by a Permittee contain requirements of land application of manure sections of the Permit, this would include Parts 15.4 through 15.7. EPA recommends that the State require Permittees selecting to use one of the alternative conservation practices included in Parts 15.4 through 15.7 include a demonstration in the MMP that the alternative conservation practice implemented on a specific land application area will provide pollutant reductions equivalent or better than the reductions achieved by a 100-foot setback.

4. If a production area is designed, constructed, operated and maintained consistent with federal regulations, the need for emergency manure application should be rare, if at all. It seems a need should only arise, if at all, at the end of the design storage period of the collection of storage devices (i.e., just before crop harvest in the fall and just before the lifting of winter land application restrictions). Permit Part 30.20 defines Emergency Manure Application, and Permit Parts 13.2 and 13.6 authorize emergency land application. Weather is inherently variable. EPA recommends that the definition of emergency manure application provide further clarification on what constitutes “unusual weather conditions” and expand the definition to include opportunities to manage manure other than storage, i.e., treatment, before emergency manure application is allowed.

DEPARTMENT OF AGRICULTURE

Examination of Soil Water Nitrate-N Concentrations from Common Land Covers and Cropping Systems in Southeast Minnesota Karst

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Abstract

The purpose of this study was to identify the range of soil water nitrate-nitrogen (nitrate) concentrations measured at a four-foot depth from nine different land covers and cropping systems in southeast Minnesota. Results from the five-year study (2011-2015) found low concentrations of soil water nitrate, generally less than 2 mg/L, from prairie, forest and low maintenance homeowner lawn sites. Cattle pasture sites and a golf course averaged 5.1 and 3.7 mg/L, respectively. A grass field border and grassed waterway had similar concentrations and averaged between 5.9 mg/L (non-fertilized) and 8.9 mg/L (fertilized). Concentrations from the grass strips were higher than expected and likely explained by subsurface mixing of soil water between adjacent land covers. Nitrate concentrations collected from lysimeters in cultivated row crop settings were comparable to tile drained sites in Minnesota, but were highly variable and averaged 22.3 mg/L with a typical range of 8.0 to 28.0 mg/L. Corn fields with alfalfa in the rotation had nitrate concentrations averaging 6.6 mg/L which were 70% lower when compared to sites without perennials. When considered within the context of this study's limitations, data collected from the Southeast Lysimeter Network could serve as a useful educational tool for farmers, crop advisors, rural homeowners and groundwater advisory groups.

Background and Purpose

The geology of southeastern Minnesota's Driftless Area is comprised of carbonate bedrock (limestone and dolostone), sandstone and shale. Over millennia, naturally acidic rain and soil water has interacted with carbonate bedrock to form karst features including dissolutionally-enlarged fractures, subterranean conduits, sinkholes, and springs. Most of the bedrock formations in this area are covered by less than 50 feet of surficial deposits (Mossler, 1995) and in many areas, moderate to well-drained soils are less than ten feet thick (Dogwiler, 2013). This can result in direct hydrologic connections between the land surface and underlying bedrock and can facilitate the rapid movement of water and potential contaminants from the land surface into bedrock aquifers used for drinking water (Green et al, 2014; Runkel et al, 2014), and ultimately groundwater return flow to springs, streams and rivers. One of the most common nutrients found in southeast Minnesota groundwater is nitrate-nitrogen (NO_3^--N, from this point forward referred simply as nitrate). Nitrate is a common form of plant-available nitrogen that is water soluble and can primarily come from nitrogen fertilizer, manure, sewage, or the breakdown of soil organic matter. If not utilized by plants or retained in soil organic material, nitrate can move rapidly by water and leach through the soil and into groundwater.

The loss of nitrogen from agricultural lands has both local and regional impacts. Regionally, excess nitrogen lost from agricultural applications, primarily from the upper Midwest, are one of the main contributors to the hypoxic zone in the Gulf of Mexico (Alexander et al, 2008, Robertson et al, 2019). A 2013 report estimated that about 89% of the nitrogen measured in surface water in southeast Minnesota watersheds was derived from cropland, primarily through groundwater pathways (MPCA, 2013). More locally, results from private drinking water testing in Houston, Fillmore and Winona Counties have shown 15.3% to 19.1% of the sampled wells were at or above the drinking water health standard of 10 mg/L for nitrate (MDA, 2017).

Understanding the source of nitrate and how it moves into groundwater is a key step in helping manage the region's water resources. A common question raised during nitrate reduction planning discussions is how do nitrates compare between different crops or landcovers? The objective of this five-year study was to identify the range of nitrate concentrations present in soil water infiltrating from the unsaturated root zone across common land covers and cropping systems in southeast Minnesota. Land use in this region mainly consists of cultivated row crops so much of this investigation focused on agricultural land covers, but other non-agricultural land covers including prairies, forests, pastures and turf were also studied. Although this investigation does not attempt to fully quantify the magnitude of the nitrate flux or loading to aquifers, our results provide insight to the potential risk of loss to groundwater associated with various land covers. These data will help inform farmers, their advisors and other stakeholders as they work toward reducing nitrate in drinking water and surface water.

Information presented in this report were collected as part of an initiative known as the Southeast Minnesota Lysimeter Network (SLN). This undertaking represented a collaboration among several partners, including the Fillmore Soil and Water Conservation District (SWCD), Winona SWCD, Winona State University-Southeastern Minnesota Water Resources Center (SMWRC), Minnesota Pollution Control Agency (MPCA) and Minnesota Department of Agriculture (MDA). Funding for this work was provided in-part by Minnesota's Clean Water Fund from MPCA and through MDA's Root River Field to Stream Partnership (RRFSP).

Methods

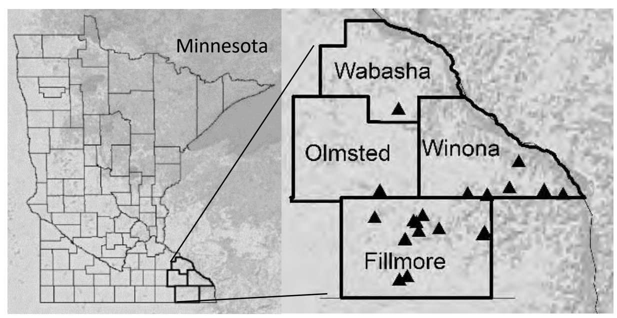

Figure 1. Lysimeter network locations across a four County area in southeast Minnesota.

The study took place across four counties and 23 sites in southeast Minnesota from 2011-2015 (Figure 1). Table 1 summarizes the 2015 land use across the four-county study area. On average, land managed for corn-soybean production, forest, and grass/pasture was over 80% while landcovers in alfalfa, turf and golf courses were less than 10%. Sampling sites were located on private property and cooperators were identified by staff from the Fillmore SWCD, Winona SWCD and MDA. The most common agricultural practices in southeast Minnesota were sampled, as well as several other common non-agricultural land cover types (Table 2). Land covers were grouped into three categories: non-agriculture, ag pasture/grass strips and ag row-crop. Crop and nitrogen management information were collected for each agricultural site and consisted of nitrogen application rates, timing, source and placement (Table 3). Nitrogen application rates included the actual amount of nitrogen from commercially applied fertilizers, first and second year manure credits and credits from alfalfa. Total nitrogen rates also included incidental nitrogen sources from starter, ammonium thiosulfate (AMS), diammonium phosphate (DAP) and monoammonium phosphate (MAP) fertilizers containing nitrogen. Tables 1 and 2 provide additional management details about each site. Soils at the monitoring locations consisted of well drained to moderately well drained silt-loam soil types. The typical range of organic matter in these soils is 2.7% to 3.9% with an average of 3.3%.

Table 1. Land use as a percentage of county area. (Source: 2015 Cropscape Cropland Data Layer-Center for Spatial Information and Science Systems)

County	Corn and Soybeans	Alfalfa	Forest	Grass/Pasture	Turf/Homeowner Lawns[1]	Golf Course[2]
	------------------------------% of county area------------------------------------					
Fillmore	45%	6%	22%	21%	3%	<0.1%
Olmsted	43%	4%	15%	23%	6%	0.1%
Winona	22%	6%	39%	21%	4%	0.1%
Wabasha	33%	5%	24%	23%	3%	<0.1%
Overall Avg.	36%	5%	25%	22%	4%	<0.1%

[1]Uses the developed open space classification in CropScape and likely overestimates the area managed for turf.
[2] Digitized from the MNGEO 2015 aerial photography.

Equipment

Soil water samples were collected using 50 porous cup tensiometers (Figure 2), more commonly called suction cup lysimeters. Lysimeters consisted of a 24-inch long piece of PVC pipe, sampling and suction lines and porous ceramic tip. The basic construction involved attaching and sealing a ceramic tip to one end of a 1.5 inch diameter PVC pipe with epoxy and attaching a rubber stopper to the other end. The rubber stoppers were secured with electrical tape and special adhesive to ensure complete sealing. Two, 0.25 inch diameter plastic tubes were passed through the rubber stopper to ensure an air tight seal. One tube was used as the sample line. It extended to the bottom of the porous ceramic tip and was used for sampling water from the lysimeter. The other line, the suction line, was used to create a vacuum within the lysimeter.

At cultivated row crop sites, lysimeters were installed to a depth of four feet within the vadose zone and placed a minimum of 40 feet into the field. This distance was used to minimize edge of field variability caused by compaction, non-uniform fertilizer applications, and help avoid other factors that can be common in the headland areas of row-crop fields. At most locations, at least two lysimeters were paired together at each site to better understand variability. Having two lysimeters also provided redundancy in the event one lysimeter failed. Typically, paired lysimeters were installed 20 feet apart. To prevent damage from tillage equipment, a trenching machine was used to create a 2.5 foot deep trench to route the sample and suction lines from lysimeters to the field edge. The sample and suction line tubing was routed through PVC conduit to protect it from being crushed by the soil during reburial and terminated in a single sampling port. At the desired lysimeter location within the field, an additional 1.5 foot deep hole was excavated within the bottom of the trench using a four-inch diameter soil auger. To minimize soil disturbance directly above the lysimeters, the hole was hand augered at an approximate 20-degree angle from the bottom and long axis of the machined trench. This ensured that the sampling tip was beneath undisturbed soil and not directly under the

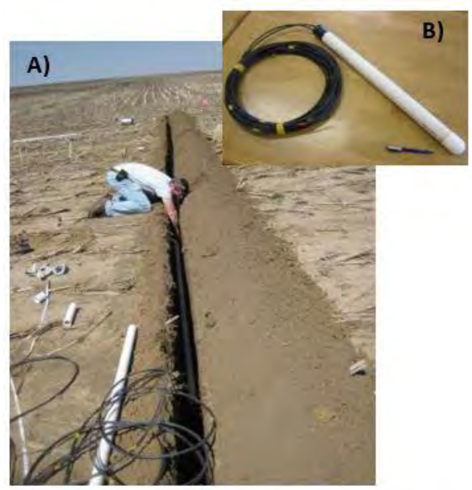

Figure 2. A) Installation of lysimeter sample and vacuum lines in a field managed for continuous corn silage and dairy manure. Sample lines were trenched 2.5 feet below the surface while lysimeters were placed four feet below the soil surface. **B)** Porous tension ceramic cup lysimeter with vacuum and sampling lines. Pen in lower right corner of photograph used for scale and is pointing at the ceramic tip.

excavated trench. A distilled water and silica slurry mixture was placed in the augered hole around the ceramic tip to ensure adequate hydraulic contact and movement of water to the lysimeter. Bentonite clay was packed above the ceramic tip during backfill to prevent drainage along the side of the lysimeter. At the golf course and homeowner lawn sites, lysimeters were installed using a hand auger to a depth of about two feet. At two row-crop sites, the full four-foot depth was not achieved because of refusal due to shallow bedrock. In all cases the lysimeters were installed a minimum of 4 to 6 inches above the bedrock at least two feet below the surface. At all sites the depth of the lysimeter sampling tip was below the rooting depth of the associated land cover vegetation. Lysimeters were permanently installed at each location and not removed during the study period. Lysimeter construction, installation and training was provided by MDA and SMWRC with assistance from Fillmore SWCD and MPCA.

Sampling and Analysis

A 30-40 centibar vacuum was applied to the lysimeters between sampling periods. Sampling intervals were consistent throughout the study period and were collected every two weeks during the frost-free period, typically from April through October (Figure 3). In some years it was possible to start sampling in March and extend sampling through November due to above normal temperatures. Samples were collected using a hand operated vacuum pump and one-liter Erlenmeyer flask. In most cases 300-600 mL of water was available for sampling of which 100 mL was used for nitrate analysis. Samples were placed on ice in a cooler and kept refrigerated until analysis. Water samples were analyzed using a Hach® DR6000 UV spectrophotometer (pour-through method 357-10049, DOC 316.53.01072) located in the MDA Preston field office within a week of sample collection. The detection limit using this method is 0.1 mg/L. Samples were analyzed using standardized quality assurance and control (QA/QC) procedures. As part of the QA/QC, a duplicate of no less than 10% of the water samples were selected randomly and analyzed by the Minnesota Department of Agriculture (MDA Lab) certified laboratory located in St. Paul. It should be noted that the MDA lab method includes both nitrite and nitrate (NO_2-N + NO_3-N) while the DR6000 method does not report nitrite(NO_2-N). Nitrite is seldom present in groundwater and if detected is typically less than 0.3 mg/L, transforms quickly to the more stable nitrate form (USEPA, 1987), and therefore is not considered to be a significant factor when comparing the two methods. Additional details regarding the duplicate sample results are included in Appendix C of this report. Statistical group tests were used to identify significant differences between the various land covers. If p values were less than or equal to 0.05 when using non-parametric tests on the nitrate median, the groups were considered statistically different. The Mann-Whitney test was used when comparing individual pairs while the Kruskal-Wallis multiple comparison test was used across all land covers. Statistical analysis was conducted using R and Minitab® statistical software.

Figure 3. *Soil water nitrate collection from a continuous corn grain site (OM70/90). The sampling port was located in a grassed waterway.*

Table 2. Land cover and farming practices evaluated during the five-year soil water nitrate study.

Land Cover	Land Cover Grouping	Lysimeter ID	Location (# of lysimeters)	Description
Prairie	Non-Agriculture	CW/CY QW/QY	Fillmore (2) Winona (2)	CW/CY field had previously been in row crops and was enrolled in the conservation reserve program (CRP) for five years prior to sampling. QW/QY field was managed since the 1980's as a long-term bluff-top prairie with no contributing area from other land covers or uses. Vegetation at both sites consisted of well-established warm season grasses and forbs.
Forest	Non-Agriculture	JW/JY	Winona (2)	Mature deciduous hardwood hillslope with a moderate level of understory vegetation. Site JW was uphill while JY was downhill, about 20 feet apart.
Lawn	Non-Agriculture	LW/LY KW/KY	Winona (4)	LW/LY did not receive fertilizer while KW/KY received a one-time application during the first year. Both residential lawn sites consisted of Kentucky bluegrass.
Golf Course	Non-Agriculture	MW/MY	Wabasha (2)	Samples collected from the fairway (MW-rough) and an adjacent tee box (MY). The fairway site received low maintenance fertilizers while the tee box received an annual rate of 120 lb N/ac divided between three different applications.
Pasture	Pasture and Grass	GW/GY RW/RY PW/PY	Winona (2) Fillmore (4)	Pastures with cow/calf beef herds that consisted of both rotationally grazed and non-rotational management with low to moderate stocking density. Site GW/GY received 50-60 lb N/ac of urea and AMS broadcast applied every spring. RW/RY was a rotationally grazed dairy pasture site. About 15 cows were pastured in a 30'x30' pen and rotated out once a month with 1-2 weeks of recovery between rotations. Heavy grazing resulted in excessive manure coverage. PW/PY received spring broadcast liquid dairy manure which contained about 30 lb N/ac. Due to lysimeter failure, this site was not sampled in 2013 and 2014.
Grass Strip (non-fertilized)	Pasture and Grass	CFE20	Fillmore (1)	This site was managed as a grassed field border. Kentucky blue and brome grasses were mowed periodically. The field border was 60 feet wide and no nitrogen fertilizers were applied. Surrounding fields consisted of corn and soybeans and had slopes between 4-6%. The lysimeter was placed in the middle of the strip near the toe slope.
Grass Strip (Fertilized)	Pasture and Grass	OMAgw OMCgw	Fillmore (2)	This site was a fertilized grassed waterway in a field managed for continuous corn grain. The grassed waterway was about 15 feet wide and was mowed occasionally and consisted of brome and timothy. The grassed waterway received the same amount of commercial nitrogen fertilizer as the corn field. The continuous corn field received 150 to 240 lb N/ac.
Alfalfa with Corn	Row Crops	A70/90, CFE60/80, F70/90, NW/NY	Fillmore (8)	All fields had a minimum of three out of the five years with alfalfa and at least one year of corn. A70/90 was an organic field that received nitrogen from organic fertilizer (fish), manure and alfalfa credits. CFE 60/80 was managed for soybeans in 2011 and corn in 2012 and then rotated to alfalfa from 2013-2015. Field F70/90 was managed for alfalfa from 2011-2014 and then rotated to corn in 2015. About 40 lb N/ac was applied annually to this alfalfa field. During the corn year it received a total of 185 lb N/ac (125 lb N/ac from commercial fertilizer at preplant, sidedress and 60 lb N/ac alfalfa credit). NW/NY was managed for alfalfa the first four years and the last year was corn. The alfalfa received periodic liquid dairy manure applications.
Corn and Soybean Rotations & Continuous Corn	Row Crops	B70/90, E70/90, H70/90,CFW40/60/80, D70/90, I70/90 (OMA7090,OMB7090, OMC7090,OMD7090B)	Fillmore (19) Olmsted (2)	All sites contained a mix of row crop fields managed for corn-soybean rotations or continuous corn. Three sites received manure while other sites received only commercial fertilizer. All sites also applied a wide range of application rates (140 lb/ac to 240 lb/ac). At one continuous corn site (OMABCD), four different rates of manure and commercial fertilizer were applied (140, 160, 190, 220 lb N/ac) during a two-year period to evaluate the relationship between nitrogen credits from dairy beef bedding pack manure and soil water nitrate. Site B70/90 was a no-till site and transitioned from CRP to row cropping in 2009. Typical N rates were 150 lb/ac for C/S and 180 lb/ac for C/C. D70/90 was continuous corn from 2011-2013 with an average 200 lb N/ac from liquid dairy manure. E70/90 was mainly managed for corn silage and soybeans. Fall seeded cover crops were established in the fall to extend cattle grazing in the spring. About 160 lb N/ac was applied for C/S and 190 lb N/ac for C/C. Lysimeters were placed below a terrace and could have been affected by upgradient lateral flow. H70/90 was managed for continuous corn and total nitrogen rates ranged from 180 to 200 lb N/ac with split nitrogen applications.

Table 3. Land cover and nitrogen management details by site and year. Total nitrogen rates in pounds per acre (lb/ac) from manure or commercial fertilizers is displayed in parenthesis. Total nitrogen includes first and second year manure nitrogen credits and credits associated with alfalfa and other incidental nitrogen sources from starter, AMS, DAP and MAP fertilizers.

Site ID	Land Cover	Land Cover Grouping	2011	2012	2013	2014	2015
CW/CY	Prairie	Non ag	CRP/Prairie (0)	CRP/Prairie (0)	CRP/Prairie (0)	CRP/Prairie (0)	CRP/Prairie (0)
QW/QY	Prairie	Non ag	Prairie (0)	Prairie (0)	Prairie (0)	Prairie (0)	Prairie (0)
JW/JY	Forest	Non ag	Forest (0)	Forest (0)	Forest (0)	Forest (0)	Forest (0)
LW/LY	Lawn	Non ag	Lawn (0)	Lawn (0)	Lawn (0)	Lawn (0)	Lawn (0)
KW/KY	Lawn	Non ag	Lawn-fertilized (160)	Lawn (0)	Lawn (0)	Lawn (0)	Lawn (0)
MW/MY	Golf Course	Non ag	Golf Course (140)	Golf Course (140)	Golf Course (140)	Golf Course (140)	Golf Course (140)
GW/GY	Pasture	Pasture and grass	Pasture, spring bdcst. No-inc. (50)	Pasture, spring bdcst. No-inc. Urea/AMS (56)	Pasture, spring bdcst. No-inc. Urea/AMS (56)	Pasture, spring bdcst. No-inc. Urea/AMS (56)	Pasture, spring bdcst. No-inc. Urea/AMS (56)
RW/RY[1]	Pasture	Pasture	Pasture (manure N, qty unknown)	Pasture (manure N, qty unknown)	Pasture (manure N, qty unknown)	Pasture (manure N, qty unknown)	Pasture (manure N, qty unknown)
PW/PY	Pasture	Pasture and grass	Pasture[1] (manure N, qty unknown)	Pasture, summer bdcst. No-inc. liquid dairy manure (13)	Pasture, summer bdcst. No-inc. liquid dairy manure (33)	Pasture, summer bdcst. No-inc. liquid dairy manure (33)	Pasture, summer bdcst. No-inc. liquid dairy manure (33)
CFE20	Grass strip NF	Pasture and grass	Grass field border (0)	Grass field border (0)	Grass field border (0)	Grass field border (0)	Grass field border (0)
OMACgw	Grass strip F	Pasture and grass	Grassed waterway (186)	Grassed waterway (180)	Grassed waterway (200)	Grassed waterway (200)	Grassed waterway (240)
A70/90	Alfalfa with corn	Row crop (organic)	Corn, spring knife inj. Swine, bank liq. Fish, legume crdt. (285)	Oats/alfalfa, foliar liq. Fish, 2nd yr manure and legume crdts (101)	Alfalfa, foliar liq fish (20)	Corn, spring bdcst, noinc. Bedding pack beef manure, band liq. Fish, 1st yr legume crdt. (140)	Oats/alfalfa, foliar liq. Fish, 2nd yr manure credit (21)
CFE60/80	Alfalfa with corn	Row crop	Soybean	Corn, fall liquid hog inject (180)	Oats/alfalfa	Alfalfa	Alfalfa
F70/90	Alfalfa with corn	Row crop	alfalfa, summer bdcst, no inc. DAP (9)	alfalfa, summer bdcst, no inc. DAP (36)	Alfalfa, summer bdcst, no inc. DAP (36)	Alfalfa, summer bdcst, no inc. DAP (36)	Corn, fall P&K strip till, side dres incorp. UAN, legume credits (185)
NW/NY[1]	Alfalfa with corn	Row crop	Alfalfa	Alfalfa	Alfalfa	Alfalfa	Corn
B70/90	C-S	Row crop	Corn, spring 4x4 band UAN Rawson cart, no till (179, split)	Soybeans, spring bdcst AMS and 9-23-30, no till (11)	Corn, spring 4x4 band UAN Rawson cart, no-till (150,split)	Soybeans, spring bdcst AMS, 9-23-30 (11), no till	Soybeans, spring bdcst AMS, no-till (2)
BCE40 /60/80	C-C	Row crop	Corn, spring commercial bdcst/incorp. urea (178)	Corn, spring commercial bdcst/incorp. urea (180)	Corn silage, spring urea, bdcst/incorp. (189)	Corn silage, fall, liquid dairy inject (151)	Corn silage, fall liquid inject (168)

Site ID	Land Cover	Land Cover Grouping	2011	2012	2013	2014	2015
CFW40/ 60/80	C-C	Row crop	Corn silage, fall liquid dairy inject (182)	Corn silage, Fall liquid dairy inject (180)	Corn silage with rye cover. Spring Urea, bdcst/incorp (207)	Corn silage, fall liquid dairy inject (199)	Corn silage, Fall liquid dairy inject (190)
D70/90	C-C	Row crop	Corn (prev. CRP), spring liq. dairy bdcst-inc., pp bdcst Urea/AMS, starter (198)	Corn, spring pp, bdcst-inc., Urea/AMS, starter, 2nd yr manure credits (204)	Corn, spring pp, bdcst-inc., Urea/ams, starter (191)	Oats/alfalfa, spring pp bdcst-inc. AMS (21)	Alfalfa (21)
E70/90	C-S w/ Rye	Row crop	Corn silage w/ rye grazed, spring pp bdcst inc. UAN/DAP, starter (188)	Corn silage w/rye grazed, spring pp bdcst, inc. UAN/DAP/starter (188)	Soybeans, spring cattle grazed off cover crop (0)	Corn w/rye grazed off in spring, spring starter, post UAN bdcst, no incorp. (156)	Soybeans, spring cattle grazed off cover crop (0)
H70/90	C-C	Row crop	Corn, fall strip till, DAP/AMS, spring Urea/ESN bdcst, inc., starter, sidedress (UAN) (183)	Corn, fall strip till, DAP/AMS, spring Urea/ESN bdcst, inc., starter, sidedress (UAN) (183)	Corn, fall strip till, DAP/AMS, spring Urea/ESN bdcst, inc., starter, sidedress (UAN) (183)	Corn, fall strip till, DAP/AMS, spring Urea/ESN bdcst, inc., starter, sidedress (UAN) (204)	Corn, fall strip till, DAP/AMS, spring Urea/ESN bdcst, inc., starter, sidedress (UAN) (204)
I70/90[1]	C-C	Row crop	Corn	Corn	Corn	Soybeans	CRP
OM70/90	C-C	Row crop	Corn, bdcst-inc. within 12 hours, fall applied beef bedding pack and UREA. Replicated test strips (175)	Corn, bdcst-inc. within 12 hours, 2nd year beef bedding pack credits and UREA. Replicated test strips (175)	Corn bdcst-inc. Urea/AMS, sidedress UAN w/coulter (240)	Corn bdcst-inc. Urea/AMS, sidedress UAN w/coulter (240)	Corn bdcst-inc. Urea/AMS, sidedress UAN w/coulter (240)

[1] Some or all nitrogen fertilizer records were not available

Abbreviation key: C-C = corn following corn rotation, C-S = Corn following soybean rotation, bdcst-inc. = broadcast-incorporate, DAP = diammonium phosphate, MAP = monoammonium phosphate, AMS = ammonium sulfate, UAN = urea ammonium nitrate, ESN = environmentally stable nitrogen, pp = preplant

Study Considerations and Limitations

Lysimeters are one of the most basic and economical ways to collect soil water samples for nitrate monitoring. See Appendix A for additional discussion: *Considerations when Interpreting Soil Water Nitrate Concentrations from Lysimeters.* This study's interpretations were constrained by several factors. The main objective was to assess the relative range of nitrate concentrations across a wide range of land covers. As such, there was limited ability to replicate some of the land cover categories at multiple sites. About two-thirds of the land cover categories had less than three replications. In the case of the golf course or homeowner lawns, only one or two sites were monitored and there were no turf sites with high nitrogen fertilizer inputs. As a percentage of the county land use, however, turf represents less than 5% of the county area and golf courses less than 0.1% (Table 2). Due to time and labor constraints and the practicality of retrieving samples, usually fewer than three lysimeters were installed within the row crop field sites. Other studies have preferred to use sub-surface pattern tile research plots to better control for other variables. (Randall and Goss, 2008 and Brouder et al, 2005). Monitoring nitrate concentrations and loss from tile drainage systems are preferred since drainage water measured at the tile outlet represents an integrated average across the entire field rather than a few point locations. However, this study was motivated to specifically assess nitrate concentration ranges associated with non-tile drained karst landscapes. The relatively steep topography and moderate to well-drained silt loam soils that are characteristic of the Driftless Area of southeastern Minnesota are generally not suitable for intensive, patterned subsurface tile drainage systems and, as such, the practice is not common within the region.

This experimental design attempted to address the cautions (described in Appendix A) that must be taken when interpreting results collected from lysimeters. Primarily, the inclusion of at least a pair of lysimeters located a minimum of 20 feet apart at each field site provides an opportunity to compare the results for each sampling event and assess if the nitrate concentrations of the paired samples were consistent, and therefore likely representative of the larger site.

Precipitation During the Study Period

Precipitation can influence the range of nitrate concentrations measured in soil water. Small soil water sample volumes collected during dry conditions tend to have higher concentrations while during very wet conditions nitrates can be reduced due to dilution. Additionally, nitrate can be 'stored' in the soil profile during unusually dry periods and then be flushed out during subsequent wet periods (Kaushal et al, 2010). This has been well documented in several studies in southeast Minnesota, northeast Iowa and Midwest streams (Schilling et al, 2019, Van Metre et al, 2016, Barry et al, 2020).

Annual precipitation totals were summarized from the National Weather Service station at Preston during the study period (Table 4). The weather station at the City of Preston was selected because it is centrally located within the study area and has a long-term precipitation record. The 30-year (1981-2010) normal or average for Preston was 35.6 inches per year. Annual precipitation totals ranged from a low 28.1 inches in 2012 to a high of 47.6 inches in 2013 with a five-year average of 34.9 inches. When compared to the percent departure from normal, values ranged from 21% below normal to 34% above normal in 2012 and 2013, respectively. When the departure from normal was within 10%, precipitation was considered near normal. If precipitation was below normal by more than 10% it was considered dry and when 10% above normal it was considered wet. Years 2011 and 2012 were both dry while years 2014 and 2015 were near normal. Figure 4 shows that 2013 was very wet with most precipitation occurring from April through June and October.

Table 4. Annual precipitation totals, departure from normal and classification during the study period. The 30-year (1981-2010) normal or average for Preston is 35.6 inches.

Year	2011	2012	2013	2014	2015
Total Annual Precip. (in.)	28.6	28.1	47.6	36.3	34.0
Departure from normal (%)	-20%	-21%	+34%	+2%	-4%
Classification	Dry	Dry	Wet	Near Normal	Near Normal

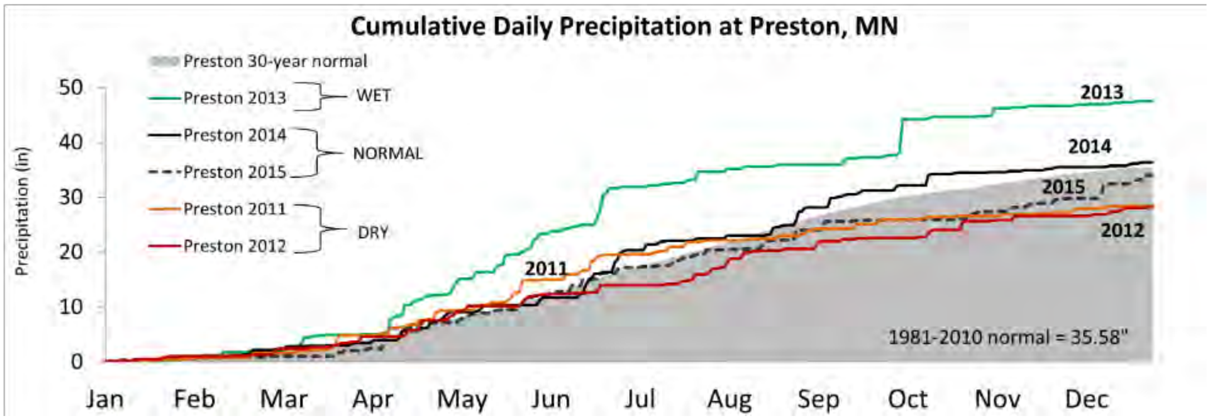

Figure 4. Cumulative daily precipitation at Preston during the study period (2011-2015). The study period contained a mixture of wet, dry and normal conditions.

Interpreting Nitrate Concentrations from Row-Crop Fields

General guidelines for interpreting nitrate concentrations measured in sub-surface tile drainage water were summarized in a 2005 report from Purdue University Extension (Brouder et al, 2005). A modified table from this report is provided as Table 5 and includes data from the Midwest corn-belt. Although soil water samples collected during this study may not be a direct comparison to tile drainage water, Table 5 is a useful reference for helping interpret soil water nitrate concentrations. Brouder et al. (2005) indicates that concentrations between 10 to 20 mg/L would be typical for Midwestern corn belt row crop systems with nitrogen applied at economically optimum nitrogen rates. It should be noted these concentrations can vary considerably by site and weather conditions.

Table 5. General guidelines for interpreting nitrate-N concentrations in tile drainage water. The interpretation is derived from numerous studies conducted throughout the Midwest corn belt and highlights land management strategies commonly found in association with a concentration measured in tile water leaving the field (modified from Brouder et al, 2005).

Tile Drainage Nitrate Concentration (mg/L)	Interpretation
≤ 5	Native grassland, Conservation Reserve Program (CRP) land, alfalfa, managed pastures.
5-10	Row crop production on a mineral soil without N fertilizer. Row crop production with N applied at 45 lb/acre below the economically optimum N rate row crop production with successful winter crop to “trap” N.
10-20	Row crop production with N applied at optimum N rate
≥ 20	Row crop production where: **a)** N applied exceeds crop need **b)** N applied is not synchronized with crop needs **c)** environmental conditions limit crop production and N fertilizer use efficiency **d)** environmental conditions favor greater than normal mineralization of soil organic matter.

Lysimeter Comparison Values

Northcentral Lysimeters

For the past several decades the MDA's Fertilizer Field unit has initiated groundwater protection demonstration projects using lysimeters. These sites have been used to help foster partnerships among farmers, their crop advisors, citizens and local, state and university staff. Some of the longest running demonstration sites are located on coarse textured irrigated soils in northcentral Minnesota (Figure 5).

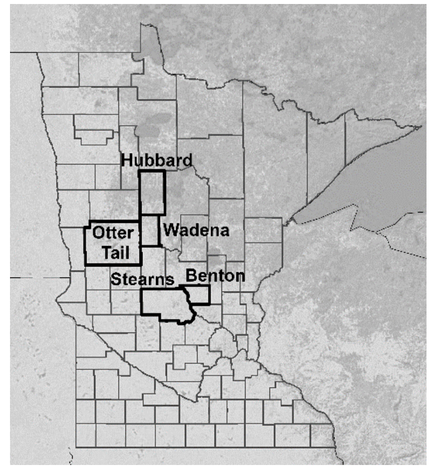

Figure 5. MDA northcentral water quality demonstrations sites. Project counties outlined in black.

Soil water nitrate collected from a wide range of cropping systems and weather conditions provide a useful comparison with the SLN. It should be noted that all the northcentral sites contain coarse textured sandy loam or loamy sand soil textures and many sites were irrigated. Table 6 provides the summary statistics and reflect sampling conducted between years 2000-2019.

Table 6. Soil water nitrate-N summary statistics across various cropping systems in northcentral Minnesota. Data reflect years from 2000-2019.

Crops grown	Number of Samples	Mean	St Dev	Min.	Q1	Median	Q3	Max.
		-------------------------Soil water nitrate-N (mg/L)------------------------------						
corn-soybeans	4,755	30.4	17.9	<0.1	16.3	28.0	41.1	120.0
corn, soybeans, edible beans, potato, alfalfa	5,787	35.1	29.2	<0.1	15.0	29.0	46.0	240.0

Table 7 displays the summary statistics of soil water nitrate measured from turf sites located in Otter Tail and Stearns county. Data collected from the Otter Tail county site reflect years 2000-2004 and the Stearns site reflect years 2014-2019. Lysimeter depth was about 16 to 20 inches at these sites. The Stearns site is a long-term study to evaluate the relationship between soil water nitrate and lawn nitrogen fertilizer application rates. Replicated and randomized treatments included a zero-rate check, a low rate of 3 lb N/1,000 ft^2, a medium rate of 6 lb N/1,000 ft^2 and a high rate of 9 lb N/1,000 ft^2. These data provide a very useful reference for nitrate concentrations measured from fertilized and non-fertilized turf sites in Minnesota.

Table 7. Soil water nitrate-N summary statistics from the two turf sites in northcentral Minnesota. Data reflects years from 2000-2019.

Cover Type	Number of Samples	Mean	St Dev	Min.	Q1	Median	Q3	Max.
		-------------------------Soil water nitrate-N (mg/L)------------------------------						
Turf/Lawn	1,946	2.3	4.1	<0.1	0.7	1.1	2.1	50.0

Lysimeter Comparison Values

MDA and Discovery Farms Minnesota On-Farm Drainage Tile Monitoring

Another source of information that can be used for comparison with the SLN is from a network of on-farm sub-surface tile drainage monitoring sites associated with the MDA and Discovery Farms Minnesota. Table 8 summarizes the annual flow weighted mean concentrations (FWMC) and yield (lb/ac) from 2011-2015. Samples were collected across nine counties (Figure 6) using automated equal flow increment composite sampling methods. Crops grown included corn, soybean and corn with alfalfa rotations. It also included sites that received dairy and hog manure and sites with only commercial fertilizer. The FWMC across all sites was 21.4 mg/L with a typical range (i.e. interquartile range) of 15.6 mg/L to 25.6 mg/L. The average nitrate loss was 17.0 lb/ac with an interquartile range of 5.5 lb/ac to 31.1 lb/ac.

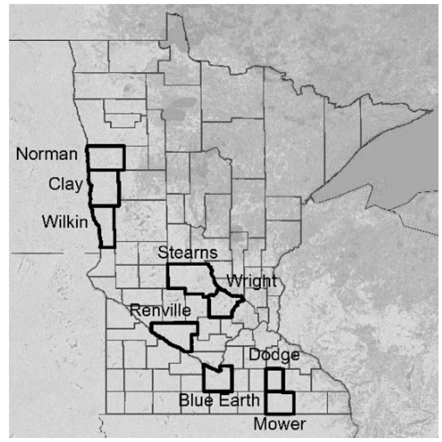

Figure 6. On-farm drainage tile monitoring locations associated with the MDA and Discovery Farms Minnesota. Project counties are outlined in black.

Table 8. Annual FWMC's and loss from sub-surface tile drainage across in nine counties from 2011-2015. Data from Discovery Farms Minnesota and Minnesota Department of Agriculture.

Number of Site Years	Mean	St Dev	Minimum	Q1	Median	Q3	Maximum
	-------------------------------------FMWC (mg/L)-------------------------------------						
34	21.4	8.9	3.7	15.6	19.8	25.6	50.3
	-------------------------------------Loss (lb/ac)-------------------------------------						
35	17.0	15.2	0.0	5.5	10.5	31.1	55.1

Results and Discussion

Soil water nitrate concentrations measured across nine different types of land covers in the SLN are summarized in Figure 7 and Table 9. Nearly 3,000 individual nitrate tests were analyzed from 50 different lysimeters across 23 different sites during the five-year study. In Figure 7, land cover types were grouped into three different categories and the averages were sorted from lowest to highest N concentration within each category. The box plot represents the middle 50% of the data or the interquartile range. Although soil water sampled from lysimeters is not used directly for drinking water, the Environmental Protection Agency (EPA) maximum contaminant level of 10 mg/L for drinking water is provided for reference and shown as a dashed horizontal line. The length of each box indicates variability. Figure 7 clearly shows that the non-agriculture sites have much less variability and lower soil water nitrate while the agricultural sites have both higher nitrate and higher variably. Results from the group statistical tests are also provided in Figure 7 and last row of Table 9. Time-series charts showing the average monthly nitrate concentrations by individual site can be found in Appendix B. Table 10 provides the statistical analysis results between the various paired land cover types. When significant, the value in parenthesis below the *p* value represents the median point difference in mg/L between the respective pairs. For instance, when comparing the prairie versus forest land covers there were no significant differences (*p* value = 0.718). However, when comparing the prairie to the golf course, the golf course had significantly higher concentrations ($p < 0.01$) and this difference was estimated to be 2.4 mg/L.

Non-Agriculture

The lowest nitrate concentrations were found in the 'non-agriculture' group which included grassland prairie (CRP), deciduous forest, low maintenance homeowner lawns and a golf course. Soil water nitrate concentrations within this category averaged between 0.1 mg/L to 3.7 mg/L with a typical range (i.e. interquartile range) of <0.1 to 5.3 mg/L. Standard deviations for the prairie and forest were very small and ranged from 0.3 mg/L to 0.9 mg/L. For comparison, Randall et al, (1997) found flow weighted average nitrate concentrations of 2 mg/L from a drainage tile research plot managed for CRP in southcentral Minnesota. The highest concentration observed at one of the lysimeter network prairie sites was 3.1 mg/L. This high reading is likely related to a millipede infestation within one of the lysimeter sampling ports. This particular species, a yellow-spotted millipede (Apheloria tigana), produces cyanide to fend off potential predators. Under aerobic conditions, the biodegradation of cyanide compounds produces ammonia which is then converted to nitrite and nitrate in the presence of nitrifying bacteria (Richards and Shieh, 1989).

For the lawn and golf course sites the average concentrations ranged from 1.1 to 3.3 mg/L. For comparison, average soil water nitrate concentrations from the northcentral Minnesota turf sites were similar and averaged 2.3 mg/L (Table 7) . A maximum concentration of 26 mg/L was observed at the homeowner lawn site in 2011. This was the result of a one-time over-application of nitrogen to the lawn by the homeowner. The golf course represented samples collected from the fairway and tee box. The fairway received minimal nitrogen fertilizer applications while the tee box received scheduled applications throughout the growing season. Fertilizer application records were not available, but conversations with the course manager indicated that low rates (less than 1.0 lb/1000ft^2 or ~40 lb/ac) were applied typically three times a year on the tee and only one time on the fairway. A 2015 and 2016 study sampled nitrate from shallow monitoring wells across six golf courses in Iowa (Schilling et al, 2018). The average nitrogen rate applied to the tee box, fairway and rough was estimated at less than 40 lb N/ac. Results from that study found that nitrate was not detected above 1.0 mg/L at half of the six courses and the overall mean concentration was 2.2 mg/l. Schilling et al. (2018) also approximated the mass of nitrate recharge to groundwater. This was estimated to be less than 10% of the commercial fertilizer nitrogen that was applied.

Statistically, the prairie and forest sites had the same concentrations. The homeowner lawn sites had higher concentrations when compared to the prairie and forest while the golf course had the highest average concentrations of 3.7 mg/L. When comparing the golf course site to the row crop sites, the row crop sites had significantly higher concentrations ($p = <0.01$) and this median point difference was estimated to be 14.0 mg/L.

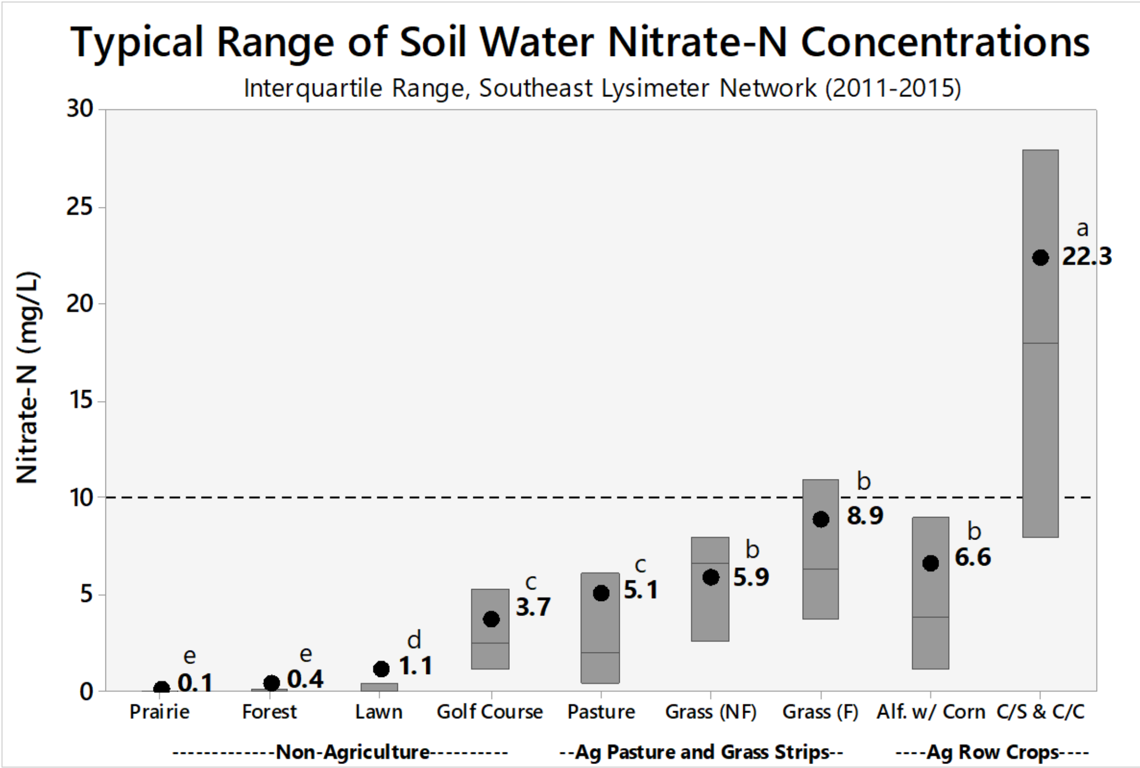

Figure 7. Typical range of soil water nitrate concentrations measured across nine different types of land covers in southeast Minnesota from 2011-2015. This chart represents nearly 3,000 individual samples collected from suction-cup lysimeters, typically from a depth of four feet. The boxes represent the interquartile range or middle 50% of the data. Average values as black dots are displayed next to each box while the median is represented by the horizontal line. Sites that do not share the same letter (displayed above the average value) are significantly different at the 0.05 level when using a Kruskal-Wallis multiple comparison test on the median. Although soil water is not used directly for drinking water, the dashed horizontal line is included as a reference and represents the 10 mg/L drinking water standard. For the grass strip sites, NF is non-fertilized, and F is fertilized. For the Ag row crops, alfalfa with corn had at least three years of alfalfa in the rotation and one year of corn during the sampling period. C/S were fields managed for corn-soybean rotations while C/C were sites managed for corn following corn or continuous corn. These two rotations were grouped together.

Table 9. Soil water nitrate-N summary statistics by land cover type from 2011-2015.

	--------Non-Agriculture-------				-Ag Pasture and Grass Strips -			--Ag Row Crops--	
Variable	Prairie	Forest	Lawn	Golf Course	Pasture	Grass Strip (NF)	Grass Strip (F)	Alf. w/ Corn	C-S and C-C
					---Nitrate-N mg/L---				
Mean	0.1	0.4	1.1	3.7	5.1	5.9	8.9	6.6	22.3
Std. dev.	0.3	0.9	3.6	3.2	8.2	3.3	9.6	8.2	21.8
Minimum	<0.1	<0.1	<0.1	0.1	<0.1	1.0	0.1	<0.1	0.1
Q1	0.1	<0.1	0.1	1.2	0.5	2.6	3.8	1.2	8.0
Median	0.1	0.1	0.1	2.6	2.0	6.7	6.3	3.9	18.0
Q3	0.1	0.2	0.5	5.3	6.2	8.0	11.0	9.0	28.0
Maximum	3.1	4.5	26.0	16.0	46.0	13.0	64.0	64.0	170.0
# of sites	2	1	2	1	3	1	1	4	8
# of lys.	4	2	4	2	6	1	2	8	21
# samples	150	96	235	104	198	60	106	546	1,478
Significance*	e	e	e	c	c	b	b	b	a

*(NF) = non-fertilized, (F) = fertilized, C-S = corn following soybeans and C-C = corn following corn *Sites that do not share the same letter were considered significantly different at the 0.05 level when using a Kruskal-Wallis multiple comparison test between medians.*

Table 10. Statistical analysis results between paired land cover types. The top value represents the *p* value. Cells shaded gray were considered statistically different at the 0.05 level when using the Mann-Whitney paired test between medians. Shaded cells with an asterisk are significant at the <0.01 level. When significant, the median point nitrate-nitrogen concentration (mg/L) difference between respective pairs is displayed in parentheses. For instance, when comparing the prairie versus the forest there were no significant differences (*p* value = 0.718). However, when comparing the prairie (column) to the golf course (row), the golf course had significantly higher concentrations (*p* < 0.01) and this difference was estimated to be 2.4 mg/L.

**p value < 0.01*	Prairie	Forest	Lawn	Golf Course	Pasture	Grass Strip non-fertilized	Grass Strip fertilized	Alfalfa w/Corn
Forest	0.718							
Lawn	* (<0.1)	0.033 (<0.1)						
Golf Course	* (2.4)	* (2.2)	* (2.0)					
Pasture	* (1.9)	* (1.7)	* (1.6)	0.123				
Grass Strip- non-fertilized	* (6.5)	* (6.3)	* (6.1)	* (2.4)	* (2.5)			
Grass Strip- fertilized	* (6.2)	* (6.0)	* (5.7)	* (3.3)	* (3.5)	0.187		
Alfalfa w/Corn	* (3.8)	* (3.8)	* (3.4)	* (1.0)	* (1.2)	0.092	* (-2.0)	
C-S and C-C	* (17.9)	* (17.9)	* (17.0)	* (14.0)	* (14.5)	* (12.1)	* (10.1)	* (12.3)

Ag Pasture and Grass Strips

The average soil water nitrate concentrations in the 'ag pasture and grass strip' category averaged between 5.1 to 8.9 mg/L with an interquartile range 0.5 mg/L to 11.0 mg/L. Nitrate concentrations from pasture sites averaged 5.1 mg/L and were significantly lower than the ag grass strips ($p < 0.01$), but were not significantly different from the golf course ($p = 0.123$). Pasture sites were seeded to perennial cool season forage grasses and grazed by cow/calf beef operations. Nitrogen inputs were limited to that supplied by manure and low amounts of commercial fertilizer. Some sites were rotationally grazed with no additional commercial fertilizer applied during the study while other sites received up to 60 lb N/ac/year of nitrogen fertilizer. At some sites, nitrogen inputs from manure were underestimated due to limited grazing records. At pasture site GW/GY it was observed in 2015 that cattle were loafing near the lysimeter sampling port. This presumably resulted in concentrated manure and urine input directly above the lysimeter, resulting in atypical nitrate transport to the lysimeter. Six months of samples ranging in nitrate-N concentrations of 66 to 360 mg/L were considered outliers and not used in the analysis.

In addition to the three pasture sites, two grass strips were monitored. One was managed as a grass field border while the other was a grassed waterway. The field border did not receive nitrogen while the grassed waterway received the same amount of fertilizer as the adjacent corn field. At the field border site, the 50-foot wide strip of grass ran parallel with the field slope and was located between two row-crop fields. This site was managed for cool-season grasses and was mowed occasionally for forage. At a second site, a grass strip was managed as a grassed waterway within a concentrated flow area within a field managed for continuous corn. Typical of most commercial fertilizer applications, the grassed waterway received the same rate of fertilizer as the adjacent corn field. Even though the field border didn't receive fertilizer while the grassed waterway did, statistically both grass strip sites had similar concentrations (p=0.187). It's possible that in some years, some of the nitrogen fertilizer applied to the field could have been broadcast beyond the target application area and incidentally fertilized the field border as well. Another contributing factor could be related to shallow sub-surface soil water flow from an adjacent crop field. Lateral flow and mixing of shallow soil water from adjacent corn fields likely occurred at both the fertilized and non-fertilized grass strip sites. Adjacent fields near the non-fertilized field border site have slopes of 4-6%, therefore, soil water sampled from the lysimeter could have been a mix of water that infiltrated through both the grass strip and an adjacent crop field that received nitrogen fertilizer. Piezometers were not installed to measure groundwater flow direction, but visual evidence during lysimeter installation suggested that subsurface groundwater flow direction was consistent with surface slope of the field. With that said, nitrate concentrations were significantly lower in both the fertilized and non-fertilized grass strips when compared to continuous corn or corn-soybean rotations (p<0.01). When comparing the ag grass strips to average nitrate concentrations found in corn-soybean land covers, the non-fertilized and fertilized grass strips had 60-74% less nitrate in soil water. Grass strips placed at the field edge were likely helping reduce concentrations contained in shallow, lateral flow from adjacent cropland. This reduction could be caused by a variety of factors including lower nutrient inputs within the grass strip, dilution from rainwater infiltrating within the grass strip, nitrogen uptake by the cool-season grass over a longer growing season when compared to the adjacent row crops, landscape position, immobilization and denitrification.

Ag Row Crop

The third category, 'Ag Row Crop', represented row crop fields managed for corn and soybean rotations (C-S) and continuous corn (C-C) and corn rotations with alfalfa. The 'Alfalfa with corn' classification had at least three years of alfalfa in the rotation and one year of corn during the sampling period. Row crop sites without alfalfa received a mix of both manure and commercial fertilizers and one site was organic. Soil water nitrate averaged 6.6 mg/L under row crop sites with alfalfa which equated to 70% less nitrate when compared to row crop fields without alfalfa in the rotation. Randal et al (1997) found that nitrate loss in subsurface drainage water from continuous corn and corn-soybean systems were about 37 and 35 times higher, respectively, than from alfalfa and CRP systems primarily due to greater evapotranspiration. This results in less drainage and greater uptake and/or immobilization of nitrogen by perennial crops.

Sites managed for continuous corn and corn-soybean rotations without perennials had the highest concentrations in the lysimeter network and averaged 22.3 mg/L with an interquartile range between 8 mg/L to 28 mg/L. This range indicates a high degree of variability and likely reflects the wide range of nitrogen management on the selected farms, diverse weather conditions and inherent variability associated with lysimeters. The standard deviation for the corn and soybean row-crop sites was 21.8 mg/L. For comparison, the standard deviations from the non-agriculture sites ranged from just 0.3 to 3.2 mg/L.

Results from a row-crop field in Fillmore County, site B70/90, were interesting. It was expected that this site would have concentrations between a typical range of 10-20 mg/L. However, in four of the five study years, concentrations remained at or below 10 mg/L and during the first two years nitrate concentrations were typically below 2.0 mg/L. This field was previously in CRP for ten years and did not receive nitrogen fertilizer. This resulted in less residual soil nitrate stored within the soil profile and less nitrate available for leaching in subsequent years. A legacy effect caused by the CRP grassland combined with dry conditions in 2011 and 2012 likely explain why concentrations remained very low during the first two years of row crop production. This farmer also applied lower rates of nitrogen because less nitrogen was expected to be lost through volatilization and leaching with a split nitrogen application program. Although the effectiveness of split applications can be mixed and weather dependent, this practice generally results in higher nitrogen use efficiencies and about 7% less nitrate loss when compared to a pre-plant nitrogen fertilizer application program (Iowa State University, 2013).

Nitrate loss calculation estimates

Nitrate loading was approximated from the SLN row crop sites. Nitrate loss expressed in traditional farm scale units (pounds per acre) was estimated by multiplying the volume of recharge passing through the soil by the nitrate concentration when using the following equation:

Nitrate loss (lb/ac) = 27,154 gal/ac. in. *8.34 lb/gal / 1,000,000 * nitrate concentration (mg/L) * drainage (in.) This equation results in a conversion factor of 0.226 and the following simplified equation:

$$0.226 * \text{nitrate (mg/l)} * \text{drainage (in.)} = \text{lb/ac nitrate}$$

For example, assuming a nitrate concentration of 10.0 mg/L and 5-acre inches of drainage water, the amount of nitrate loss equates to 0.226 * 10.0 * 5.0 = 11.3 lb/ac. In this study, drainage volumes were not measured directly from the lysimeters, but were estimated from a nearby long-term tile monitoring site and applied to the row crop sites in the lysimeter network. This comparison assumes that drainage and evapotranspiration rates were similar across the lysimeter network. Where accurate weather data exist, nitrate loading estimates from the lysimeter network could be improved by using a water balance method and applying an evapotranspiration model that is specific to each site. At a tile drainage monitoring site located about 30 miles west of the Lysimeter Network study area (station SRT, MDA-Root River Field to Stream Partnership) in Mower county, Minnesota an average 24% of the annual precipitation or 8.0 inches of drainage per acre was measured from 2011-2015 (Table 8). This equated to a FWMC of 15.7 mg/L or when 25.3 lb/ac nitrate loss. This field was managed for a corn-soybean rotation and the corn crop typically received a total of 170 lb/ac of pre-plant nitrogen.

Table 11. Annual sub-surface drainage, and nitrate FWMC's and loss from a 59-acre field managed for corn and soybeans in Mower County. This long-term monitoring site is located about 30 miles west of the Lysimeter Network and is one of several edge of field demonstration sites associated with the Root River Field to Stream Partnership.

	2011*	2012	2013	2014	2015	Average
Annual precip. (in.)	22.6	23.4	40.0	32.0	34.1	30.4
Drainage (in./ac)	3.0	0.9	11.9	9.8	14.5	8.0
Drainage: Precip (%)	13%	4%	30%	31%	43%	24%
Nitrate-N (FWMC, mg/L)	13.0	23.7	13.5	15.8	12.5	15.7
Nitrate-N (lb/ac)	8.8	5.1	36.6	35.0	40.9	25.3

*Values are underestimated and represent a partial season. Data were not available from January 1, 2011 through May 17, 2011.

With the assumption that 8-acre inches of drainage water also occurred on the lysimeter network fields, the average nitrate loss was estimated to be 40.3 lb/ac with an interquartile range of 14.5 lb/ac to 50.6 lb/ac. For comparison, the average nitrate loss from the Mower site was 25.3 lb/ac. This was about 60% lower than the SLN. These differences can be partly explained by the following factors: (1) Lower permeability of the glacial till soils at the Mower county site could result in higher rates of denitrification under certain years and conditions and therefore less nitrate measured in drainage leachate (Rodvang and Simpkins, 2001) (2) Nitrate losses from 2011 reflect a partial year at the Mower county site and are underestimated due to a partial year of sampling (3) lysimeter loss estimates may not represent the entire field when compared to tile drainage samples, and (4) the SLN contains a greater diversity of nitrogen management practices including rotations with continuous corn and manure that had higher nitrogen fertilizer inputs.

Row-crop Nitrate Comparisons

To aid interpretation, results from the SLN were compared to other lysimeter and tile drainage sites in Minnesota and Midwest corn belt.

Generally, nitrates measured from the corn-soybean and continuous corn sites in the SLN were within the range of concentrations found in sub-surface drainage tile across Minnesota (Table 8). Nitrate concentrations were not significantly different (p=0.212) and both data sets averaged between 21.4 to 22.3 mg/L. Although the averages were very similar, the standard deviation from the lysimeter network was 12.9 mg/L higher. The likely reason for this difference is because lysimeters represent small point measurements within the field and therefore subject to more variation. In contrast, pattern tiled drainage sites have less variation since the concentration measured at the tile outlet represents a composite mixture of drainage water that is representative of the entire area of the drained field. When concentrations were compared to tile drainage sites across the Midwest corn belt (Table 5), the SLN concentrations were about 12% higher than the 20 mg/L row crop reference value contained in that report.

When the SLN corn-soybean and continuous corn sites were compared to a irrigated northcentral corn-soybean site (Table 6) during the same monitoring period of 2011-2015, the northcentral site had significantly higher concentrations ($P<0.05$) and the median point difference was estimated to be 6.6 mg/L. Higher nitrate concentrations are to be expected in this region of the state because the sandy soils that are common in this area can result in greater nitrate loss below the crop root zone. Furthermore, row crops grown on coarse textured soils require higher rates of nitrogen fertilizer, therefore, soil pore water can contain higher nitrate in solution.

Suggestions for Further Study

Where appropriate weather data are available, nitrate loss estimates could be refined using a water balance method and evapotranspiration model for each site. In future studies, performance monitoring of septic system drain fields in areas with low and high density housing, cover crops and alternative crops such as hemp should be explored. For site B70/B90, concentrations were much lower than expected and additional investigation could be warranted regarding the effect of no-till and split nitrogen applications in a corn-soybean rotation. Additional monitoring of grassed waterways and edge of field grass strips would also be beneficial. Grassed waterways are one of the most widely used conservation practices by farmers in southeast Minnesota and quantifying the effect of these practices would be beneficial as an input for groundwater modeling. For best management practice (BMP) comparison sites, additional statistical analysis should be conducted to estimate how many samples would be needed to detect a given percent change in nitrate concentration at the 0.10 and 0.05 confidence levels. This could help lower labor and analytical costs in future monitoring efforts.

Summary and Conclusions

Low levels of soil water nitrate, generally less than 0.5 mg/L, were consistent across the prairie and forest sites. In these land covers, nitrate concentrations are very low because nitrogen is mineralized from soil organic sources and the nitrogen supplied is in equilibrium with plant nitrogen needs. A fertilized golf course site averaged less than 4 mg/L and had similar concentrations when compared to cattle pasture sites. Fertilized and non-fertilized grass strips (grassed waterway and field border) were higher than expected but averaged less than 9.0 mg/L. Elevated concentrations, especially in the non-fertilized grass field border, are likely explained by subsurface mixing of soil water between adjacent land covers. Nitrate concentrations in row crop settings averaged 22.3 mg/L and were spread across a large range of values as depicted by a standard deviation of 21.8 mg/L. This high degree of variability can be explained by the wide range of cropping systems and management systems sampled, diverse weather conditions and variability that is inherent with lysimeter sampling. Although highly variable, average row crop nitrate levels from the lysimeter network were similar to flow weighted concentrations collected from sub-surface drainage tile sites across Minnesota during the same monitoring period.

Any nitrate not used by row crops is susceptible to leaching from the rooting zone and can increase the risk for transport to groundwater, especially in karst landscapes. The use of BMPs, especially proper rate and timing of nitrogen, are key practices to help reduce nitrate concentrations in groundwater. Though, it's important to recognize that these practices alone may not consistently obtain levels below the drinking water standard of 10 mg/L. Integrating perennials into row crop systems can be a key practice for reducing nitrate in groundwater. The use of perennials is used by many livestock farmers in southeast Minnesota and the performance of this practice was measured. In corn rotations with alfalfa, soil water nitrate averaged 6.6 mg/L which was 70% lower when compared to row crop sites without perennials. This reduction can be explained by lower nitrogen inputs, increased nitrogen uptake and/or immobilization and higher rates of evapotranspiration by perennial covers over a longer growing season when compared to row crops (Randal et al, 2008).

The use of lysimeters proved to be a cost-effective tool to estimate the relative range of concentrations and nitrate risk to groundwater between various types of land covers. When shared within the context of this study's limitations, data collected from the Southeast Lysimeter Network serves as a useful educational tool for farmers, crop advisors, rural homeowners and groundwater advisory groups.

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Literature Cited

Alexander, Richard B., Smith, Richard A., Schwarz, Gregory E., Boyer, Elizabeth W., Nolan, Jacquelin V. and Brakebill, John W. (2008). Differences in phosphorus and nitrogen delivery to the Gulf of Mexico from the Mississippi River Basin. Environmental Science and Technology. 42, 822-830, pg. 828.

Barry, John D., Miller, Tom, P.,Steenberg, Julia R., Runkel, Anthony C, Kuehner, Kevin J, Alexander, Calvin E. Jr. (2020). Combining high resolution spring monitoring, dye tracing, watershed analysis, and outcrop and borehole observations to characterize the Galena Karst, Southeast Minnesota, USA. 16th Sinkhole Conference, NCKRI symposium 8.

Brouder, S., Hofmann, B., Kladivko, E., Turco, R., Bongen, A. and Frankenberger, J., (2005). Interpreting nitrate concentration in tile drainage water. Purdue University Extension.

Cropscape. Year 2015 Cropland Data Layer. Center for Spatial Information and Science Systems, George Mason University. https://nassgeodata.gmu.edu/CropScape/.

Dogwiler, Toby. (2013). Southeastern Minnesota Soil Water Lysimeter Network Project Final Report. Winona State University Department of Geosciences.

Faaga, J. and Selker, J. (2004). Field Measurements of Nitrate Leaching Below Willamette Valley Row and Mint Crops. Oregon State University Extension Service.

Green, Jeffrey A., John D. Barry and E. Calvin Alexander, Jr., (2014). Springshed Assessment Methods for Paleozoic Bedrock Springs of Southeastern Minnesota. Report to the LCCMR. Sept. 2014, 48 pp.

Haarder, E.B, M.C, Looms, Johnson, K.H and L. Nielsen. (2011). Vadose Zone J. 10:84-97.

Iowa State University, (2013). Nutrient Reduction Strategy. Reducing Nutrient Loss: Science shows what works. Retrieved from https://store.extension.iastate.edu/product/Reducing-Nutrient-Loss-Science-Shows-What-Works.

Kaushal, S.S., Pace, M.L., Groffman, P.M., Band, L.E., Belt, K.T., Meyer, P.M., and Welty, C., (2010), Land Use and Climate Variability Amplify Contaminant Pulses: Eos, Transactions, American Geophysical Union, v. 91, p. 221–222, doi:10.1029/2010EO250001.

Minnesota Department of Agriculture Township Testing Program. Various reports retrieved from https://www.mda.state.mn.us/township-testing-program.

Mossler, J.H., (1995). C-08 Geologic atlas of Fillmore County, Minnesota [Parts A and C]. Minnesota Geological Survey. Retrieved from the University of Minnesota Digital Conservancy, http://hdl.handle.net/11299/58513.

Nitrogen in Minnesota Surface Waters, (2013). Minnesota Pollution Control Agency. Report, wq-s6-26a, Minnesota Pollution Control Agency, 2013. Retrieved from https://www.pca.state.mn.us/sites/default/files/wq-s6-26a.pdf.

Randall, G. W. and M.J. Goss. (2008). Nitrate Losses to Surface Water through Subsurface, Tile Drainage. In Nitrogen in the Environment: Sources, Problems, and Management, ed. J.L. Hatfield, and R.F. Follett. P. 145- 175. Elsevier Sciences B.V.

Randall, G.W., Huggins, D.R., Russelle, M.P., Fuchs, D.J., Nelson, W.W. and Anderson, J.L., (1997). Nitrate Losses through Subsurface Tile Drainage in Conservation Reserve Program, Alfalfa, and Row Crop Systems. Journal of Environmental Quality, 26: 1240-1247. doi:10.2134/jeq1997.00472425002600050007x.

Richards DJ, Shieh WK. (1989). Anoxic activated-sludge treatment of cyanides and phenols. Biotechnology Bioengineering. 33:32-38. Referenced in chapter 6 of Agency for Toxic Substances and Disease Registry (ATSDR). 2006. Toxicological profile for Cyanide. Atlanta, GA: U.S. Department of Health and Human Services, Public Health Service.

Robertson, D.M., and Saad, D.A. (2019), Spatially referenced models of streamflow and nitrogen, phosphorus, and suspended-sediment loads in streams of the Midwestern United States: U.S. Geological Survey Scientific Investigations Report 2019–5114, 74 p. including 5 appendixes, https://doi.org/10.3133/sir20195114.

Rodvang, S.J. & Simpkins, William.(2001). Agricultural Contaminants in Quaternary Aquitards: A Review of Occurrence and Fate in North America. Hydrogeology Journal. 9. 44-59. 10.1007/s100400000114.

Runkel, Anthony C.; Steenberg, Julia R.; Tipping, Robert G.; Retzler, Andrew J. (2014). OFR14-02, Geologic controls on groundwater and surface water flow in southeastern Minnesota and its impact on nitrate concentrations in streams. Minnesota Geological Survey. Retrieved from the University of Minnesota Digital Conservancy, http://hdl.handle.net/11299/162612.

Schilling, K. E. and Streeter, M.T. (2018). Groundwater Nutrient Concentrations and Mass Loading Rates at Iowa Golf Courses. Journal of the American Water Resources Association (JAWRA) 54(1): 211-224. https://doi.org/10.1111/1752-1688.12604.

Schilling, K.E., Jones, C.S., Clark, R.J. et al (2019). Contrasting NO3-N concentration patterns at two karst springs in Iowa (USA): insights on aquifer nitrogen storage and delivery. Hydrogeology Journal 27, 1389-1400. https://doi.org/10.1007/s10040-019-01935-y.

USEPA, (1987). Estimated national occurrence and exposure to nitrate and nitrite in public drinking water supplies. Washington, DC, United States Environmental Protection Agency, Office of Drinking Water.

Van Metre, P.C., Frey, J.W., Musgrove, M., Nakagaki, N., Qi, S., Mahler, B.J., Wieczorek, M.E. and Button, D.T. (2016). High Nitrate Concentrations in Some Midwest United States Streams in 2013 after the 2012 Drought. J. Environ. Qual., 45: 1696-1704. doi:10.2134/jeq2015.12.0591.

APPENDIX A

Considerations when interpreting soil water nitrate-nitrogen concentrations collected from lysimeters

Lysimeters are one of the most basic, versatile and economical ways to collect samples for measuring nitrate-nitrogen (nitrate) concentrations in soil water. Measuring nitrate concentrations in the unsaturated vadose zone and lowermost depth of the crop rooting zone of cultivated crops can provide important insights and feedback regarding nitrogen management practices. However, results can be highly variable. For instance, nitrate results collected two lysimeters separated only a few feet apart can vary considerably. The following is a brief list of factors to consider when interpreting results collected from lysimeters.

Soils are complex systems with various chemical, physical and biological interactions, and measuring the movement of nitrate through soil is controlled by the complex interaction of these properties combined with variations in precipitation. Consider the complex movement of water through the soil. Water moves in an irregular manner through the soil profile along a path of least resistance. During dry conditions, water moves between the small pore spaces between the soil particles very slowly. This slow form of water movement is called matrix flow. During wet conditions, such as during a large rain event when the soil is approaching saturation, flow through larger pores such as worm holes or old root channels occurs. This is a fast form of water movement called preferential flow. Nitrate concentrations vary between matrix flow and preferential flow which helps explain why soil water nitrate concentrations from lysimeters located only a few feet apart can be substantially different. These concepts are best illustrated in Figure 1 (adapted from Haarder et al., 2011) showing the cross section of a soil profile after infiltrating four inches of water-soluble blue dye on a sandy textured soil. The wetting front and irregular preferential flow pattern are clearly shown as the blue dye percolates through the soil. In this case, if a lysimeter had been placed on the left side of the soil profile, nitrate concentrations could have been much different when compared to the right side.

Figure 1. This photograph shows the cross section of a soil profile with blue dye poured at the soil surface. The wetting front and irregular preferential flow pattern are clearly shown as the blue dye percolates through the soil. This can help explain why soil water nitrate concentrations from one lysimeter can have markedly different concentrations when compared to another lysimeter only a few feet away. Figure adapted from Haarder et al, 2011.

Another factor to consider is that nitrate measured by lysimeters within the crop root zone represents the amount of nitrate present at that specific point in the soil profile and may not always correspond to what is observed in deeper groundwater. At common lysimeter install depths, usually about four feet, the fate and movement of nitrate can take several pathways. Some of those include: (i) percolate to deeper bedrock layers where it can mix with older groundwater that has been diluted from non-crop land covers (ii) migrate back to the root zone through capillary rise or (iii) be converted into nitrogen gas

(N_2) by denitrification or other reduction processes deeper in the soil profile or aquifer. Despite these factors, nitrate concentrations measured in coarse-textured/sandy aquifers or shallow, unconfined karst aquifers in southeast Minnesota can have nitrates that are consistent with the range of concentrations measured in soil water beneath row-crop fields.

Due to sample and labor constraints involved with lysimeter sampling, typically only a few lysimeters are installed within a small area of a crop field. Lysimeters in effect become point measurements that may not capture the high level of spatial variability represented within the field. This makes it difficult to discern if nitrate concentrations are an accurate representation of the entire field and management system or just that particular point within the field. That is why sub-surface pattern tile drainage sites or groundwater springs are preferred monitoring locations for nitrate, since concentrations represent a composite mixture that is averaged across the drained field area or springshed contributing area. To reduce uncertainty, pairs or groups of lysimeters are typically installed and a mean concentration is applied to the lysimeter group.

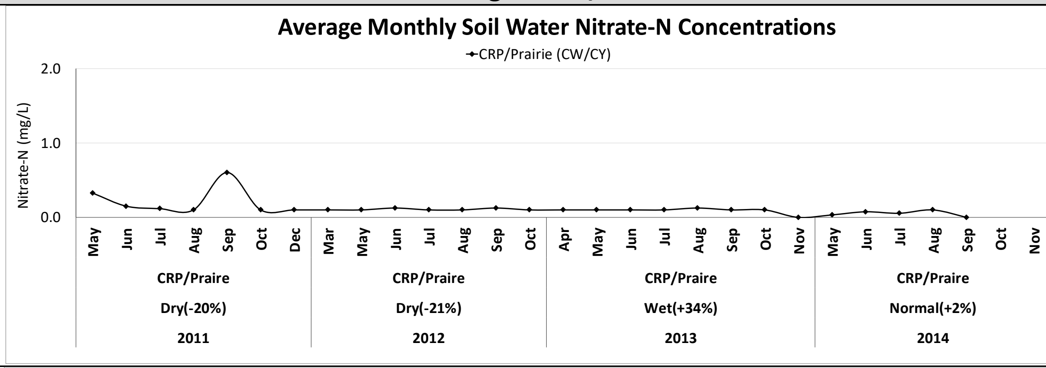
Additional factors to consider:

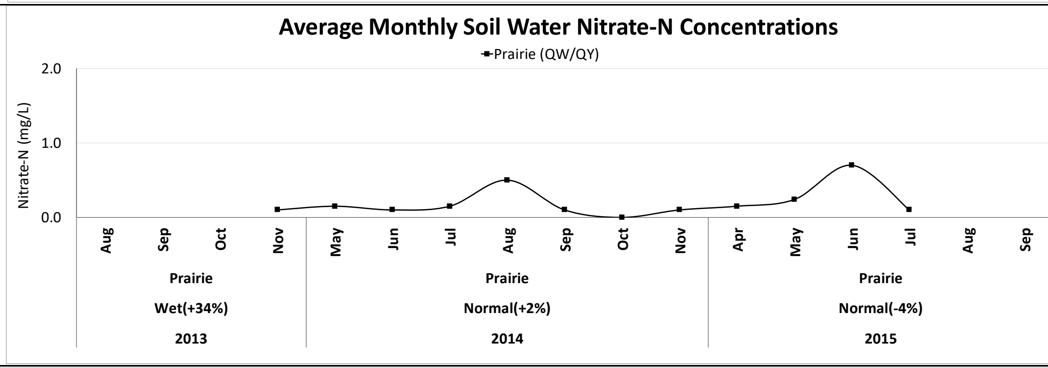
- Typically, a vacuum is paced on the lysimeter to allow collection of a soil water sample. This vacuum could bias preferential flow to the lysimeter within the soil column, causing the sample to not fully represent the water moving through the soil profile.
- Ideally, drainage volume from lysimeters should also be measured to help normalize for differences in sample size between sites and lysimeters by calculating a flow weighted mean concentration (FWMC). A FWMC is defined as the total mass load divided by the total water volume. This normalization process allows comparison among different sites based on the total volume of water rather than the concentration itself. Flow weighted averaging is an appropriate method to represent the average nitrate concentration over multiple sampling events and are much better than simply averaging the individual concentrations since sampling events with low volumes can bias results with sample events that collect small volumes with very high concentrations. Accurately measuring drainage volume from lysimeters is challenging so FWMCs are typically not calculated.
- The soil immediately surrounding lysimeters is disturbed during installation. It may take at least a year for the soil to fully settle around the lysimeters resulting in higher uncertainty in the measurements during that period.
- Samples can be influenced by adjacent, upgradient land use due to lateral movement of shallow groundwater flow paths. This can be a factor for some locations with steeper field slopes.

With these considerations in mind, the use of lysimeters can be a cost-effective tool for evaluating nitrate concentrations and can serve as an important educational tool for farmers, crop advisors, rural homeowners and groundwater advisory groups.

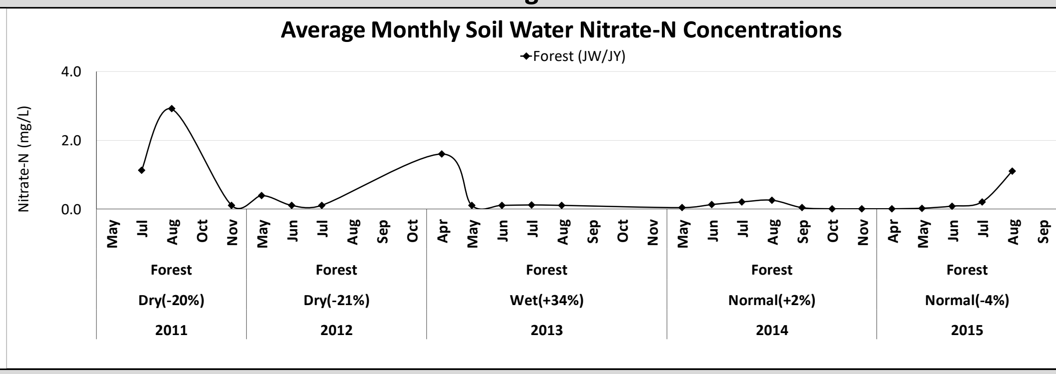
APPENDIX B- Average monthly nitrate by lysimeter site

Non-Ag Prairie/CRP

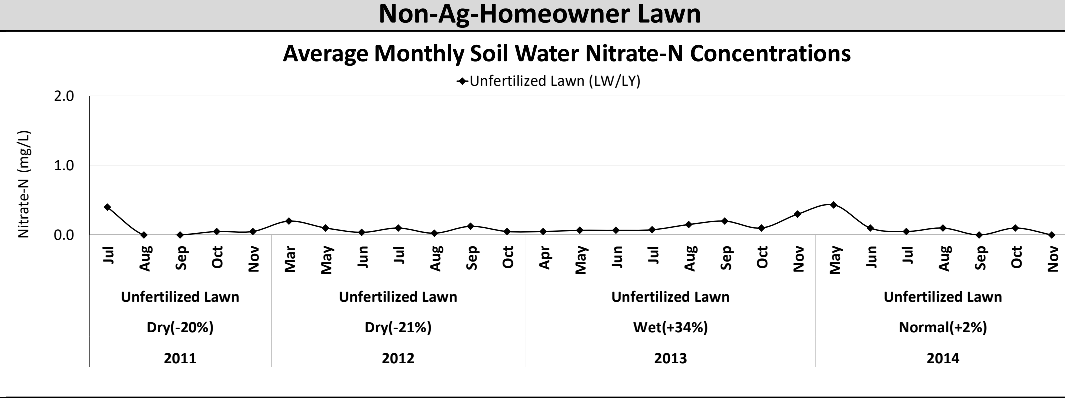




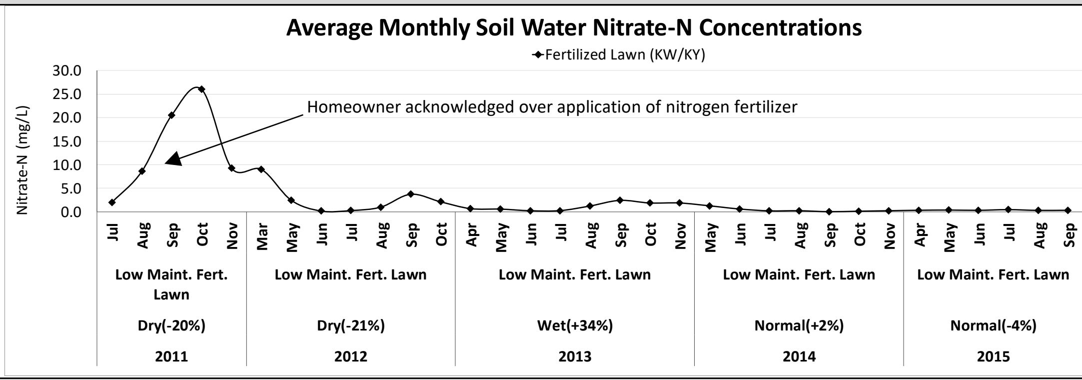
Non-Ag-Forest



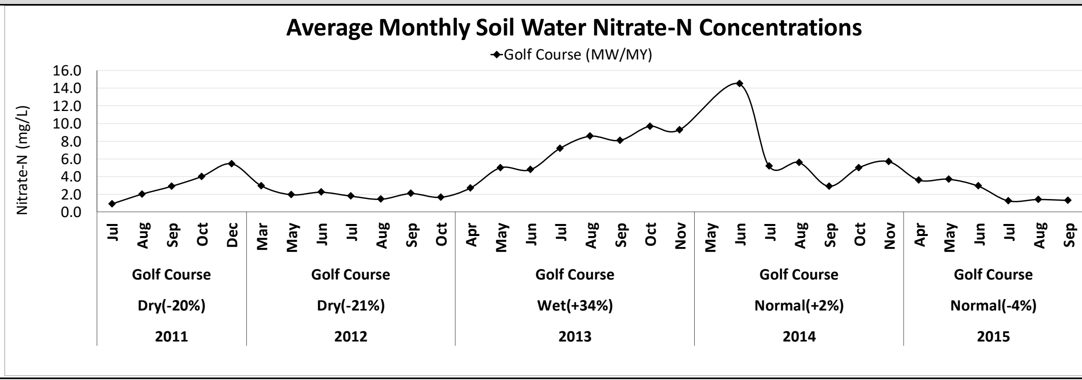
Non-Ag-Homeowner Lawn



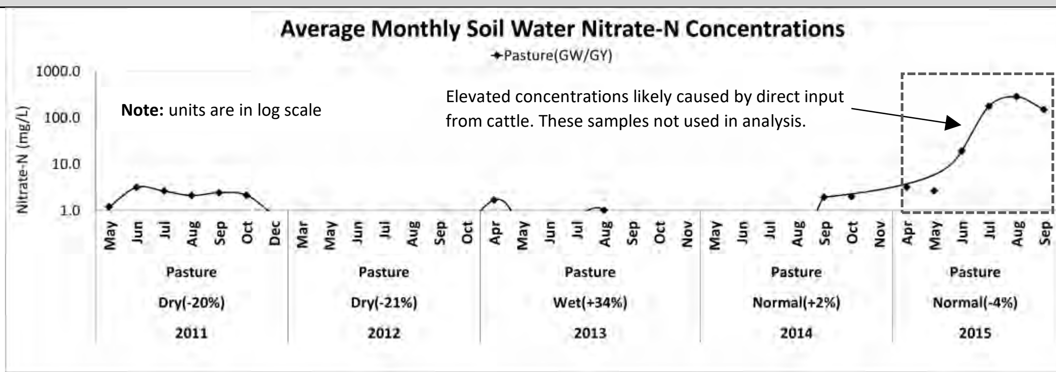
Homeowner Lawn

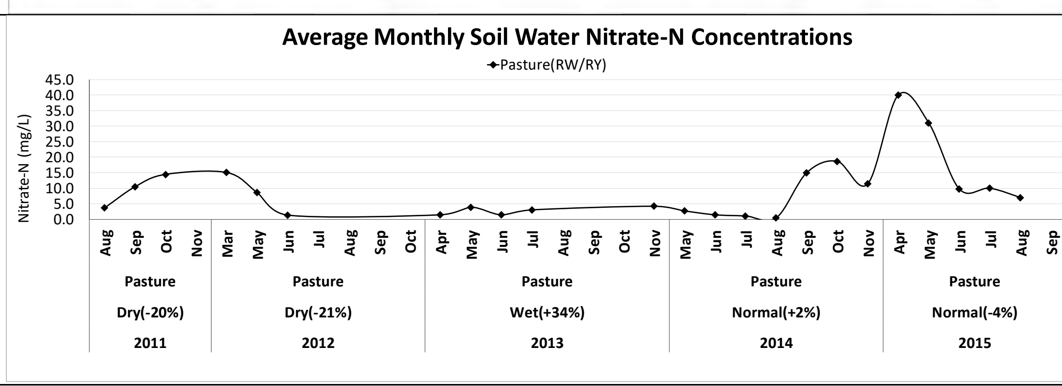


Golf Course

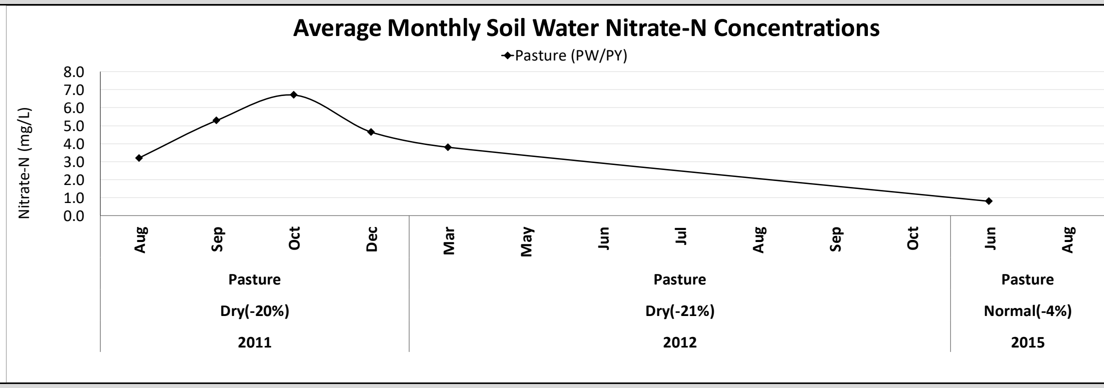


Pasture

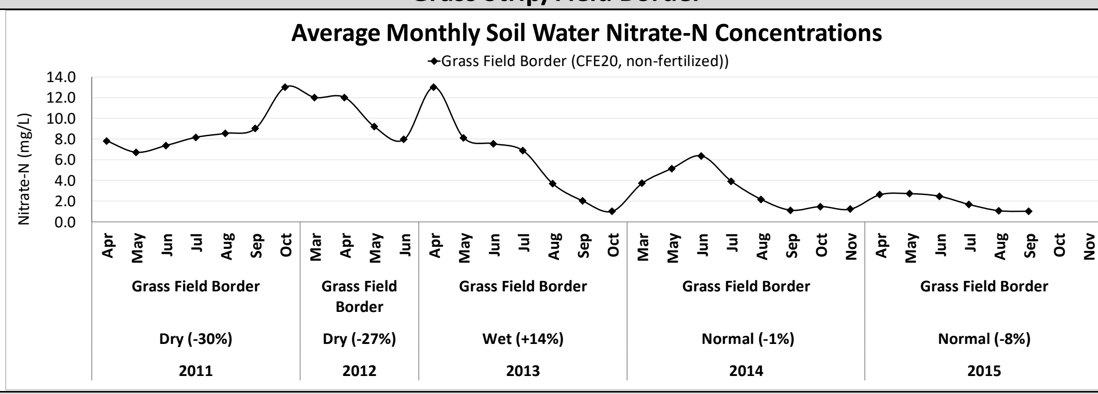




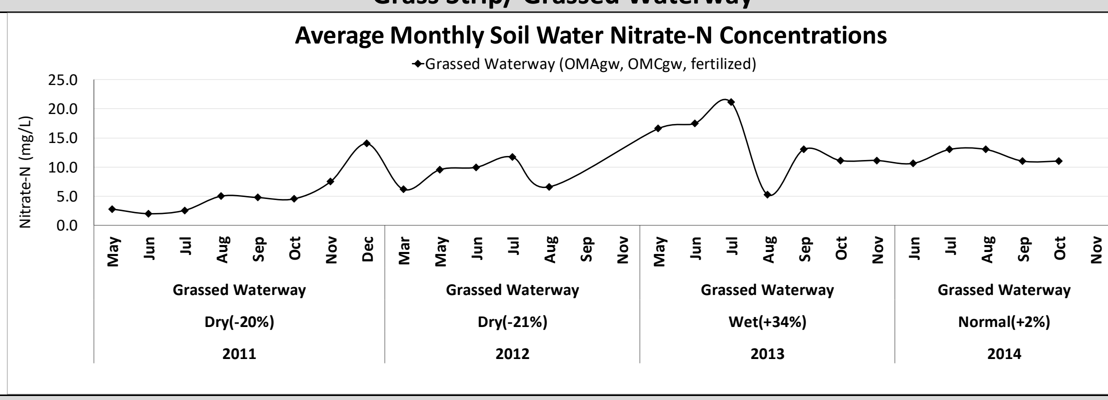
Pasture



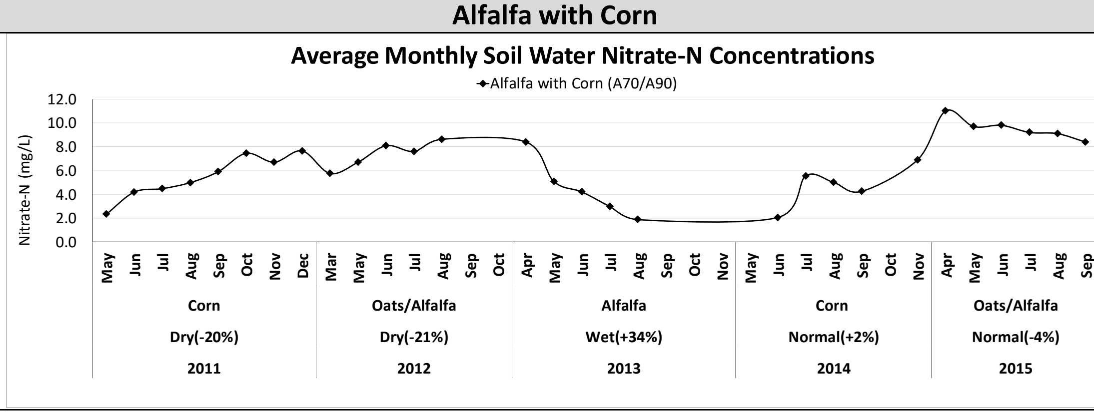
Grass Strip/Field Border



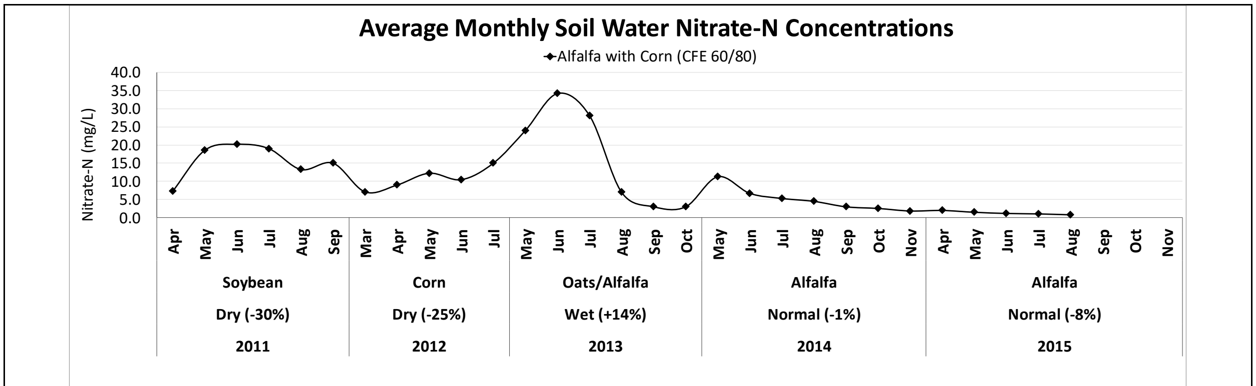
Grass Strip/ Grassed Waterway

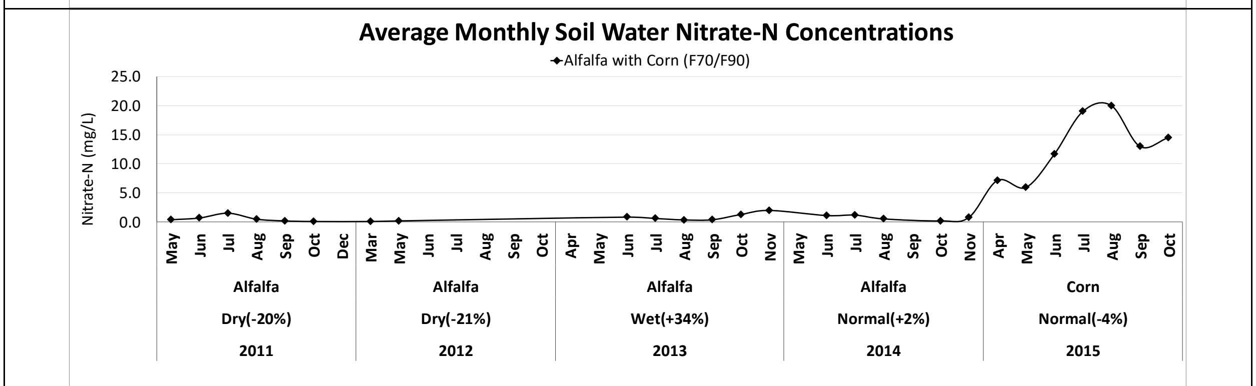


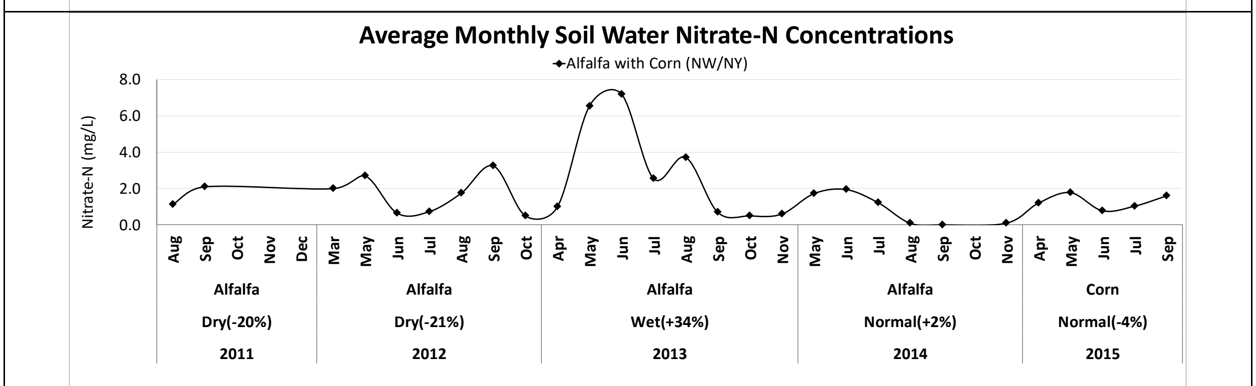
Alfalfa with Corn



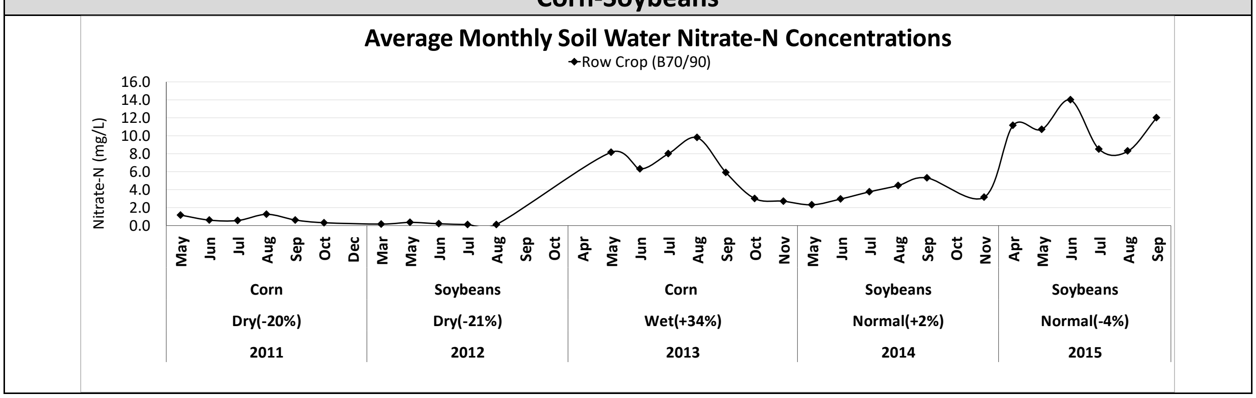
Alfalfa with Corn

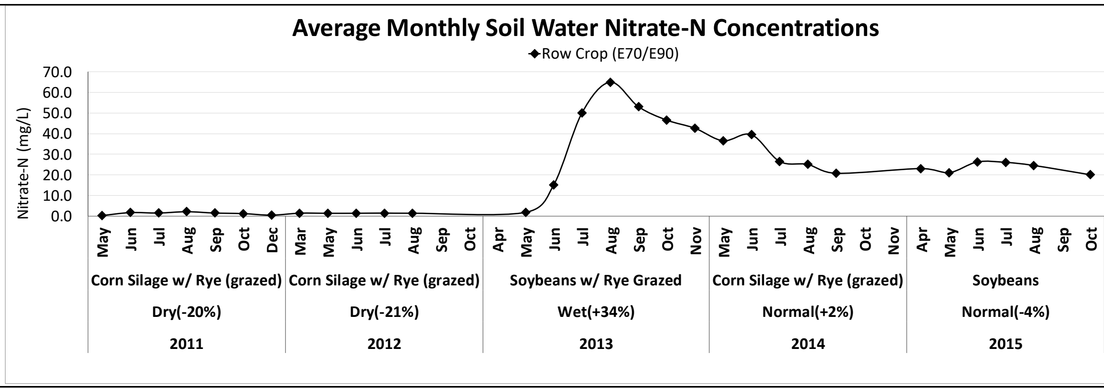




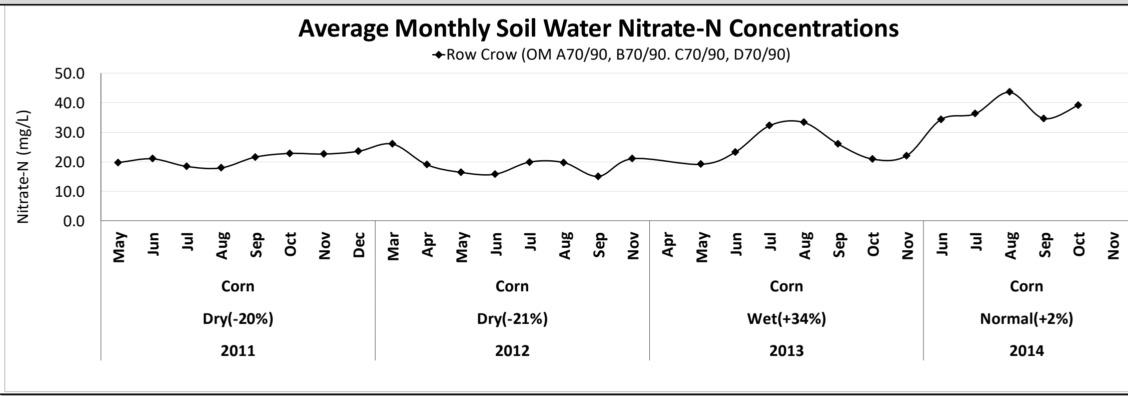


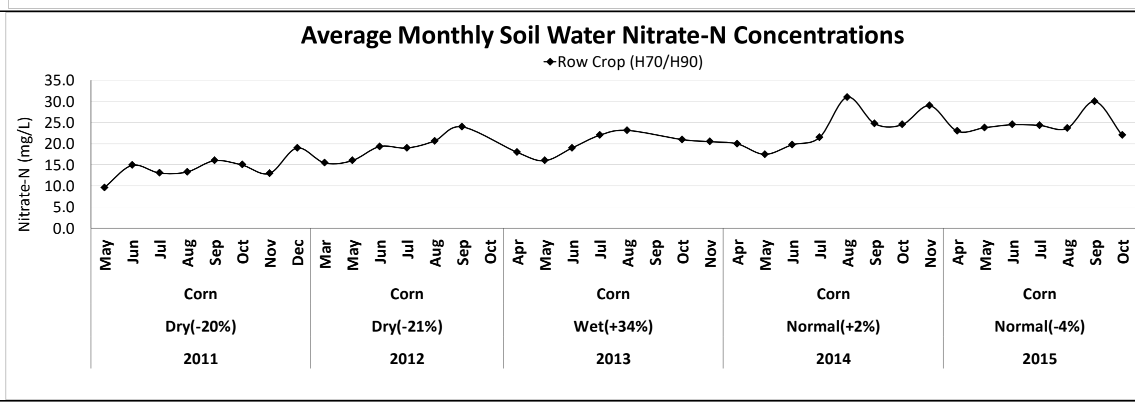
Corn-Soybeans

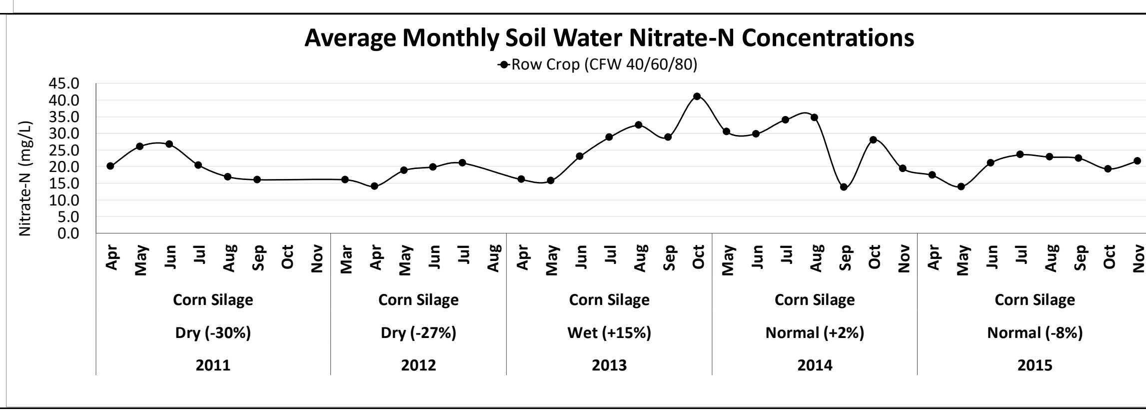


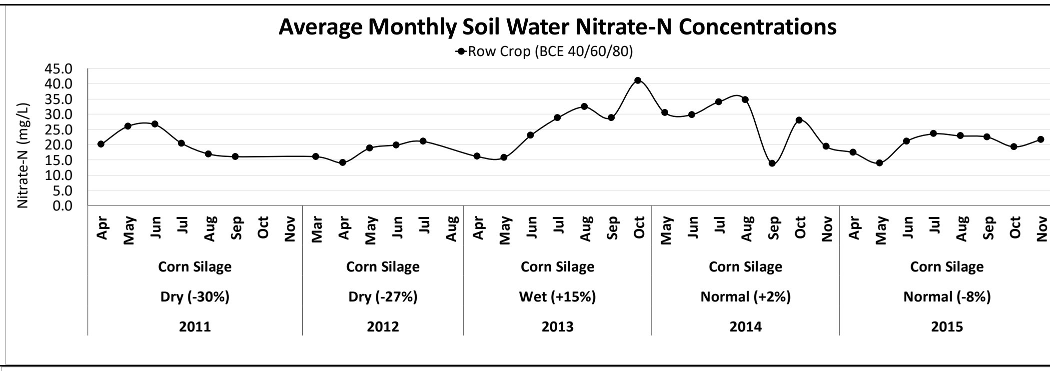


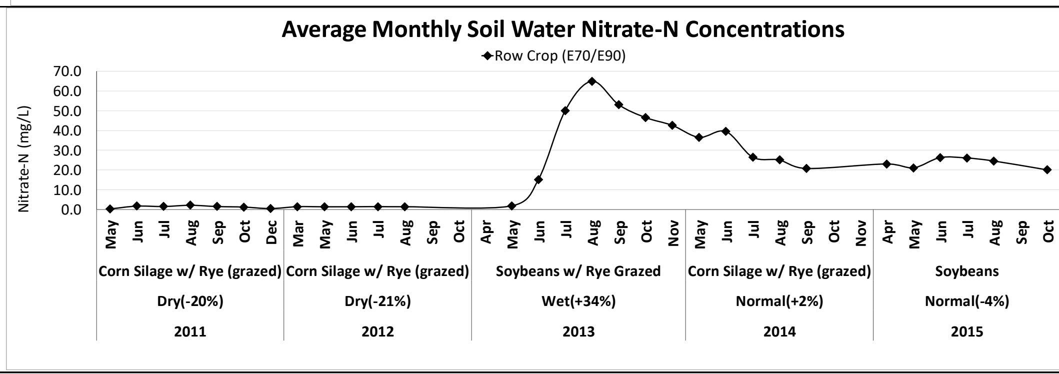
Continuous Corn

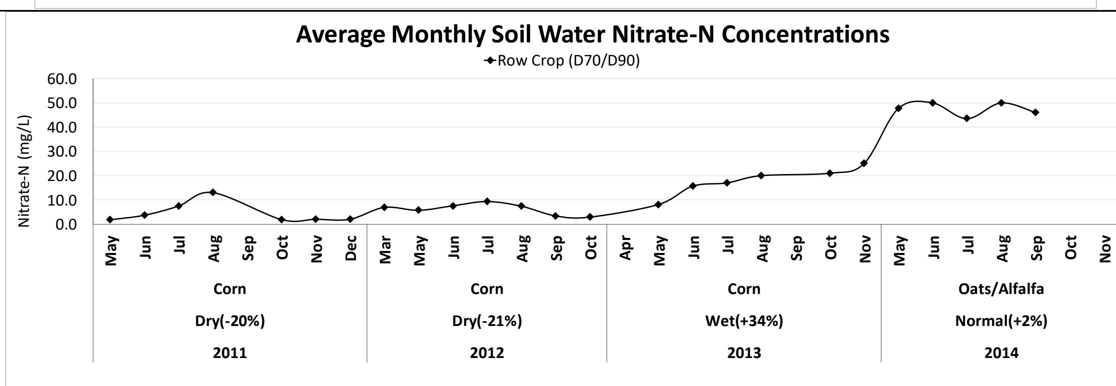


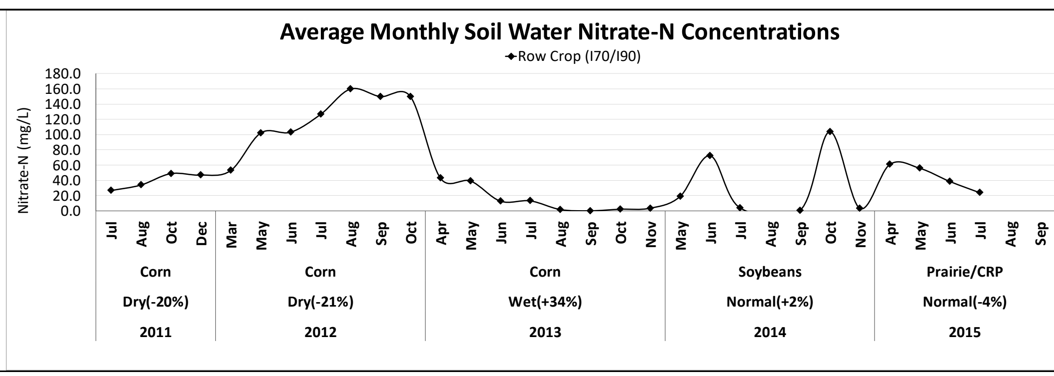





Average Monthly Soil Water Nitrate-N Concentrations
Row Crop (BCE 40/60/80)
Nitrate-N (mg/L)
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
Apr May Jun Jul Aug Sep Oct Nov Mar Apr May Jun Jul Aug Apr May Jun Jul Aug Sep Oct May Jun Jul Aug Sep Oct Nov Apr May Jun Jul Aug Sep Oct Nov
Corn Silage
Dry (-30%)
2011
Corn Silage
Dry (-27%)
2012
Corn Silage
Wet (+15%)
2013
Corn Silage
Normal (+2%)
2014
Corn Silage
Normal (-8%)
2015


Average Monthly Soil Water Nitrate-N Concentrations
Row Crop (E70/E90)
Nitrate-N (mg/L)
70.0
60.0
50.0
40.0
30.0
20.0
10.0
0.0
May Jun Jul Aug Sep Oct Dec Mar May Jun Jul Aug Sep Oct Apr May Jun Jul Aug Sep Oct Nov May Jun Jul Aug Sep Oct Nov Apr May Jun Jul Aug Sep Oct
Corn Silage w/ Rye (grazed)
Dry(-20%)
2011
Corn Silage w/ Rye (grazed)
Dry(-21%)
2012
Soybeans w/ Rye Grazed
Wet(+34%)
2013
Corn Silage w/ Rye (grazed)
Normal(+2%)
2014
Soybeans
Normal(-4%)
2015


Average Monthly Soil Water Nitrate-N Concentrations
Row Crop (D70/D90)
Nitrate-N (mg/L)
60.0
50.0
40.0
30.0
20.0
10.0
0.0
May Jun Jul Aug Sep Oct Nov Dec Mar May Jun Jul Aug Sep Oct Apr May Jun Jul Aug Sep Oct Nov May Jun Jul Aug Sep Oct Nov
Corn
Dry(-20%)
2011
Corn
Dry(-21%)
2012
Corn
Wet(+34%)
2013
Oats/Alfalfa
Normal(+2%)
2014


Average Monthly Soil Water Nitrate-N Concentrations
Row Crop (I70/I90)
Nitrate-N (mg/L)
180.0
160.0
140.0
120.0
100.0
80.0
60.0
40.0
20.0
0.0
Jul Aug Oct Dec Mar May Jun Jul Aug Sep Oct Apr May Jun Jul Aug Sep Oct Nov May Jun Jul Aug Sep Oct Nov Apr May Jun Jul Aug Sep
Corn
Dry(-20%)
2011
Corn
Dry(-21%)
2012
Corn
Wet(+34%)
2013
Soybeans
Normal(+2%)
2014
Prairie/CRP
Normal(-4%)
2015

APPENDIX C
Quality assurance report: duplicate RPD results

Water samples were analyzed using a Hach® DR6000 UV spectrophotometer (pour-through method 357-10049, DOC 316.53.01072) located in the MDA Preston field office within a week of sample collection. Samples were analyzed using standardized quality assurance and control (QA/QC) procedures. To evaluate the performance of the machine during this study, a minimum of 10% of the nitrate samples were split in the field and sent to the Minnesota Department of Agriculture certified laboratory (MDA Lab) located in St. Paul. Field duplicate samples were used as a part of the quality assurance plan to evaluate the performance and precision of the DR6000 and determine the extent of any analytical problems. Due to budget constraints, duplicate samples were sent in two out of the five years during the study. The MDA lab method (SM 4500-No3 F) using flow injection includes both nitrite and nitrate ($NO_2 + NO_3$-N) while the DR6000 method does not report nitrite. Nitrite (NO_2-N) is seldom elevated in groundwater because it is typically transformed quickly to nitrate, therefore, it is not considered to be a significant factor when comparing the two methods.

The Relative Percent Difference (RPD) calculation method was used to evaluate the precision of duplicate samples when comparing the DR6000 to the MDH certified lab for years 2014 and 2015. The RPD is the difference between the MDH certified lab and samples analyzed by the DR6000 machine divided by their average and expressed as a percent. The RPD calculation is:

$$RPD = \frac{|X1 - X2|}{(X1 + X2)/2} * 100$$

X1 = sample concentration determined by Hach DR6000 X2= sample concentration determined by MDA certified lab

A goal of this testing program was to have 90% of the duplicate samples within 10% of the RPD. Table 1 and Figure 1 summarize the RPD results. For 2014, 61 field duplicate pairs were analyzed representing 17% of the total samples analyzed on the DR6000. Of the 61 pairs, 87% of the DR6000 duplicate samples were within the 10% RPD goal and 95% were within 20% RPD. In 2015, 114 sample pairs were analyzed representing 31% of the total samples. Of the 114 sample pairs, 89% of the DR6000 samples were within 10% of the RPD and 95% of the duplicate samples were within the 20% RPD. Across both years, 88% of the samples were within 10% of the RPD. Across both years, 90% of the samples were within a RPD of 11%. The overall difference between the DR6000 samples and those analyzed by the MDH lab ranged from -0.3 mg/L to 0.6 mg/L (IQR). The median difference between the DR6000 method and the MDH certified lab was 0.3 mg/L. The method report limit is 0.1 mg/L for the DR6000.

Table 1. Relative Percent Difference (RPD) results between Hach DR6000 and MDA certified lab.

Year	Duplicates	<10% RPD	<15% RPD	<20% RPD
		-----% of duplicate samples-----		
2014	61	87%	93%	95%
2015	114	89%	96%	96%
All Years	175	88%	95%	96%

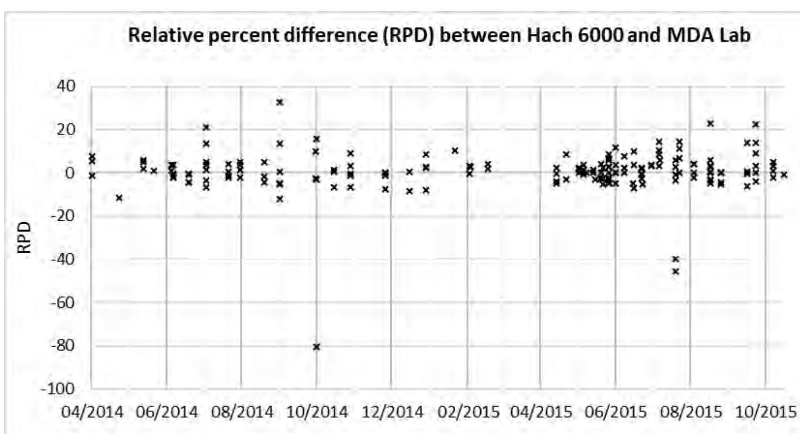


Figure 1. Time series chart of RPD results

United States Environmental Protection Agency
Region 10
1200 Sixth Avenue, Suite 155
Seattle, Washington 98101-3188

Authorization to Discharge under the
National Pollutant Discharge Elimination System

In compliance with the provisions of the Clean Water Act (CWA), 33 U.S.C. § 1251 *et seq*., as amended by the Water Quality Act of 1987, P.L. 100-4, the "Act",

Concentrated Animal Feeding Operations (CAFOs) in Idaho
as defined in Section I of this permit

are authorized to discharge in accordance with discharge point(s), effluent limitations, monitoring requirements, and other conditions set forth herein.

This permit shall become effective: June 15, 2020

This permit and the authorization to discharge shall expire at midnight: June 14, 2025

The permittee shall reapply for a permit reissuance on or before Date, 180 days before the expiration of this permit if the permittee intends to continue operations and discharges at the facility beyond the term of this permit.

/s/

Daniel D. Opalski, Director
Water Division

This permit was modified: ____________________________

Mathew J. Martinson
CAPT, USPHS
Branch Chief
Permitting, Drinking Water and Infrastructure

Table of Contents

I. PERMIT AREA AND COVERAGE

A. Permit Area and Eligibility

This permit offers National Pollutant Discharge Elimination System (NPDES) permit coverage for discharges from facilities that meet the definition of a concentrated animal feeding operation (CAFO), as defined by 40 CFR § 122.23(b)(2), in the State of Idaho. Any facility that meets the definition of a large, medium or small CAFO, as defined in 40 CFR § 122.23(b)(4), (6), and (9), and that is not specifically excluded per one of the conditions in Section I.F.1, is eligible for coverage under this permit.

CAFO owners/operators ineligible for coverage under this permit (Section I.F.1) or who believe the terms and conditions of this permit are not appropriate for their CAFO facility, must apply for an individual permit in accordance with Section I.F.3.

B. Application for Coverage

1. Owners/operators of CAFOs seeking to be covered by this permit must submit an NOI (Appendix A) and a Nutrient Management Plan (NMP) that meets the requirements of Section III.A of this permit.
2. Signature Requirements: The NOI must be signed by the owner/operator or other authorized person in accordance with Section V.C.5 of this permit.
3. Where to Submit: A signed copy of the NOI must be sent to:

   United States Environmental Protection Agency,
   Region 10 Manager, NPDES Permits Section
   1200 Sixth Avenue, Suite 155, WD 19-C04
   Seattle, WA 98101-3188

   Copies of the NOI shall also be sent to the Idaho State Department of Agriculture (ISDA), the Idaho Department of Environmental Quality (IDEQ) state office, and the appropriate IDEQ regional offices listed below.

   Beginning December 21, 2020, all NOIs must be submitted electronically.

Idaho State Department of Agriculture 2270 Old Penitentiary Road P.O. Box 790

Idaho Department of Environmental Quality Water Quality Division IDEQ State Office 1410 N. Hilton Boise, ID 83706 (208) 373-0570 tambra.phares@deq.idaho.gov			
IDEQ Boise Regional Office 1445 N. Orchard Boise, ID 83706 (208) 373-0490 chase.cusack@deq.idaho.gov	Counties:	Ada Adams Boise Canyon Elmore	Gem Owyhee Payette Valley Washington
IDEQ Coeur d'Alene Regional Office 2110 Ironwood Parkway Coeur d'Alene, ID 83814 (208) 666-4605 chantilly.higbee@deq.idaho.gov	Counties:	Benewah Bonner Boundary	Kootenai Shoshone
IDEQ Idaho Falls Regional Office 900 N. Skyline, Suite B Idaho Falls, ID 83402 (208) 528-2679 alex.bell@deq.idaho.gov	Counties:	Bonneville Butte Clark Custer Fremont	Jefferson Lemhi Madison Teton
IDEQ Lewiston Regional Office 1118 "F" St. Lewiston, ID 83501 (208) 799-4874 sujata.connell@deq.idaho.gov	Counties:	Clearwater Idaho Latah	Lewis Nez Perce
IDEQ Pocatello Regional Office 444 Hospital Way #300 Pocatello, ID 83201 (208) 239-5007 matthew.schenk@deq.idaho.gov	Counties:	Bannock Bear Lake Bingham Caribou	Franklin Oneida Power
IDEQ Twin Falls Regional Office 650 Addison Ave. W., Suite 110, Twin Falls, ID 83301 (208) 737-3877 sean.woodhead@deq.idaho.gov	Counties:	Blaine Camas Cassia Gooding	Jerome Lincoln Minidoka Twin Falls

4. Upon receipt, EPA will review the NOI and NMP for completeness. EPA may request additional information from the CAFO owner or operator if additional information is necessary to complete the NOI and NMP or to clarify, modify, or supplement previously submitted material. If EPA makes a preliminary determination that the NOI is complete, the NOI, NMP, and draft terms of the NMP to be incorporated into the permit will be made available for a thirty (30) day public review and comment period (http://yosemite.epa.gov/r10/HOMEPAGE.NSF/Information/R10PN). The process for submitting public comments and requests for hearing will follow the procedures applicable to draft permits as specified by 40 CFR §§ 124.11 through 124.13. EPA will respond to comments received during the comment period as specified in 40 CFR § 124.17 and, if necessary, require the CAFO owner or operator to revise the NMP in order to obtain permit coverage. If determined appropriate by EPA, CAFOs will be granted coverage under this general permit upon written notification by EPA. EPA will identify the terms of the NMP to be incorporated into the permit in the written notification. Each permittee must comply with the site-specific permit terms established by EPA based on the CAFO's site specific NMP.

5. For new sources, the National Environmental Policy Act (NEPA) requires EPA to conduct an environmental review pursuant to 40 CFR Part 6. NEPA requirements must be complied with prior to authorizing permit coverage to new sources (i.e., Large CAFOs whose construction began after April 14, 2003). New sources seeking permit coverage must submit an Environmental Information Document (EID) or Draft Environmental Assessment (EA) along with their NOI and NMP (40 CFR § 6.200(g)(2) and 40 CFR § 6, Subpart C). Information concerning preparation of an EID or EA can be obtained by contacting the NEPA compliance officer in the EPA, Region 10, NPDES Permits Section.

   These NEPA and NOI requirements also apply to expansions of existing CAFOs that meet the definition of a new source at 40 CFR § 122.2 and the new source criteria at 40 CFR § 122.29(a) and (b). In order to determine if an expansion is a new source, the applicant must submit to EPA information describing the expansion and a map showing the location of the expansion. If EPA determines the expansion meets the new source definition, the owner/operator must prepare and submit an EID or draft EA as described above. The information must be submitted to:

   United States Environmental Protection Agency,
   Region 10 Manager, NPDES Permits Section
   1200 Sixth Avenue, Suite 155, 19-C04
   Seattle, WA 98101-3188

C. Permit Expiration

This permit will expire five (5) years from the effective date. If this permit is not reissued or replaced prior to the expiration date, the permit will be administratively continued and remain in force and effect until it is replaced by a new/reissued permit. Any permittee who has submitted a NOI and been granted coverage will automatically remain covered by the administratively continued permit. Coverage under an administratively continued permit cannot be granted following the expiration date.

D. Change in Ownership

If a change in the ownership of a facility whose discharge is authorized under this permit occurs, coverage under the permit will automatically transfer if (1) the current permittee notifies EPA at least 30 days prior to the proposed transfer date; (2) the notice includes a written agreement between the existing and new permittees containing a specific transfer date for permit responsibility, coverage, and liability between them; and (3) EPA does not notify the existing permittee and the proposed permittee that the operation is no longer eligible for coverage under the General Permit. If the new CAFO owner or operator modifies any part of the NMP, the NMP shall be submitted to EPA in accordance with Section III.A.5 of the permit. EPA will determine if the scope of changes warrants public notice and comment per the requirements of Section I.B.4.

E. Termination of Permit Coverage

1. A permittee may request to terminate coverage under this permit if the permittee makes such a request in writing and one of the following conditions is met:
   a) The facility has ceased all operations and all wastewater or manure storage structures have been properly closed in accordance with the Idaho Natural Resources Conservation Service (NRCS) Conservation Practice Standard No. 360, Closure of Waste Impoundments (Appendix B) contained in the Natural Resources Conservation Service Field Office Technical Guide and all other remaining stockpiles of manure, litter, or process wastewater not contained in a wastewater or manure storage structure are properly disposed in accordance with Section III.C; or
   b) The facility is no longer a CAFO that discharges manure, litter, or process wastewater to waters of the United States; or
   c) The entire discharge is permanently terminated by elimination of the flow or by connection to a publicly owned treatment works (POTW).
2. Requests to terminate coverage under this permit must be made in writing and submitted to EPA at the following address:

United States Environmental Protection Agency,
Region 10 Manager, NPDES Permits Section
1200 Sixth Avenue, Suite 155, 19-C04
Seattle, WA 98101-3188

Beginning December 21, 2020, all requests to terminate coverage must be submitted electronically.

3. Termination of coverage will become effective 30 days after the EPA sends written notice to the permittee unless the permittee objects within that time.

F. Individual Permit Coverage

1. The following CAFOs are not eligible for coverage under this permit, and must apply for an individual permit:
   a) CAFOs that have been notified by EPA that they are ineligible for coverage under this general permit due to a history of non-compliance.
   b) CAFOs that are seeking coverage that will adversely affect species that are federally listed as endangered or threatened ("listed") under the Endangered Species Act (ESA) or adversely modify critical habitat of those species.
   c) CAFOs that are seeking coverage that will have the potential to affect historic properties. CAFO owners/operators must determine whether their permit-related activities have the potential to affect a property that is listed or eligible for listing on the National Register of Historic Places.
   d) CAFOs with discharges to a designated Outstanding Resource Water. As of the effective date of this permit there are no Outstanding Resource Waters approved by the Idaho Legislature.
   e) CAFOs located in Indian Country.
2. EPA may require any facility authorized by this permit to apply for, and obtain, an individual NPDES permit. EPA will notify the operator, in writing, that an application for an individual permit is required and will set a time for submission of the application. Coverage of the facility under this general NPDES permit is automatically terminated when: (1) the operator fails to submit the required individual NPDES permit application within the defined time frame; or (2) the individual NPDES permit is issued by EPA.
3. Any owner/operator who believes that the terms and conditions of this general permit are not appropriate for his/her CAFO facility, either prior to or after obtaining coverage under this permit, may request to be covered under an individual permit pursuant to 40 CFR § 122.28(b)(3)(iii). The owner/operator shall submit an application for an individual permit (Form 1 and Form 2B) with the reasons supporting the application to EPA. If a final, individual NPDES permit is issued to an owner/operator otherwise subject to this general permit, the applicability of this NPDES CAFO general permit to the facility is automatically terminated on the effective date of the individual NPDES permit. Otherwise, the applicability of this general permit to the facility remains in full force and effect.

II. EFFLUENT LIMITATIONS AND STANDARDS

A. Effluent Limitations and Standards Applicable to the Production Area

Except as provided in Section II.A.3, there must be no discharge of manure, litter, or process wastewater into waters of the United States from the production area except as provided below.

1. Whenever precipitation causes an overflow of manure, litter, or process wastewater, pollutants in the overflow may be discharged into waters of the United States provided:

   a) The production area is designed, constructed, operated, and maintained to contain all manure, litter, process wastewater, and the runoff and direct precipitation from the 25-year, 24-hour storm event for the location of the CAFO.

   b) The design storage volume is adequate to contain all manure, litter, and process wastewater accumulated during the storage period including, at a minimum, the following:

      (i) The normal precipitation less evaporation during the storage period;

      (ii) The normal runoff during the storage period;

      (iii) The direct precipitation from a 25-year, 24-hour storm event;

      (iv) The runoff from the 25-year, 24-hour storm event from the production area;

      (v) The residual solids after liquid has been removed;

      (vi) The necessary freeboard to maintain structural integrity; and

      (vii) In the case of treatment lagoons, the necessary minimum treatment volume.

2. The production area must be operated in accordance with the additional measures and records specified below:

   a) Visual Inspections. There must be routine visual inspections of the CAFO production area. At a minimum, the following must be visually inspected:

      (i) Weekly visual inspections of all storm water diversion devices, runoff diversion structures, and devices channeling contaminated storm water to the wastewater or manure storage structures;

      (ii) Daily visual inspections of all water lines, including drinking water and cooling water lines;

      (iii) Weekly inspections of the manure, litter, and process wastewater impoundments, storage and containment structures. The inspection will note the level in liquid impoundments as indicated by the depth marker in Section II.A.2.b) in this section;

   b) Depth Marker. All open surface liquid impoundments must have a depth marker that clearly indicates the minimum capacity necessary to contain the runoff and direct precipitation of the 25-year, 24-hour rain fall event. Install a depth marker in all open wastewater or manure storage structures. The depth marker must clearly indicate the minimum capacity necessary to contain the runoff and direct precipitation of the 25-year, 24-hour rainfall event.

c) Corrective Actions. Any deficiencies found as a result of the daily and weekly inspections must be corrected as soon as possible.

d) Mortality Handling. Mortalities shall not be disposed of in any liquid manure or process wastewater system and must be handled in such a way as to prevent the discharge of pollutants to surface waters of the United States.

e) Record keeping requirements for the production area. The maintenance of complete on-site records documenting the implementation of all required additional measures and corrective actions listed above must be maintained for a period of five years.

3. For all swine, poultry, and veal facilities for which construction of the facility began after April 14, 2003 (New Sources), there shall not be a discharge of manure, litter or process wastewater pollutants into waters of the United States from the production area.

B. Effluent Limitations and Standards Applicable to the Land Application Area

For CAFOs where manure, litter, or process wastewater is applied to land under the control of the CAFO owner/operator, the NMP required by Section III of this permit must include the following requirements:

1. Nutrient transport potential. The NMP must incorporate elements in Section III.A.2.f) based on a field-specific assessment of the potential for nitrogen and phosphorus transport from the field.

2. Form, source, amount, timing, and method of application. The NMP must address the form, source, amount, timing, and method of application of nutrients on each field to achieve realistic production goals, while minimizing nitrogen and phosphorus movement to surface waters.

3. Determination of application rates. Application rates for manure, litter, or process wastewater must minimize phosphorus and nitrogen transport from the field to surface waters in accordance with the Section III.A.2.h).

4. Site-specific conservation practices. Identify appropriate site-specific conservation practices to be implemented, including as appropriate buffers or equivalent practices, to control runoff of pollutants to waters of the United States in accordance with Section III.A.2.f).

5. Protocols to land apply manure, litter or process wastewater. Establish protocols to land apply manure, litter or process wastewater in accordance with site specific nutrient management practices that ensure appropriate agricultural utilization of the

nutrients in the manure, litter or process wastewater in accordance with Section III.A.2.h).

6. Manure and soil sampling. Manure must be analyzed at least once annually for nitrogen and phosphorus content in accordance with Section III.A.2.g)(i). Soil must be analyzed annually for nitrogen and phosphorus content in accordance with Section III.A.2.g)(ii). The results of these analyses must be used in determining application rates for manure, litter, and process wastewater;

7. Inspection of land application equipment for leaks. Equipment used for land application of manure, litter, or process wastewater must be inspected periodically for leaks;

8. Land application setback requirements. Unless the permittee exercises one of the compliance alternatives of this section as provided below in (a) or (b), manure, litter, and process wastewater may not be applied closer than 100 feet to any down-gradient surface waters, open tile line intake structures, sinkholes, agricultural well heads, or other conduits to surface waters.

   a) Vegetated buffer compliance alternative. As a compliance alternative, the CAFO may substitute the 100-foot setback with a 35-foot wide vegetated buffer where applications of manure, litter, or process wastewater are prohibited.

   b) Alternative practices compliance alternative. As a compliance alternative, the CAFO may demonstrate that a setback or buffer is not necessary because implementation of alternative conservation practices or field-specific conditions will provide pollutant reductions equivalent or better than the reductions that would be achieved by the 100-foot setback. Alternative conservation practices can include practices that are designed in consultation with a Professional Engineer licensed in the state of Idaho. Alternatively, an adequate demonstration may include the use of site-specific data using a tool such as the Idaho NRCS Water Quality Technical Note #6, Idaho Nutrient Transport Risk Assessment (INTRA) (Appendix E) or the Idaho Phosphorus Site Index (Appendix I) and associated implementation of alternative conservation practices recommended as a result of these tools.

9. No Dry Weather Discharge. There shall be no dry weather discharge of manure, litter, or process wastewater to a water of the United States from a CAFO as a result of the application of manure, litter or process wastewater to land areas under the control of the CAFO. This prohibition includes discharges to waters of the United States through tile drains, ditches or other conveyances, and irrigation return.

   a) During any land application of manure, litter, or process wastewater to a land application area, a visual inspection of the downgradient edge of the field and any other potential discharge locations (e.g., tile drains, ditches, or other conveyances) must be conducted during the land application event and after the land application event to check for field runoff and discharges. This also applies where a land application setback or compliance alternative is required pursuant to Section II.B.8 of this permit, to confirm that the land application setback or compliance alternative is being maintained and functioning as intended, and to determine if there are any discharges. In the event of a discharge, the monitoring requirements of Section IV.E.1 must be implemented.

10. Prohibition on Land Application to Frozen, Snow-Covered and Saturated Soils. The land application of manure, litter, or process wastewater must not occur when the land application area is:

   a) Frozen and/or snow-covered soils, or

   b) When the top two inches of soil are saturated from rainfall, snow melt, irrigation, or when current or predicted weather is capable of producing such conditions.

III. SPECIAL CONDITIONS

A. Nutrient Management Plan

The permittee shall develop, submit, and implement a site-specific Nutrient Management Plan (NMP). The NMP shall identify and describe practices that will be implemented to ensure compliance with the effluent limitations and special conditions of this permit (Sections II and III). Unless otherwise stated in this permit, the NMP must be developed in accordance with Section III.A.2 below.

1. Schedule. The completed NMP must be submitted to EPA with a NOI for CAFOs seeking coverage under this permit. The permittee shall implement its NMP upon authorization under this permit.

2. NMP Content. The NMP must include site-specific practices and procedures necessary to implement the applicable effluent limitations and standards. In addition, the NMP must:

   a) Ensure adequate storage of manure, litter, and process wastewater including procedures to ensure proper operation and maintenance of the wastewater and manure storage structures. All wastewater and manure storage structures shall be designed, constructed, operated, and maintained in accordance with the requirements specified in Section II.A.1 of this permit.

      (i) The permittee must determine if existing or planned wastewater and manure storage structures are adequately sized in accordance with Section II.A.1 by evaluating each wastewater or manure storage structure. The permittee may use the Idaho Animal Waste Management (IDAWM) Software, Version 4, December 2000 (Appendix C) and accompanying spreadsheet, the NRCS

Animal Waste Management Software, or demonstrate that the facility is designed with adequate storage capacity as determined by runoff and design calculations followed by an as-built survey conducted by a Professional Engineer licensed in the state of Idaho. If the evaluation determines that the existing wastewater or manure storage structures have a storage capacity less than the minimum capacity requirements specified in Section II.A.1, the NMP must include measures the permittee will take to ensure that the storage capacity specified in Section II.A.1 is met. The NMP must include in the evaluation the results of the wastewater and manure storage structure evaluations, including any corrective and interim measures, and a schedule for implementation.

(ii) The permittee must ensure the proper operation and maintenance of each wastewater and manure storage structure by evaluating compliance with NRCS Appendix 10D and IDAPA 02.04.14.030.01. If the evaluation of the wastewater or manure storage structures identifies deficiencies in the operation or maintenance of the structures, the permittee must identify measures to address those deficiencies in its NMP. This evaluation must be completed in one of the following ways:

(a) By a Professional Engineer, geologist, hydrogeologist, or another qualified individual, in which case the NMP must include the results of the evaluation; or

(b) By completing the Washington NRCS Engineering Technical Note #23, January 2013 (Appendix D), in which case the NMP must include the results of the evaluation.

(iii) The permittee must include a subsurface discharge monitoring plan to identify and monitor any subsurface discharges from each wastewater or manure storage structure in accordance with the specifications in Section IV.D.6. The NMP must include the subsurface discharge monitoring plan and the results of all subsurface monitoring from each wastewater and manure storage structure. The permittee must develop a subsurface discharge monitoring plan as part of the NMP unless the exceptions in (a) or (b) below are met:

(a) Each wastewater or manure storage structure must be evaluated by a Professional Engineer, geologist, hydrogeologist or another qualified individual documenting that each wastewater or manure storage structure does not have a subsurface discharge to Waters of the United States.

(b) Confirm, and maintain documentation in NMP, that each wastewater and manure storage structure is constructed of concrete or steel, or with a double-layer synthetic liner with leak detection, and is properly operated and maintained in accordance with III.A.2.a.ii.

b) Ensure proper management of mortalities (i.e., dead animals) to ensure that they are not disposed of in a liquid manure, storm water, or process wastewater storage or treatment system that is not specifically designed to treat animal mortalities. Mortality handling practices must be in accordance with all applicable Federal, State, and local regulatory requirements.

The permittee must include information in its NMP that addresses both typical and catastrophic mortalities. At a minimum, the NMP must identify the following:

(i) Schedules for collecting, storing, and disposing of carcasses;

(ii) Description of on-site storage before disposal;

(iii) Description of final disposal method;

(iv) Additional management practices to protect waters of the United States for on-site disposal including composting or burial; and

(v) Contingency plans for mass mortalities.

c) Ensure that clean water is diverted, as appropriate, from the production area. Any clean water that is not diverted and comes into contact with raw materials, products, or byproducts including manure, litter, process wastewater, feed, milk, eggs, or bedding is subject to the effluent limitations specified in Section II.A of this permit. Where clean water is not diverted from the production area, the wastewater or manure storage structure shall include adequate storage capacity for the additional clean water. Clean water includes, but is not limited to, snow melt and/or rain falling on the roofs of facilities and runoff from adjacent land. The NMP must identify the BMPs or engineering controls, existing or needed, to exclude clean water from the production area. The NMP must include operation and maintenance procedures required to maintain the existing BMPs or engineering controls or the timing for the construction of needed BMPs or engineering controls.

d) Prevent the direct contact of animals confined or stabled at the facility with waters of the United States. Animals confined at the CAFO must not come into direct contact with waters of the United States. At a minimum, the NMP must describe the BMPs or engineering controls the CAFO will use to prevent animals in the production area from coming into contact with waters of the United States.

e) Ensure that chemicals and other contaminants handled on-site are not disposed of in any manure, litter, process wastewater, or storm water storage or treatment system unless specifically designed to treat such chemicals or contaminants. All wastes from dipping vats, pest and parasite control units, and other facilities utilized for the management of potentially hazardous or toxic chemicals shall be handled and disposed of in a manner sufficient to prevent pollutants from entering the manure, litter, or process wastewater storage structure or waters of the United States. The NMP must include references to any applicable chemical storage and handling protocols and incorporate specific BMPs and actions that will be taken to prevent the improper disposal of chemicals and other contaminants into any manure, litter, process wastewater, or storm water storage or treatment system. The NMP should also consider chemical handling plans for the protection of wells, water supplies, and any drainage ways that are close to chemical storage and handling areas.

f) Identify appropriate site-specific conservation practices to be implemented on the land application areas, including as appropriate buffers or equivalent practices as stipulated in Section II.B.8, to control runoff of pollutants to waters of the United States. The NMP must include appropriate conservation practices identified by evaluating each land application area using the Idaho NRCS Water Quality Technical Note #6, Idaho Nutrient Transport Risk Assessment (INTRA) (Appendix E). CAFOs may opt to utilize the Idaho Phosphorus Site Index (P Index) (Appendix I). The NMP must include the results of the INTRA or P Index evaluations. All CAFOs must follow guidance provided by INTRA and the P Index. If the site-specific conservation practices are NRCS conservation practice standards, the NMP must include provisions to operate and maintain those site-specific conservation practices according to the specific NRCS conservation practices standard. If the owner/operator proposes alternative practice or performance standards, the NMP must describe and cite those standards so that EPA can perform an adequate review. In addition, the NMP must include a schedule for implementation of site-specific conservation practices and proper operation and maintenance procedures.

g) Protocols for appropriate testing of manure, litter, process wastewater, and soil.

(i) Manure must be analyzed at least once annually for nitrogen and phosphorus content in accordance with the University of Idaho Manure and Wastewater Sampling CIS 1139 (Appendix F). The results of these analyses must be included in the NMP and be used in determining application rates for manure, litter, and process wastewater as described in Section III.A.2.h).

(ii) Soil samples must be taken from every field to which manure, litter and process wastewater will be applied. Soil must be analyzed annually in accordance with University of Idaho Bulletin 704 (Appendix G). At a minimum, soil samples must be analyzed for the following constituents: pH, soil organic matter (SOM), Nitrate- Nitrogen (NO_3-N), Ammonium-Nitrate (NH_4-N), and phosphorus (P). The results of these analyses must be included in the NMP and used in determining application rates for manure, litter, and process wastewater as described in Section III.A.2.h).

(iii) Soil samples must be analyzed by a laboratory certified by the North American Proficiency Testing Program (NAPT). Manure samples must be analyzed by a certified Manure Analysis Proficiency Laboratory.

h) Establish protocols to land apply manure, litter, or process wastewater in accordance with site specific nutrient management practices that ensure appropriate agricultural utilization of the nutrients in the manure, litter, or process wastewater.

Annual nutrient budgets must be generated to determine land application rates for each field where manure, litter, or process wastewater is applied. The annual budget must be included in the NMP and be developed in accordance with the University of Idaho Fertilizer Guides or related University of Idaho Crop Production Guide. In the absence of an appropriate University of Idaho Fertilizer or Crop Production Guide, a fertilizer or production guide from a Pacific Northwest Land Grant University may be used (i.e., Oregon State University or Washington State University). In the absence of specific Land Grant University fertilizer or production guides, the NMP must identify and include the best available data used to determine specific land application rates for the crop. The NMP must express land application rates of nutrients in pounds per acre, and volume of manure, litter, and process wastewater in tons, gallons or cubic feet. Ensuring accurate application rates reduces probability of off-site transport. The NMP developed to meet the requirements of this permit, and submitted to the permitting authority for review, must include all necessary calculations. Thereafter, for the remainder of the permit term, application rates may be calculated annually, or immediately prior to land application, if all data and calculations are appropriately documented in the NMP.

i) Identify and maintain site specific records to document the implementation and management of the minimum elements described in Sections **Error! Reference source not found.**-h and in compliance with the permit.

3. Signatory. The NMP shall be signed by the owner/operator or other signatory authority in accordance with Section V.C.5 (Signatory Requirements) of this permit.

4. NMP Availability**.** A current copy of the NMP shall be kept on site at the permitted facility in accordance with Section IV.A of this permit and provided to the permitting authority upon request.

5. Changes to the NMP

a) When a permittee makes changes to the CAFO's NMP previously submitted to EPA, the CAFO owner or operator must provide EPA with the most current version of the CAFO's NMP and identify changes from the previous version.

b) When changes to a NMP are submitted to EPA, EPA will review the revised NMP to ensure that it meets the requirements of Section II and Section III.A.2. If EPA determines that the changes to the NMP necessitate revision to the terms of the NMP incorporated into the permit issued to the CAFO, EPA will determine whether such changes are substantial as defined by 40 CFR 122.42(e)(6).

Substantial changes to the terms of a NMP incorporated as terms and conditions of a permit include, but are not limited to:

(i) Addition of new land application areas not previously included in the CAFO's NMP;

(ii) Changes to the maximum amounts of nitrogen and phosphorus derived from all sources for each crop;

(iii) Addition of any crop or other uses not included in the terms of the CAFO's NMP; and

(iv) Changes to site specific components of the CAFO's NMP, where such changes are likely to increase the risk of nitrogen and phosphorus transport to waters of the United States.

c) If EPA determines that the changes to the terms of the NMP are not substantial, EPA will make the revised NMP publicly available and include it in the permit file, revise the terms of the NMP incorporated into the permit, and notify the permittee and the public of any changes to the terms of the NMP that are incorporated into the permit.

d) If EPA determines that the changes to the terms of the NMP are substantial, EPA will provide the public with the opportunity to comment upon the changes to the NMP and the information submitted by the CAFO owner or operator as set forth in Section III.A.2. of this permit. EPA will respond to all significant comments received during the comment period. The process for public comments, hearing requests and the hearing process, if a hearing is held, will follow the procedures set forth in 40 CFR 124.11 through 124.13.

EPA may require the permittee to further revise the NMP, if necessary. Once EPA incorporates the revised terms of the NMP into the permit, EPA will notify the permittee of the revised terms and conditions of the permit.

B. Lagoon Liner Requirements

Liner Requirements: CAFOs constructing new wastewater or manure storage structures or modifying existing wastewater or manure storage structures shall have a liner that is constructed and maintained in accordance with Idaho NRCS practice standards. Any damage to the liner must be evaluated by a Professional Engineer and corrected within thirty (30) days of the damage, unless the Permitting Authority approves an alternative schedule. The permittee must submit the request within thirty (30) days of the damage, and it must include the Professional Engineer's evaluation of the risks of pollutant releases if the liner is not repaired immediately. All documentation of liner maintenance shall be kept with the NMP.

C. Facility Closure

The following conditions shall apply to the closure of lagoons and other earthen or synthetic lined basins and other manure, litter, or process wastewater storage and handling structures:

1. Closure of Lagoons and Other Surface Impoundments

   a) No lagoon or other earthen or synthetic lined basin shall be permanently abandoned.

   b) Lagoons and other earthen or synthetic lined basins shall be maintained at all times until closed in compliance with this section.

   c) All lagoons and other earthen or synthetic lined basins that are no longer needed as a part of a waste management system and are to be permanently decommissioned or converted for another use must be properly closed consistent with the Idaho NRCS Practice Standard Code 360 contained in Natural Resources Conservation Service Field Office Technical Guide (Appendix B). Consistent with this standard the permittee shall remove all waste materials to the maximum extent practicable and dispose of them in accordance with the permittee's NMP, unless otherwise authorized by EPA.

   d) For any lagoon or other earthen or synthetic lined basin that is not in use for a period of twelve (12) consecutive months but will not be permanently decommissioned or converted to another use, the permittee shall:

      (i) Maintain the structure as though it were actively in use in order to prevent compromise of structural integrity.

      (ii) The permittee shall notify EPA, in writing, of the action taken, and shall conduct routine inspections, maintenance, and record keeping as though the structure were in use. Prior to restoration of use of the structure, the permittee shall notify EPA, in writing, and provide the opportunity for inspection. The permittee shall properly handle and dispose of the water used to preserve the integrity synthetic or earthen liner during periods of non-use in accordance with the NMP.

   e) Unless otherwise authorized by EPA, completion of closure for lagoons and other earthen or synthetic lined basins shall occur as promptly as practicable after the permittee ceases to operate or, if the permittee has not ceased operations, twelve (12) months from the date on which the use of the structure ceased, unless the lagoons or basins are being maintained for possible future use in accordance with the requirements above.

2. Closure Procedures for Other Manure, Litter, or Process Wastewater Storage and Handling Structure

   No other manure, litter, or process wastewater storage and handling structure shall be abandoned. Closure of all such structures shall occur as promptly as practicable within twelve (12) months after the date on which the use of the structure ceased, unless the lagoons or basins are being maintained for possible future use in accordance with the requirements above. To close a manure, litter, or process wastewater storage and handling structure, the permittee shall remove all manure, litter, or process wastewater and dispose of it in accordance with the permittee's NMP, or document its transfer from the permitted facility in accordance with off-site transfer requirements specified in this permit Section III.D, unless otherwise authorized by EPA.

D. Requirements for the Transfer of Manure, Litter, and Process Wastewater

1. In cases where CAFO-generated manure, litter, or process wastewater is sold or given away, the permittee must comply with the following conditions:

   a) Maintain records showing the date and amount of manure, litter, and/or process wastewater that leaves the permitted facility;

   b) Record the name and address of the recipient;

   c) Provide the recipient(s) with representative information on the nutrient content of the manure, litter, and/or process wastewater analyzed in accordance with Section III.A.2.g)(i); and

   d) Retain the records on-site, for a period of five years, and submit the records to EPA, upon request.

IV. RECORDS, REPORTING, MONITORING, AND NOTIFICATION

A. Records Management

1. Record Keeping Requirements for the Production Area

   The permittee must maintain on-site for a period of five (5) years from the date they are created a complete copy of the NOI, the NMP, records to document the implementation and management of Section II.A and Section **Error! Reference source not found.**-(e), Section IV.D and Section IV.A.1.a)-i below. The permittee must make these records available to EPA upon request.

   a) Records documenting the inspections of all storage, containment and treatment structures as required under Section II.A.2.a) and Section **Error! Reference source not found.**;

   b) Weekly records of the depth of the manure and process wastewater in storage, containment and/or treatment structure(s), as applicable, as indicated by the depth marker under Section II.A.2.b);

   c) Documentation of whether or not the wastewater level in all liquid waste storage structures is below the level required to maintain capacity to store the runoff and precipitation from a 25-year, 24-hour storm under Section II.A.2.b);

d) Records documenting the inspections of all stormwater diversion and channel structures under Section III.A.2.c);

e) Records documenting the inspections of all water line inspections, including drinking and cooling water lines and whether or not leaks were discovered;

f) For all structures in Section II.A.2.a)(i)-iii, records documenting any actions taken to correct deficiencies required under Section II.A.2.c). Deficiencies not corrected with thirty (30) days must be accompanied by an explanation of the factors preventing immediate correction;

g) Records of mortalities management and practices used by the permittee to meet the requirements of Section II.A.2.d) and Section III.A.2.b);

h) Records documenting the current design of any wastewater or manure storage structure to meet the requirements of Section II.A.1.b). including volume for solids accumulation, design treatment volume, total design volume, and approximate number of days of storage capacity; and

i) Records of the date, time, and estimated volume of any overflow and additional requirements of Section IV.D.

2. Record Keeping Requirements for the Land Application Area

Each permittee must maintain on-site for a period of five (5) years from the date they are created, a complete copy of the information required by Section II.B and Section III.A.2.f)-i, and the records specified in Section IV.A.2.a)-g below. The permittee must make these records available to EPA upon request. For every field, provide the following information associated with the same unique field identification used in the NMP:

a) The date(s) manure, litter, or process waste water application was begun for each field, for each land application event and all methods associated with the application of the manure, litter or process wastewater, including application method, incorporation method, soil surface conditions, weather conditions, number of acres utilized, amounts of manure, litter and process wastewater, and total amounts of nitrogen and phosphorus applied under Sections II.B.2, 3 and 5 and Section III.A.2.h);

b) Documentation of all manure, litter or process wastewater sample collection and analysis protocols under Section II.B.6 and Section III.A.2.g)(i);

c) Documentation of all soil sample collection and analysis protocols under Section II.B.6 and Section III.A.2.g)(ii);

d) Documentation that all required setbacks, buffers or approved alternatives and conservation practices identified in the NMP were observed and/or implemented, and an explanation for any deviation from these practices under Section II.B.4 and Section II.B.8;

e) The date that the equipment used for the land application event was last inspected under Section II.B.7; and

f) Documentation for all requirements for manure, litter and process wastewater transfers under Section III.D.

g) Documentation of visual inspections of potential land application area discharge locations and land application setback(s) or compliance alternative(s) specified in Sections II.B.9.a)

B. Annual Reporting Requirements

1. The permittee shall submit an annual report by March 1st of each year. Prior to December 20, 2020, reports must be submitted electronically or in hard copy to EPA, the appropriate IDEQ district office and Idaho State Department of Agriculture. Hard copies may be submitted to the addresses below.

   U.S. EPA Region 10
   Attn: ICIS Data Entry Team
   1200 6th Avenue, Suite 155 ECAD-101
   Seattle, Washington 98101-3188

   Idaho State Department of Agriculture
   Division of Animal Industries
   P.O. Box 790
   Boise, Idaho 83701

   After December 20, 2020, annual reports must be submitted *electronically only* to IDEQ. Annual Reports must continue also be submitted to the Idaho State Department of Agriculture.

2. The permittee may seek an electronic reporting waiver by submitting a request. Prior to July 1, 2020, this request must be submitted to EPA. Beginning July 1, 2020, this request must be submitted to IDEQ. This waiver request should contain the following details: facility name; NPDES permit number; facility address; name, address and contact information for the owner, operator, or duly authorized facility representative; and a brief written statement regarding the basis for claiming such a temporary waiver. The request will be either approved or denied within 120 days. The duration of the temporary waiver will not exceed 5 years.

3. The annual report must include all of the information detailed in the Annual Report Template in Appendix H. The permittee may use the fillable pdf template provided or may compile all of the required information in a separate document. Completion and electronic submittal of the Annual Report template shall fulfill the electronic reporting requirements.

C. Notification of Unauthorized Discharges Resulting from Manure, Litter, and Process Wastewater Storage, Handling, On-site Transport and Application

1. If, for any reason, there is an unauthorized discharge of pollutants to a water of the United States, the permittee is required to make immediate oral notification within 24-hours to the EPA Region 10, NPDES Compliance Section, Enforcement and Compliance Assurance Division, Seattle, WA at 206-553-1846 and notify ISDA, the appropriate IDEQ regional office, and the appropriate county authorities in writing, within five (5) working days of the discharge of pollutants to a water of the United States from the facility. In addition, the permittee shall keep a copy of the notification submitted to EPA and ISDA together with the other records required by this permit. The discharge notification shall include the following information:
   a) A description of the discharge and its cause, including a description of the flow path to the receiving water body and an estimate of the flow and volume discharged; and
   b) The period of non-compliance, including exact dates and times, the anticipated time it is expected to continue, and steps taken or planned to reduce, eliminate and prevent recurrence of the discharge.

D. Monitoring Requirements for All Discharges from Wastewater or Manure Storage Structures

1. In the event of any overflow or other discharge, including any subsurface discharges, of pollutants to waters of the United States from a manure or wastewater storage structure, whether or not authorized by this permit the following actions shall be taken:
   a) All discharges from wastewater or manure storage structures to waters of the United States shall be sampled and analyzed. Samples must, at a minimum, be analyzed for the following parameters: total nitrogen, nitrate nitrogen, ammonia nitrogen, total phosphorus, *E. coli*, five-day biochemical oxygen demand (BOD5), total suspended solids, pH, and temperature. The discharge must be analyzed in accordance with approved EPA methods for water analysis listed in 40 CFR Part 136;
   b) For any overflow or other discharge, including any subsurface discharge, subject to monitoring under paragraph 1, if the duration of the discharge event exceeds 24 hours, the discharge shall be monitored daily until the discharge ceases.
2. Record an estimate of the volume of the release and the date and time;
3. Samples shall consist of grab samples collected from the point of overflow or discharge from the waste impoundment or production area. Subsurface discharges shall be sampled at the point of discharge to the receiving water. If the point of discharge to the receiving water is inaccessible, samples of subsurface discharges shall be collected at a point that provides a sample that is representative of the discharge to the receiving water. A minimum of one sample shall be collected within 30 minutes of the detection of the overflow or discharge and the sample(s) of the overflow or discharge must be collected and analyzed in accordance with EPA

approved methods for water analysis listed in 40 CFR Part 136. The sample(s) collected from the overflow or discharge must be representative of the overflow or discharge;

4. If conditions are not safe for sampling, the permittee must provide documentation of why samples could not be collected and analyzed. For example, the permittee may be unable to collect samples during dangerous weather conditions (such as local flooding, high winds, hurricane, tornadoes, electrical storms, etc.). However, once dangerous conditions have passed, the permittee shall collect a sample from the wastewater or manure storage structure from which the discharge occurred;

5. The analytical results of the representative sample(s) taken from the overflow or discharge must be submitted to EPA Region 10, Enforcement and Compliance Assurance Division, within thirty (30) days of the overflow or discharge. Copies of the analytical results shall also be submitted to ISDA and the IDEQ state and appropriate regional office at the addresses listed in Section I.B.3 of this permit; and

6. Subsurface Discharge Monitoring Plan. For those CAFOs required to include a subsurface discharge monitoring plan in the NMP, pursuant to Section **Error! Reference source not found.** of this permit, the plan that is included in the CAFO's NMP must include site-specific information and procedures that will be implemented to address the following:

   a) Identification of the structures and/or locations to be monitored;

   b) Routine periodic monitoring adequate to identify leaks, damage, and other issues that could cause a subsurface discharge, including the frequency of monitoring and the specific technology or protocols that will be used;

   c) Criteria or protocols that will be used to determine whether a subsurface discharge has occurred; and

   d) Site specific protocols for monitoring subsurface discharges in accordance with the requirements in Section IV.D.

E. Monitoring Requirements for Discharges from Land Application Areas

1. In the event of any runoff or discharge from a CAFO's land application area to a water of the United States, the actions specified below must be taken. Discharges subject to monitoring requirements include, but are not limited to, (1) dry weather discharges resulting from land application of manure, litter, or process wastewater, including discharges through tile drains, ditches, or other conveyances, and irrigation return, and (2) stormwater or snowmelt runoff or discharges of manure, litter, or process wastewater that has not been applied in accordance with site specific nutrient management practices that ensure appropriate agricultural utilization of the nutrients

in the manure, litter or process wastewater as provided in 33 U.S.C. § 1362(14) and 40 CFR § 122.23(e).

a) All discharges that meet either of the two criteria specified in Section E.1 above from land application areas to waters of the United States shall be sampled and analyzed as follows.

  (i) Grab samples of the discharge must be collected at a location prior to mixing with the receiving waters, that will provide for a representative sample of the discharge. The specific sampling location(s) must be documented.

  (ii) Samples shall be collected in accordance with the protocols described in Section 3 of EPA's Industrial Stormwater Monitoring and Sampling Guide (EPA 832-B-09-003, April 2021). For sheet flow discharges that are too shallow to collect with a sample bottle, the protocols in the Industrial Stormwater Monitoring and Sampling Guide may be supplemented with procedures for installing a temporary barrier device or similar structure to intercept runoff flow.

  (iii) Samples must, at a minimum, be analyzed for the following parameters: total Kjeldahl nitrogen (TKN), nitrate nitrogen, nitrite nitrogen, total phosphorus, E. coli, fecal coliform, and five-day biochemical oxygen demand (BOD_5).

  (iv) The discharge samples must be analyzed in accordance with approved EPA methods for water analysis listed in 40 CFR Part 136.

b) Samples of the receiving water shall be collected upstream and downstream of the point of discharge to the receiving stream as follows.

  (i) Upstream samples must be collected at a location that provides a representative sample of the water quality immediately upstream of the discharge, prior to mixing with the discharge. Downstream samples must be collected at a location that provides a representative sample of the water quality after mixing with the discharge and prior to the introduction of other pollutant sources. The specific sampling locations must be documented.

  (ii) Samples shall be collected in accordance with EPA Region 4's Surface Water Sampling procedures (LSASDPROC-201-R5, December 2021).

  (iii) Grab samples of ambient receiving waters must, at a minimum, be analyzed for the following parameters: total Kjeldahl nitrogen (TKN), nitrate nitrogen, nitrite nitrogen, total phosphorus, E. coli, fecal coliform, and five-day biochemical oxygen demand (BOD_5).

  (iv) The receiving water samples must be analyzed in accordance with approved EPA methods for water analysis listed in 40 CFR Part 136.

c) A log shall be kept of the receiving water conditions throughout the reach bounded by the upstream and downstream sampling locations during the discharge event. The log must document any discoloration; bottom deposits; condition of any aquatic life observed; presence of visible films, sheens or coatings; fungi, slimes or objectionable growths; and potential nuisance conditions.

d) For any discharge subject to monitoring under Section E.1, if the duration of the discharge event exceeds 24 hours, the discharge and receiving water shall be monitored daily until the discharge ceases.

e) An estimate of the volume of the discharge and the date and time must be recorded;

f) If conditions are not safe for sampling, the permittee must provide documentation of why samples could not be collected and analyzed. For example, the permittee may be unable to collect samples during dangerous weather conditions (such as local flooding, high winds, hurricane, tornadoes, electrical storms, etc.). However, once dangerous conditions have passed, the permittee shall collect a sample of the discharge. If the discharge stops before dangerous conditions have passed, and therefore cannot be sampled, the permittee shall record the estimated time, duration, and volume of the discharge, and the reason the sample could not be collected, and include this information in the Notification of Unauthorized Discharge submitted in accordance with Section IV.C of this permit.

g) The analytical results of the representative sample(s) taken from the discharge and receiving water must be submitted to EPA Region 10, Enforcement and Compliance Assurance Division, within thirty (30) days of the discharge. Copies of the analytical results shall also be submitted to ISDA and the IDEQ state and appropriate regional office at the addresses listed in Section I.B.3 of this permit.

F. Spills / Releases in Excess of Reportable Quantities

1. This permit does not relieve the permittee of the federal reporting requirements of 40 CFR §§ 110, 117 and 302 relating to spills or other releases of oils or hazardous substances.

   Where a release containing a hazardous substance or oil in an amount equal to or in excess of a reportable quantity established under either 40 CFR § 110, 40 CFR § 117 or 40 CFR § 302, occurs during a 24-hour period:

a) The permittee must provide notice to the National Response Center (NRC) (800–424–8802; in the Washington, DC, metropolitan area, call 202–267– 2675) in accordance with the requirements of 40 CFR §§ 110, 117 and 302 as soon as site staff have knowledge of the discharge; and

b) The permittee must, within 7 calendar days of knowledge of the release, provide a description of the release, the circumstances leading to the release, and the date of the release. The permittee must also implement measures to prevent the reoccurrence of such releases and to respond to such releases.

2. Any spill of hazardous material must be immediately reported to the appropriate IDEQ regional office (see table below). Spills of petroleum products that exceed 25 gallons or that cause a visible sheen on nearby surface waters should be reported to IDEQ within 24-hours. Petroleum product spills of less than 25 gallons that do not cause a sheen on nearby surface waters shall only be reported to IDEQ if clean-up cannot be accomplished within 24-hours.

   IDEQ Regional Office contact information for reporting spills

Regional Office	Phone #	Regional Office	Phone #
Boise	(208) 373-0550	Lewiston	(208) 799-4370
Coeur d'Alene	(208) 769-1422	Pocatello	(208) 236-6160
Idaho Falls	(208) 528-2650	Twin Falls	(208) 736-2190

   Outside of regular business hours, qualified spills should be reported to the IDEQ 24-hour reporting hotline at 1-833-IPDES24.

V. Standard Permit Conditions

A. General Monitoring, Recording, and Reporting Requirements

1. Representative Sampling

   Samples and measurements must be representative of the volume and nature of the monitored discharge.

2. Reporting of Monitoring Results

   If applicable, the permittee must submit the legible originals of the monitoring results to the Director of the Enforcement and Compliance Assurance Division with copies to ISDA at the following addresses:

   US EPA Region 10
   Attn: ICIS Data Entry Team
   1200 Sixth Avenue, Suite 155 ECAD 20-C04
   Seattle, Washington 98101-3140
   Idaho State Department of Agriculture
   Division of Animal Industries
   P.O. Box 790
   Boise, ID 83701

3. Monitoring Procedures

   Monitoring must be conducted according to test procedures approved under 40 CFR § 136, unless other test procedures have been specified in this permit or approved by EPA as an alternate test procedure under 40 CFR § 136.5.

4. Additional Monitoring by Permittee

   If the permittee monitors any pollutant more frequently than required by this permit, using test procedures approved under 40 CFR § 136 or as specified in this permit, the permittee must include the results of this monitoring in the calculation and reporting of the data submitted to EPA.

   Upon request by EPA, the permittee must submit results of any other sampling, regardless of the test method used.

5. Records Contents.

   Records of monitoring information must include:

   a) The date, exact place, and time of sampling or measurements;
   b) The name(s) of the individual(s) who performed the sampling or measurements;
   c) The date(s) analyses were performed;
   d) The names of the individual(s) who performed the analyses;
   e) The analytical techniques or methods used; and
   f) The results of such analyses.

6. Retention of Records

   The permittee must retain records of all monitoring information, including, all calibration and maintenance records and all original strip chart recordings for continuous monitoring instrumentation, copies of all reports required by this permit, a copy of the NPDES permit, and records of all data used to complete the application for this permit, for a period of at least five years from the date of the sample, measurement, report or application. This period may be extended by request of EPA or State/Tribal agency at any time.

7. Other Noncompliance Reporting

   The permittee must report all instances of noncompliance, not required to be reported within 24 hours, at the time that monitoring reports for Section V.A.2 (Reporting of Monitoring Results) are submitted. The reports must contain the information listed in Section IV.B of this permit ("Notification of Discharges Resulting from Manure, Litter, and Process Wastewater Storage, Handling, On- site Transport and Application").

8. Changes in Discharge of Toxic Pollutant

   The permittee must notify the Director of the Water Division and IDEQ as soon as it knows, or has reason to believe:

   a) That any activity has occurred or will occur that would result in the discharge, on a routine or frequent basis, of any toxic pollutant that is not limited in the permit, if that discharge may reasonably be expected to exceed the highest of the following "notification levels":

(i) One hundred micrograms per liter (100 ug/l);

(ii) Two hundred micrograms per liter (200 ug/l) for acrolein and acrylonitrile; five hundred micrograms per liter (500 ug/l) for 2,4- dinitrophenol and for 2-methyl-4, 6-dinitrophenol; and one milligram per liter (1 mg/l) for antimony;

(iii) Five (5) times the maximum concentration value reported for that pollutant in the permit application in accordance with 40 CFR § 122.21(g)(7); or

(iv) The level established by EPA in accordance with 40 CFR § 122.44(f).

b) That any activity has occurred or will occur that would result in any discharge, on a non-routine or infrequent basis, of any toxic pollutant that is not limited in the permit, if that discharge may reasonably be expected to exceed the highest of the following "notification levels":

(i) Five hundred micrograms per liter (500 ug/l);

(ii) One milligram per liter (1 mg/l) for antimony;

(iii) Ten (10) times the maximum concentration value reported for that pollutant in the permit application in accordance with 40 CFR § 122.21(g)(7); or

(iv) The level established by EPA in accordance with 40 CFR § 122.44(f).

c) The permittee must submit the notification to the Water Division at the following address:

US EPA Region 10
Attn: NPDES Permits Section Manager
1200 Sixth Avenue, Suite 155, 19-C04
Seattle, Washington 98101-3188

B. Compliance Responsibilities

1. Duty to Comply

The permittee must comply with all conditions of this permit. Any permit noncompliance constitutes a violation of the Act and is grounds for enforcement action, for permit termination, revocation and reissuance, or modification, or for denial of a permit renewal application.

2. Penalties for Violations of Permit Conditions

a) Civil and Administrative Penalties. Pursuant to 40 CFR § 19 and the Act, any person who violates section 301, 302, 306, 307, 308, 318 or 405 of the Act, or any permit condition or limitation implementing any such sections in a permit issued under section 402, or any requirement imposed in a pretreatment program approved under sections 402(a)(3) or 402(b)(8) of the Act, is subject to a civil penalty not to exceed the maximum amounts authorized by Section 309(d) of the Act and the Federal Civil Penalties Inflation Adjustment Act (28 U.S.C. § 2461 note) as amended by the Debt Collection Improvement Act (31 U.S.C. § 3701 note) (currently $66,712 per day for each violation).

b) Administrative Penalties. Any person may be assessed an administrative penalty by the Administrator for violating section 301, 302, 306, 307, 308, 318 or 405 of this Act, or any permit condition or limitation implementing any of such sections in a permit issued under section 402 of this Act. Pursuant to 40 CFR 19 and the Act, administrative penalties for Class I violations are not to exceed the maximum amounts authorized by Section 309(g)(2)(A) of the Act and the Federal Civil Penalties Inflation Adjustment Act (28 U.S.C. § 2461 note) as amended by the Debt Collection Improvement Act (31 U.S.C. § 3701 note) (currently $26,685 per violation, with the maximum amount of any Class I penalty assessed not to exceed $66,712). Pursuant to 40 CFR 19 and the Act, penalties for Class II violations are not to exceed the maximum amounts authorized by Section 309(g)(2)(B) of the Act and the Federal Civil Penalties Inflation Adjustment Act (28 U.S.C. § 2461 note) as amended by the Debt Collection Improvement Act (31 U.S.C. § 3701 note) (currently $26,685 per day for each day during which the violation continues, with the maximum amount of any Class II penalty not to exceed $333,552).

c) Criminal Penalties:

(i) Negligent Violations. The Act provides that any person who negligently violates sections 301, 302, 306, 307, 308, 318, or 405 of the Act, or any condition or limitation implementing any of such sections in a permit issued under section 402 of the Act, or any requirement imposed in a pretreatment program approved under section 402(a)(3) or 402(b)(8) of the Act, is subject to criminal penalties of $2,500 to $25,000 per day of violation, or imprisonment of not more than 1 year, or both. In the case of a second or subsequent conviction for a negligent violation, a person shall be subject to criminal penalties of not more than $50,000 per day of violation, or by imprisonment of not more than 2 years, or both.

(ii) Knowing Violations. Any person who knowingly violates such sections, or such conditions or limitations is subject to criminal penalties of $5,000 to $50,000 per day of violation, or imprisonment for not more than 3 years, or both. In the case of a second or subsequent conviction for a knowing violation, a person shall be subject to criminal penalties of not more than $100,000 per day of violation, or imprisonment of not more than 6 years, or both.

(iii) Knowing Endangerment. Any person who knowingly violates section 301, 302, 303, 306, 307, 308, 318 or 405 of the Act, or any permit condition or limitation implementing any of such sections in a permit issued under section 402 of the Act, and who knows at that time that he thereby places another person in imminent danger of death or serious bodily injury, shall, upon conviction, be subject to a fine of not more than $250,000 or imprisonment of not more than 15 years, or both. In the case of a second or subsequent conviction for a knowing endangerment violation, a person shall be subject to a fine of not more than $500,000 or by imprisonment of not more than 30 years, or both. An organization, as defined in section 309(c)(3)(B)(iii) of the Act, shall, upon conviction of violating the imminent danger provision, be subject to a fine of not more than $1,000,000 and can be fined up to $2,000,000 for second or subsequent convictions.

(iv) False Statements. The Act provides that any person who falsifies, tampers with, or knowingly renders inaccurate any monitoring device or method required to be maintained under this permit shall, upon conviction, be punished by a fine of not more than $10,000, or by imprisonment for not more than 2 years, or both. If a conviction of a person is for a violation committed after a first conviction of such person under this paragraph, punishment is a fine of not more than $20,000 per day of violation, or by imprisonment of not more than 4 years, or both. The Act further provides that any person who knowingly makes any false statement, representation, or certification in any record or other document submitted or required to be maintained under this permit, including monitoring reports or reports of compliance or non-compliance shall, upon conviction, be punished by a fine of not more than $10,000 per violation, or by imprisonment for not more than 6 months per violation, or by both.

3. Need to Halt or Reduce Activity not a Defense

   It shall not be a defense for the permittee in an enforcement action that it would have been necessary to halt or reduce the permitted activity in order to maintain compliance with this permit.

4. Duty to Mitigate

   The permittee must take all reasonable steps to minimize or prevent any discharge in violation of this permit that has a reasonable likelihood of adversely affecting human health or the environment.

5. Proper Operation and Maintenance

   The permittee must at all times properly operate and maintain all facilities and systems of treatment and control (and related appurtenances) which are installed or used by the permittee to achieve compliance with the conditions of this permit. Proper operation and maintenance also includes adequate laboratory controls and appropriate quality assurance procedures. This provision requires the operation of back-up or auxiliary facilities or similar systems which are installed by the permittee only when the operation is necessary to achieve compliance with the conditions of the permit.

6. Bypass of Treatment Facilities

   a) Bypass not exceeding limitations. The permittee may allow any bypass to occur that does not cause effluent limitations to be exceeded, but only if it also is for essential maintenance to assure efficient operation. These bypasses are not subject to the provisions of paragraphs b and c of this Part.

   b) Notice.

      (i) Anticipated bypass. If the permittee knows in advance of the need for a bypass, it must submit prior written notice, if possible at least 10 days before the date of the bypass.

      (ii) Unanticipated bypass. The permittee must submit notice of an unanticipated bypass as required under Section IV.C. ("Notification of Discharges Resulting from Manure, Litter, and Process Wastewater Storage, Handling, On-site Transport and Application").

   c) Prohibition of bypass.

      (i) Bypass is prohibited, and the Director of the Enforcement and Compliance Assurance Division may take enforcement action against the permittee for a bypass, unless:

         (a) The bypass was unavoidable to prevent loss of life, personal injury, or severe property damage;

         (b) There were no feasible alternatives to the bypass, such as the use of auxiliary treatment facilities, retention of untreated wastes, or maintenance during normal periods of equipment downtime. This condition is not satisfied if adequate back-up equipment should have been installed in the exercise of reasonable engineering judgment to prevent a bypass that occurred during normal periods of equipment downtime or preventive maintenance; and

         (c) The permittee submitted notices as required under paragraph b of this Section.

      (ii) The Director of the Enforcement and Compliance Assurance Division may approve an anticipated bypass, after considering its adverse effects, if the Director determines that it will meet the three conditions listed above in paragraph c.i. of this Part.

7. Upset Conditions

   a) Effect of an upset. An upset constitutes an affirmative defense to an action brought for noncompliance with such technology-based permit effluent limitations if the permittee meets the requirements of paragraph b of this Section. No determination made during administrative review of claims that noncompliance was caused by upset, and before an action for noncompliance, is final administrative action subject to judicial review.

b) Conditions necessary for a demonstration of upset. To establish the affirmative defense of upset, the permittee must demonstrate, through properly signed, contemporaneous operating logs, or other relevant evidence that:

(i) An upset occurred and that the permittee can identify the cause(s) of the upset;

(ii) The permitted facility was at the time being properly operated;

(iii) The permittee submitted notice of the upset as required under Section IV.C, "Notification of Discharges Resulting from Manure, Litter, and Process Wastewater Storage, Handling, On- site Transport and Application;" and

(iv) The permittee complied with any remedial measures required under Section V.B.4, "Duty to Mitigate."

c) Burden of proof. In any enforcement proceeding, the permittee seeking to establish the occurrence of an upset has the burden of proof.

8. Toxic Pollutants

The permittee must comply with effluent standards or prohibitions established under Section 307(a) of the Act for toxic pollutants within the time provided in the regulations that establish those standards or prohibitions, even if the permit has not yet been modified to incorporate the requirement.

9. Planned Changes

The permittee must give written notice to the Director of the Water Division as specified in Section III.A.5.b). as soon as possible of any planned physical alterations or additions to the permitted facility whenever:

a) The alteration or addition to a permitted facility may meet one of the criteria for determining whether a facility is a new source as determined in 40 CFR § 122.29(b); or

b) The alteration or addition could significantly change the nature or increase the quantity of pollutants discharged. This notification applies to pollutants that are subject neither to effluent limitations in the permit, nor to notification requirements under Section V.A.8. ("Changes in Discharge of Toxic Substances").

10. Anticipated Noncompliance

The permittee must give written advance notice to the Director of the Enforcement and Compliance Assurance Division any planned changes in the permitted facility or activity that may result in noncompliance with this permit.

C. General Provisions

1. Permit Actions

This permit may be modified, revoked and reissued, or terminated for cause as specified in 40 CFR §§ 122.62, 122.64, or 124.5. The filing of a request by the permittee for a permit modification, revocation and reissuance, termination, or a notification of planned changes or anticipated noncompliance does not stay any permit condition.

2. Duty to Reapply

If the permittee intends to continue an activity regulated by this permit after the expiration date of this permit, the permittee must apply for and obtain a new permit. In accordance with 40 CFR § 122.21(d), and unless permission for the application to be submitted at a later date has been granted by the Regional Administrator, the permittee must submit a new application at least 180 days before the expiration date of this permit.

3. Duty to Provide Information

The permittee must furnish to EPA, within the time specified in the request, any information that EPA may request to determine whether cause exists for modifying, revoking and reissuing, or terminating this permit, or to determine compliance with this permit. The permittee must also furnish to EPA, upon request, copies of records required to be kept by this permit.

4. Other Information

When the permittee becomes aware that it failed to submit any relevant facts in a permit application, or that it submitted incorrect information in a permit application or any report to EPA, it must promptly submit the omitted facts or corrected information in writing.

5. Signatory Requirements

All applications, reports or information submitted to EPA must be signed and certified as follows.

a) All permit applications must be signed as follows:

(i) For a corporation: by a responsible corporate officer.

(ii) For a partnership or sole proprietorship: by a general partner or the proprietor, respectively.

(iii) For a municipality, state, federal, Indian tribe, or other public agency: by either a principal executive officer or ranking elected official.

b) All reports required by the permit and other information requested by EPA must be signed by a person described above or by a duly authorized representative of that person. A person is a duly authorized representative only if:

(i) The authorization is made in writing by a person described above;

(ii) The authorization specifies either an individual or a position having responsibility for the overall operation of the regulated facility or activity, such as the position of plant manager, operator of a well or a well field, superintendent, position of equivalent responsibility, or an individual or position having overall responsibility for environmental matters for the company; and

(iii) The written authorization is submitted to the Director of the Enforcement and Compliance Assurance Division.

c) Changes to authorization. If an authorization under Section V.C.5.b) is no longer accurate because a different individual or position has responsibility for the overall operation of the facility, a new authorization satisfying the requirements of Section V.C.5.b) must be submitted to the Director of the Enforcement and Compliance Assurance Division and the Idaho State Department of Agriculture prior to or together with any reports, information, or applications to be signed by an authorized representative.

d) Certification. Any person signing a document under this Section must make the following certification:

"I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations."

6. Availability of Reports

In accordance with 40 CFR § 2, information submitted to EPA pursuant to this permit may be claimed as confidential by the permittee. In accordance with the Act, permit applications, permits and effluent data are not considered confidential. Any confidentiality claim must be asserted at the time of submission by stamping the words "confidential business information" on each page containing such information. If no claim is made at the time of submission, EPA may make the information available to the public without further notice to the permittee. If a claim is asserted, the information will be treated in accordance with the procedures in 40 CFR § 2, Subpart B (Public Information) and 41 Fed. Reg. 36902 through 36924 (September 1, 1976), as amended.

7. Inspection and Entry

The permittee must allow the Director of the Enforcement and Compliance Assurance Division, EPA Region 10; State/Tribal agency; or an authorized representative (including an authorized contractor acting as a representative of the Administrator), upon the presentation of credentials and other documents as may be required by law, to:

a) Enter upon the permittee's premises where a regulated facility or activity is located or conducted, or where records must be kept under the conditions of this permit;
b) Have access to and copy, at reasonable times, any records that must be kept under the conditions of this permit;
c) Inspect at reasonable times any facilities, equipment (including monitoring and control equipment), practices, or operations regulated or required under this permit; and
d) Sample or monitor at reasonable times, for the purpose of assuring permit compliance or as otherwise authorized by the Act, any substances or parameters at any location.

8. Property Rights

The issuance of this permit does not convey any property rights of any sort, or any exclusive privileges, nor does it authorize any injury to persons or property or invasion of other private rights, nor any infringement of federal, tribal, state or local laws or regulations.

9. Transfers

This permit is not transferable to any person except after written notice to the Director of the Water Division as specified in Part I.D. The Director may require modification or revocation and reissuance of the permit to change the name of the permittee and incorporate such other requirements as may be necessary under the Act. (See 40 CFR § 122.61; in some cases, modification or revocation and reissuance is mandatory).

10. State Laws

Nothing in this permit shall be construed to preclude the institution of any legal action or relieve the permittee from any responsibilities, liabilities, or penalties established pursuant to any applicable state law or regulation under authority preserved by Section 510 of the Act.

VI. DEFINITIONS

1. **Animal feeding operation (AFO)** means a lot or facility (other than an aquatic animal production facility) where the following conditions are met: (i) animals (other than aquatic animals) have been, are, or will be stabled or confined and fed or maintained for a total of forty-five (45) days or more in any twelve (12) month period, and (ii) crops, vegetation, forage growth, or post-harvest residues are not sustained in the normal growing season over any portion of the lot or facility.
2. **Application** means the EPA standard national forms for seeking coverage under for an NPDES permit, including any additions, revisions or modifications to the forms; or forms approved by EPA for use in "approved States," including any approved modifications or revisions [e.g. for NPDES general permits, a written "notice of intent" pursuant to 40 CFR § 122.28; for NPDES individual permits, Form 1 and 2B pursuant to 40 CFR § 122.1(d)].
3. **Concentrated animal feeding operation (CAFO)** means an AFO which is defined as a Large CAFO or Medium CAFO by 40 CFR § 122.23 (b)(4) and (b)(6), or that is designated as a CAFO per 40 CFR § 122.23(b)(9)(c).
4. **Grab sample** means a sample which is taken from a waste stream on a one-time basis without consideration of the flow rate of the waste stream and without consideration of time.
5. **Land application** means the application of manure, litter, or process wastewater onto or incorporated into the soil.
6. **Land application area** means land under the control of a CAFO owner or operator, whether it is owned, rented, or leased, to which manure, litter, or process wastewater from the production area is or may be applied.
7. **Large CAFO** means an AFO that stables or confines as many as or more than the numbers of animals specified in any of the following categories: (i) 700 mature dairy cattle, whether milked or dry; (ii)1,000 veal calves; (iii)1,000 cattle other than mature dairy cows or veal calves. Cattle includes but is not limited to heifers, steers, bulls and cow/calf pairs; (iv) 2,500 swine each weighing 55 pounds or more; (v)10,000 swine each weighing less than 55 pounds; (vi) 500 horses; (vii) 10,000 sheep or lambs; (viii) 55,000 turkeys; (ix) 30,000 laying hens or broilers, if the AFO uses a liquid manure handling system; (x)125,000 chickens (other than laying hens), if the AFO uses other than a liquid manure handling system; (xi) 82,000 laying hens, if the AFO uses other than a liquid manure handling system; (xii) 30,000 ducks (if the AFO uses other than a liquid manure handling system); or (xiii) 5,000 ducks (if the AFO uses a liquid manure handling system).

8. **Liquid manure handling system** means a system that collects and transports or moves waste material with the use of water, such as in washing of pens and flushing of confinement facilities. This would include the use of water impoundments for manure and/or wastewater treatment.

9. **Manure** is defined to include manure, litter, bedding, compost and raw materials or other materials commingled with manure or set aside for land application or other use.

10. **Medium CAFO** means any AFO that stables or confines as many or more than the numbers of animals specified in any of the following categories: (i) 200 to 699 mature dairy cattle, whether milked or dry cows; (ii) 300 to 999 veal calves; (iii) 300 to 999 cattle other than mature dairy cows or veal calves. Cattle includes but is not limited to heifers, steers, bulls and cow/calf pairs; (iv) 750 to 2,499 swine each weighing 55 pounds or more; (v) 3,000 to 9,999 swine each weighing less than 55 pounds; (vi)150 to 499 horses, (vii) 3,000 to 9,999 sheep or lambs, (viii) 16,500 to 54,999 turkeys, (ix) 9,000 to 29,999 laying hens or broilers, if the AFO uses a liquid manure handling system; (x) 37,500 to 124,999 chickens (other than laying hens), if the AFO uses other than a liquid manure handling system; (xi) 25,000 to 81,999 laying hens, if the AFO uses other than a liquid manure handling system; (xii) 10,000 to 29,999 ducks (if the AFO uses other than a liquid manure handling system); or (xiii) 1,500 to 4,999 ducks (if the AFO uses a liquid manure handling system) **and** either one of the following conditions are met (a) pollutants are discharged into waters of the United States through a man-made ditch, flushing system, or other similar man-made device; or (b) pollutants are discharged directly into waters of the United States which originate outside of and pass over, across, or through the facility or otherwise come into direct contact with the animals confined in the operation.

11. **Notice of Intent (NOI)** is a form submitted by the owner/operator applying for coverage under a general permit. It requires the applicant to submit the information necessary for adequate program implementation, including, at a minimum, the legal name and address of the owner or operator, the facility name and address, type of facility or discharges, and the receiving stream(s). [40 CFR § 122.28(b)(2)(ii)].

12. **Process wastewater** means water directly or indirectly used in the operation of the CAFO for any or all of the following: spillage or overflow from animal or poultry watering systems; washing, cleaning, or flushing pens, barns, manure pits, or other AFO facilities; direct contact swimming, washing, or spray cooling of animals; or dust control. Process wastewater also includes any water which comes into contact with or is a constituent of raw materials, products, or byproducts including manure, litter, feed, milk, eggs, or bedding.

13. **Production area** means that part of an AFO that includes the animal confinement area, the manure storage area, the raw materials storage area, and the waste containment areas. The animal containment area includes but is not limited to open

lots, housed lots, feedlots, confinement houses, stall barns, free stall barns, milkrooms, milking centers, cowyards, barnyards, medication pens, walkers, animal walkways, and stables. The manure storage area includes but is not limited to lagoons, runoff ponds, storage sheds, stockpiles, under house or pit storages, liquid impoundments, static piles, and composting piles. The raw materials storage area includes but is not limited to feed silos, silage bunkers, and bedding materials. The waste containment area includes but is not limited to settling basins, and areas within berms and diversions which separate uncontaminated storm water. Also included in the definition of production area is any egg washing or egg processing facility, and any area used in the storage, handling, treatment, or disposal of mortalities.

14. **Small CAFO** means an AFO that is designated as a CAFO and is not a Medium CAFO.
15. **Setback** means a specified distance from waters of the United States or potential conduits to waters of the United States where manure, litter, and process wastewater may not be land applied. Examples of conduits to surface waters include but are not limited to: Open tile line intake structures, sinkholes, and agricultural well heads.
16. **The Act** means Federal Water Pollution Control Act as amended, also known as the Clean Water Act as amended, found at 33 USC 1251 et seq.
17. **Vegetated buffer** means a narrow, permanent strip of dense perennial vegetation established parallel to the contours of and perpendicular to the dominant slope of the field for the purposes of slowing water runoff, enhancing water infiltration, and minimizing the risk of any potential nutrients or pollutants from leaving the field and reaching waters of the United States.
18. **Waters of the United States** means waters as defined in 40 CFR Part 122.2.

APPENDIX A - NOTICE OF INTENT - EPA FORM 2B

United States Environmental Protection Agency | Office of Water Washington, D.C. | EPA Form 3510-2B Revised March 2019

Water Permits Division

Application Form 2B

Concentrated Animal Feeding Operations and Concentrated Aquatic Animal Production Facilities

NPDES Permitting Program

Note: Complete this form ***and*** Form 1 if your facility is a new or existing concentrated animal feeding operation or concentrated aquatic animal production facility.

Paperwork Reduction Act Notice

The U.S. Environmental Protection Agency (EPA) estimates the average burden for concentrated animal feeding operation respondents to collect information and complete Form 2B to be 9.2 hours (8.7 hours to complete and submit the application and 0.5 hours to complete and submit a nutrient management plan). EPA estimates the average burden for concentrated aquatic animal production respondents to collect information and complete Form 2B to be 5.5 hours. These estimates include time for reviewing instructions, searching existing data sources, gathering and maintaining the needed data, and completing and reviewing the collection of information. Send comments about the burden estimates or any other aspect of this collection of information to the Chief, Information Policy Branch (PM-223), U.S. Environmental Protection Agency, 1200 Pennsylvania Avenue, NW, Washington, DC 20460, and to the Office of Information and Regulatory Affairs, Office of Management and Budget, 725 17th Street, NW, Washington, DC 20503, marked "Attention: Desk Officer for EPA."

FORM 2B—INSTRUCTIONS

General Instructions

Who Must Complete Form 2B?

You must complete Form 2B if you answered "Yes" to Item 1.2.1 on Form 1—that is, if you are a concentrated animal feeding operation (CAFO) or a concentrated aquatic animal production (CAAP) facility.

Where to File Your Completed Form

Submit your completed application package (Forms 1 and 2B) to your National Pollutant Discharge Elimination System (NPDES) permitting authority. Consult Exhibit 1–1 of Form 1's "General Instructions" to identify your NPDES permitting authority.

Public Availability of Submitted Information

The U.S. Environmental Protection Agency (EPA) will make information from NPDES permit application forms available to the public for inspection and copying upon request. You may not claim any information on Form 2B (or related attachments) as confidential.

You may make a claim of confidentiality for any information that you submit to EPA that goes beyond the information required by Form 2B. Note that NPDES authorities will deny claims for treating any effluent data as confidential. If you do not assert a claim of confidentiality at the time you submit your information to the NPDES permitting authority, EPA may make the information available to the public without further notice to you. EPA will handle claims of confidentiality in accordance with the Agency's business confidentiality regulations at Part 2 of Title 40 of the *Code of Federal Regulations* (CFR).

Completion of Forms

Print or type in the specified areas only. If you do not have enough space on the form to answer a question, you may continue on additional sheets, as necessary, using a format consistent with the form.

Provide your EPA Identification Number from the Facility Registry Service, NPDES permit number, and facility name at the top of each page of Form 2B and any attachments. If your facility is new (i.e., not yet constructed), write or type "New Facility" in the space provided for the EPA Identification Number and NPDES permit number. If you do not know your EPA Identification Number, contact your NPDES permitting authority. See Exhibit 1–1 of the "General Instructions" of Form 1 for contact information.

Do not leave any response areas blank unless the form directs you to skip them. If the form directs you to respond to an item that does not apply to your facility or activity, enter "NA" for "not applicable" to show that you considered the item and determined a response was not necessary for your facility.

The NPDES permitting authority will consider your application complete when it and any supplementary material are received and completed according to the authority's satisfaction. The NPDES permitting authority will judge the completeness of any application independently of the status of any other permit application or permit for the same facility or activity.

Definitions

The legal definitions of all key terms used in these instructions and Form 2B are in the "Glossary" at the end of the "General Instructions" in Form 1.

Line-by-Line Instructions

Section 1. General Information

Item 1.1. Mark whether your facility/business type is a CAFO or a CAAP.

- For a CAFO, you must complete Sections 1 through 6 and Section 8.
- For a CAAP, you must complete Sections 1, 7, and 8.

Item 1.2. Indicate whether your facility is an existing or proposed facility. Mark "Proposed Facility" if your facility is presently not in operation or is expanding to meet the definition of a CAFO in accordance with the regulations at 40 CFR 122.23.

Section 2. CAFO Owner/Operator Contact Information

Item 2.1. Provide the name, title, telephone number, and email address of the owner/operator of the facility/business.

Item 2.2. Provide the complete mailing address of the owner/operator of the facility/business.

Section 3. CAFO Location and Contact Information

Item 3.1. Provide the legal name and location (complete mailing address) of the facility. Also indicate whom the NPDES permitting authority should contact about the application, including a telephone number and email address.

Item 3.2. Provide the latitude and longitude of the entrance to the production area (i.e., the part of the operation that includes the animal confinement area, the manure storage area, the raw materials storage area, and the waste containment areas). Latitude and longitude coordinates may be obtained in a variety of ways, including use of hand held devices (e.g., a GPS enabled smartphone), internet mapping tools (e.g., https://mynasadata.larc.nasa.gov/latitudelongitude-finder/), geographic information systems (e.g., ArcView), or paper maps from trusted sources (e.g., U.S. Geological Survey or USGS). For further guidance, refer to http://www.epa.gov/geospatial/latitudelongitude-data-standard.

Item 3.3. If the facility uses a contract grower, provide the name and complete mailing address of the integrator.

Section 4. CAFO Topographic Map

Item 4.1. Provide a topographic map of the geographic area in which the facility is located, showing the specific location of the production area(s). You are not required to provide the topographic map required by Section 7 of Form 1.

On each map, include the map scale, a meridian arrow showing north, and latitude and longitude to the nearest second. Latitude and longitude coordinates may be obtained in a variety of ways, including use of hand held devices (e.g., a GPS enabled smartphone), internet mapping tools (e.g., https://mynasadata.larc.nasa.gov/latitudelongitude-finder/), geographic information systems (e.g., ArcView), or paper maps from trusted sources (e.g., USGS).

On all maps of rivers, show the direction of the current. In tidal waters, show the directions of ebb and flow tides.

You may develop your map by going to the United States USGS's National Map website at http://nationalmap.gov/. (For a map from this site, use the traditional 7.5-minute quadrangle format. If none is available, use a USGS 15-minute series map.) You may also use a plat or other appropriate map. Briefly describe land uses in the map area (e.g., residential, commercial.). Note that you have completed your topographic map and attached it to the application.

Section 5. CAFO Characteristics

Supply all information in Section 5 if you checked "Existing facility" in response to Item 1.2.

Item 5.1. Provide the maximum number of each type of animal in open confinement or housed under roof (either partially or totally) that are held at your facility for a total of 45 days or more in any 12-month period. Provide the total number of animals confined at the facility.

Item 5.2. Identify the applicable types of containment and storage for manure, litter, and process wastewater at the facility and indicate the capacity of storage in days and gallons or tons.

Item 5.3. Indicate the total number of acres that are drained and collected in the containment and storage structure(s).

Item 5.4. Specify the tons of manure or litter and the gallons of process wastewater generated at the facility on an annual basis.

Item 5.5. Indicate whether the manure, litter, and/or process wastewater is land applied. If yes, continue to Item 5.6. If no, skip to Item 5.8.

Item 5.6. Indicate the number of acres of land under the control of the applicant that are available for land application of the manure, litter, or process wastewater.

Item 5.7. Check any of the identified best management practices that are being implemented at the facility to control runoff and protect water quality.

Item 5.8. Indicate if the manure, litter, and/or process wastewater is transferred to any other persons. If yes, continue to Item 5.9. If no, skip to Item 5.10.

Item 5.9. Specify the tons of manure or litter or the gallons of process wastewater transferred annually to other people.

Item 5.10. Describe any alternative uses of manure, litter, or process wastewater, if any (e.g., composting, pelletizing, energy generation).

Section 6. CAFO Nutrient Management Plans

Item 6.1. Indicate if you have submitted a nutrient management plan that satisfies the requirements at 40 CFR 122.42(e) and, if applicable, the requirements at 40 CFR 412.4(c).

Item 6.2. If you have not yet submitted a nutrient management plan, explain why not.

Item 6.3. Indicate if a nutrient management plan is being implemented at the CAFO. If not land applying, describe the alternative uses of the manure, litter, and wastewater (e.g., composting, pelletizing, energy generation).

Item 6.4. Indicate the date of the last review or revision of the nutrient management plan.

Note: A permit application is not complete until a nutrient management plan is submitted to the NPDES permitting authority.

Section 7. CAAP Facility Characteristics

Item 7.1. Indicate if the CAAP facility is located on land. If the facility is located in water (e.g., a net pen or submerged cage system), check "No" and skip to Item 7.3. If yes, continue to Item 7.2.

Item 7.2. Provide the maximum daily and maximum average monthly discharge at the CAAP facility by outfall number. Outfall numbers should correspond with the outfall numbers provided on the map submitted in Section 7 of Form 1. Values given for flow should be representative of your normal operation. The maximum daily flow is the maximum measured flow occurring over a calendar day. The maximum average monthly flow is the average of measured daily flow over the calendar month of highest flow.

Item 7.3. Indicate the number of ponds, raceways, net pens, submerged cages, or similar structures at your facility that result in discharges to waters of the United States. Describe each type and provide the name of the associated receiving water and intake water source.

Item 7.4. List the species of fish or aquatic animals held and fed at your facility. Distinguish between cold-water and warm-water species. The names of fish species should be proper, common, or scientific names as given in Special Publication 34 of the American Fisheries Society, *Common and Scientific Names of Fishes from the United States, Canada, and Mexico*.

For each species, provide the total harvestable weight in pounds (lbs.) for a typical calendar year. Also indicate the maximum weight present at any one time at your facility.

Item 7.5. Indicate the maximum monthly pounds of food given at your facility. Also indicate the month given. The amounts should be representative of your normal operations.

Section 8. Checklist and Certification Statement

Item 8.1. Review the checklist provided. In Column 1, mark the sections of Form 2B that you have completed and are submitting with your application. For each section in Column 2, indicate whether you are submitting attachments.

Item 8.2. The Clean Water Act provides for severe penalties for submitting false information on this application form. CWA Section 309(c)(2) provides that, "Any person who knowingly makes any false statement, representation, or certification in any application, …shall upon conviction, be punished by a fine of no more than $10,000 or by imprisonment for not more than six months, or both."

FORM 2B—INSTRUCTIONS CONTINUED

FEDERAL REGULATIONS AT 40 CFR 122.22 REQUIRE THIS APPLICATION TO BE SIGNED AS FOLLOWS:

A. For a corporation, by a responsible corporate officer. For the purpose of this section, a responsible corporate officer means: (1) a president, secretary, treasurer, or vice-president of the corporation in charge of a principal business function, or any other person who performs similar policy- or decision-making functions for the corporation, or (2) the manager of one or more manufacturing, production, or operating facilities, provided the manager is authorized to make management decisions which govern the operation of the regulated facility including having the explicit or implicit duty of making major capital investment recommendations, and initiating and directing other comprehensive measures to assure long term environmental compliance with environmental laws and regulations; the manager can ensure that the necessary systems are established or actions taken to gather complete and accurate information for permit application requirements; and where authority to sign documents has been assigned or delegated to the manager in accordance with corporate procedures.

B. For a partnership or sole proprietorship, by a general partner or the proprietor, respectively.

C. For a municipality, state, federal, or other public facility, by either a principal executive officer or ranking elected official. For purposes of this section, a principal executive officer of a federal agency includes: (1) The chief executive officer of the agency, or (2) a senior executive officer having responsibility for the overall operations of a principal geographic unit of the agency (e.g., Regional Administrators of EPA).

END

Submit your completed Form 1, Form 2B, and all associated attachments (and any other required NPDES application forms) to your NPDES permitting authority.

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EPA Identification Number	NPDES Permit Number	Facility Name	Form Approved 03/05/19 OMB No. 2040-0004

Form 2B NPDES

U.S. Environmental Protection Agency
Application for NPDES Permit to Discharge Wastewater

CONCENTRATED ANIMAL FEEDING OPERATIONS and CONCENTRATED AQUATIC ANIMAL PRODUCTION FACILITIES

SECTION 1. GENERAL INFORMATION (40 CFR 122.21(I)(1))

General Information

1.1 Indicate the facility/business type. (Check only one response.)

- ☐ CAFO → Complete Sections 1 through 6 and Section 8.
- ☐ CAAP → Complete Sections 1, 7, and 8.

1.2 Indicate the operational status of the facility. (Check one.)

- ☐ Existing facility
- ☐ Proposed facility

SECTION 2. CAFO OWNER/OPERATOR CONTACT INFORMATION (40 CFR 122.21(f)(2) and (4) and 122.21(i)(1)(i))

CAFO Owner/Operator Contact Information

2.1 **Owner/Operator Contact**

Name (first and last)	Title
Phone number	Email address

2.2 **Owner/Operator Mailing Address**

Street or P.O. box		
City or town	State	Zip code

SECTION 3. CAFO LOCATION AND CONTACT INFORMATION (40 CFR 122.21(i)(1)(ii and iii))

CAFO Location and Contact Information

3.1 **CAFO Location and Contact**

Name		
Address (street, route number, or other specific identifier)	County	
City or town	State	Zip code
Facility contact name	Phone number	Email address

3.2 **Latitude/Longitude of Entrance to Production Area** (see instructions)

Latitude	Longitude
° ′ ″	° ′ ″

EPA Identification Number	NPDES Permit Number	Facility Name	Form Approved 03/05/19 OMB No. 2040-0004

CAFO Location and Contact Information Continued

3.3 **Integrator Name and Address**

Name		
Street address		
City or town	State	Zip code

SECTION 4. CAFO TOPOGRAPHIC MAP (40 CFR 122.21(i)(1)(iv))

CAFO Topographic Map

4.1 Have you attached a topographic map containing all required information to this application? (See instructions for specific requirements.)

☐ Yes ➔ SKIP to Section 5. ☐ No

SECTION 5. CAFO CHARACTERISTICS (40 CFR 122.21(i)(1)(v ix))

CAFO Characteristics

5.1 Provide information on the type and number of animals in the table below.

Animal Type	Number in Open Confinement	Number Housed Under Roof	Animal Type	Number in Open Confinement	Number Housed Under Roof
☐ Mature dairy cows			☐ Sheep or lambs		
☐ Dairy heifers			☐ Chickens (broilers)		
☐ Veal calves			☐ Chickens (layers)		
☐ Cattle (not dairy or veal calves)			☐ Ducks		
☐ Swine (55 lbs. or more)			☐ Other (specify)		
☐ Swine (under 55 lbs.)			☐ Other (specify)		
☐ Horses			☐ Other (specify)		
☐ Turkeys			**Total Animals**		

5.2 Indicate the type of containment and storage, total number of days, and total capacity for manure, litter, and process wastewater storage in the table below.

Type of Containment and Storage	Total Number of Days	Total Capacity (specify gallons or tons)	Type of Containment and Storage	Total Number of Days	Total Capacity (specify gallons or tons)
☐ Anaerobic lagoon			☐ Belowground storage tanks		
☐ Evaporation			☐ Roofed storage shed		
☐ Aboveground storage tanks			☐ Concrete pad		
☐ Storage pond			☐ Impervious soil pad		
☐ Underfloor pit			☐ Other (specify)		

5.3 Indicate the total number of acres drained and collected in the containment and storage structure(s) reported under Item 5.2.

____________ acres

EPA Identification Number	NPDES Permit Number	Facility Name	Form Approved 03/05/19 OMB No. 2040-0004

CAFO Characteristics Continued

Manure, Litter, and/or Process Wastewater Production and Use			
5.4	How many tons of manure or litter and gallons of process wastewater are generated annually at the CAFO?		
	Manure	tons	
	Litter	tons	
	Process wastewater	gallons	
5.5	Is manure, litter, and/or process wastewater generated at the CAFO land applied?		
	☐ Yes	☐ No ➔ SKIP to Item 5.8.	
5.6	How many acres of land under the control of the applicant are available for applying the CAFO's manure, litter, or process wastewater? _____________ acres		
5.7	Check all land application best management practices that are being implemented.		
	☐ Buffers	☐ Infiltration field	
	☐ Setbacks	☐ Grass filter	
	☐ Conservation tillage	☐ Terrace	
	☐ Constructed wetlands	☐ Other (specify)	
5.8	Is manure, litter, and/or process wastewater transferred to any other persons?		
	☐ Yes	☐ No ➔ SKIP to Item 5.10.	
5.9	How many tons of manure or litter and gallons of process wastewater, produced by the CAFO, are transferred annually to other people?		
	Manure	tons	
	Litter	tons	
	Process wastewater	gallons	
5.10	Describe alternative use(s) of manure, litter, or process wastewater, if any.		

SECTION 6. CAFO NUTRIENT MANAGEMENT PLANS (40 CFR 122.21(i)(1)(x))

CAFO Nutrient Management Plans

6.1	Has the applicant attached a nutrient management plan that satisfies the requirements at 40 CFR 122.42(e) and, if applicable, the requirements at 40 CFR 412.4(c)? **Note:** A permit application is not complete until a nutrient management plan is submitted to the NPDES permitting authority. ☐ Yes ➔ SKIP to Item 6.3. ☐ No	
6.2	Explain why a nutrient management plan is not attached to the application.	
6.3	Is a nutrient management plan being implemented at the CAFO? ☐ Yes ☐ No	
6.4	What was the date of the last review or revision of the nutrient management plan?	Date ______________________

EPA Identification Number	NPDES Permit Number	Facility Name	Form Approved 03/05/19 OMB No. 2040-0004

SECTION 7. CAAP FACILITY CHARACTERISTICS (40 CFR 122.21(i)(2))

CAAP Facility Characteristics

7.1 Is the CAAP facility located on land?

☐ Yes ☐ No → SKIP to Item 7.3.

7.2 Provide the maximum daily and maximum average monthly discharge at CAAP by outfall.

Outfall Number	Discharge	
	Maximum Daily Discharge	Maximum Average Monthly Discharge
	gpd	gpd
	gpd	gpd
	gpd	gpd

7.3 Indicate the type and number of discharge structures at the CAAP. Provide a brief description of each structure. Also note the name of the receiving water and the source of the intake water for each structure.

Structure Type	Number of Each	Description	Receiving Water Name	Source of Intake Water
Ponds				
Raceways				
Net pens				Not applicable
Submerged cages				Not applicable
Similar structures (specify) ______				

7.4 List the cold-water and/or warm-water aquatic species raised/produced in the table below. For each species listed, indicate the total yearly and maximum harvestable weight (in pounds).

Cold Water Species			Warm Water Species		
Species	Harvestable Weight		Species	Harvestable Weight	
	Total Yearly	Maximum		Total Yearly	Maximum
	lbs.	lbs.		lbs.	lbs.
	lbs.	lbs.		lbs.	lbs.
	lbs.	lbs.		lbs.	lbs.
	lbs.	lbs.		lbs.	lbs.

7.5 Indicate the calendar month of maximum feeding and the total mass of food fed (in pounds) during that month.

Month of Maximum Feeding	Total Mass of Food Fed
	lbs.

EPA Identification Number	NPDES Permit Number	Facility Name	Form Approved 03/05/19 OMB No. 2040-0004

SECTION 8. CHECKLIST AND CERTIFICATION STATEMENT (40 CFR 122.22(a) and (d))

Checklist and Certification Statement

8.1 In Column 1, below, mark the sections of Form 2B that you have completed and are submitting with your application. For each section, specify in Column 2 any attachments that you are enclosing to alert the permitting authority. Note that not all applicants are required to provide attachments.

Column 1	Column 2
☐ Section 1: General Information	☐ w/ attachments
☐ Section 2: CAFO Owner/Operator Contact Information	☐ w/ attachments
☐ Section 3: CAFO Location and Contact Information	☐ w/ attachments
☐ Section 4: CAFO Topographic Map	☐ w/ topographic map ☐ w/ additional attachments
☐ Section 5: CAFO Characteristics	☐ w/ attachments
☐ Section 6: CAFO Nutrient Management Plans	☐ w/ nutrient management plan ☐ w/ attachments
☐ Section 7: CAAP Facility Characteristics	☐ w/ attachments
☐ Section 8: Checklist and Certification Statement	☐ w/ attachments

8.2 **Certification Statement**

I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

Name (print or type first and last name)	Official title
Signature	**Date signed**

APPENDIX B - ID NRCS CONSERVATION PRACTICE STANDARD CODE 360

NATURAL RESOURCES CONSERVATION SERVICE

CONSERVATION PRACTICE STANDARD

CLOSURE OF WASTE IMPOUNDMENTS

(No.)

CODE 360

DEFINITION

The closure of waste impoundments (treatment lagoons and liquid storage facilities), that are no longer used for their intended purpose, in an environmentally safe manner.

PURPOSE

- Protect the quality of surface water and groundwater resources
- Eliminate a safety hazard for humans and livestock
- Safeguard the public health

CONDITIONS WHERE PRACTICE APPLIES

This practice applies to agricultural waste impoundments that are no longer needed as a part of a waste management system and are to be permanently closed or converted.

The structure must be constructed to meet NRCS standards or show structural integrity if these impoundments are to be converted to fresh water storage ponds. Investigations for structural integrity must be conducted as specified in the National Engineering Manual (NEM) 501.23.

CRITERIA

General Criteria Applicable to All Purposes

The closure shall comply with all federal, state and local laws, rules and regulations including pollutant discharge elimination system requirements.

All structures used to convey waste to waste impoundments or to provide drainage from the impoundment area shall be removed and replaced with compacted earth material or otherwise rendered unable to convey waste.

Liquid and slurry wastes shall be agitated and pumped to the extent conventional pumping will allow. Clean water shall be added as necessary to facilitate the agitation and pumping. The wastewater shall be utilized in accordance with Waste Utilization (633), as well as Nutrient Management (590). The sludge remaining on the bottom and sides of the waste treatment lagoon or waste storage facility may remain in place if it will not pose a threat to the environment. If leaving the sludge in place would pose a threat, it shall be removed to the fullest extent practical and utilized in accordance with Waste Utilization (633), as well as Nutrient Management (590).

Land Reclamation. Impoundments with embankments may be breached so that they will no longer impound water, and excavated impoundments may be backfilled so that these areas may be reclaimed for other uses. Waste impoundments that have water impounded against the embankment are considered embankment structures if the depth of water is three feet or more above natural ground.

(1) Embankment Impoundments. Waste shall be removed from the site before the embankment is breached. The slopes and bottom of the breach shall be stable for the soil material involved; however, the side slopes shall be no steeper than three horizontal to one vertical (3:1).

(2) Excavated Impoundments. The backfill height shall exceed the design finished grade by 5 percent to allow for settlement. The top one foot of the backfill shall be constructed of soil with greater than 20% clay content and mounded to shed rainfall

runoff. Incorporate available topsoil where feasible to aid establishment of vegetation.

Closed waste storage structures shall be demolished or disassembled or otherwise altered to such an extent that no water can be impounded. Disassembled materials such as pieces of metal shall be temporarily stored until their final disposition in such a manner that they do not pose a hazard to animals or humans.

Demolished materials shall be buried on-site, as allowed by local regulation of landfills or moved off-site to locations designated by state or local officials. If buried on-site, the materials are to be covered with soil to a settled depth of one foot, and the backfill be sufficiently mounded such that runoff will be diverted from the site after the backfill settles.

Conversion to Fresh Water Storage. The converted impoundment shall meet the requirements as set forth in the appropriate NRCS practice standard for the intended purpose.

Safety. When sludge is not removed from a waste impoundment that is being converted to fresh water storage, the impoundment shall not be used for fish production, swimming or livestock watering until water quality is adequate for these purposes. Precautions such as fencing and warning signs shall be used to ensure that the facility is not used for purposes incompatible with the current quality of water.

Personnel shall not enter an enclosed waste impoundment without breathing apparatus or taking other appropriate measures.

Protection. All disturbed areas shall be re-vegetated or other suitable measures used to control erosion and restore the esthetic value of the site. Sites not suitable for re-vegetation through normal cropping practices shall be vegetated using Critical Area Planting (342).

Measures shall be taken during construction to minimize site erosion and pollution of downstream water resources. This may include such items as silt fences, hay bale barriers, temporary vegetation and mulching.

CONSIDERATIONS

Reduce pumping effort to empty waste impoundments where the surface is covered by a dense mat of floating vegetation by first applying herbicide to the vegetation and then burning the residue. Appropriate permits must be obtained before burning.

Minimize the impact of odors associated with emptying and land applying wastewater and sludge from a waste impoundment by using an incorporation application method at a time when the humidity is low, winds are calm and wind direction is away from populated areas.

Soil to fill excavated ponds should not come from important farmlands (prime, statewide, local and/or unique).

Breeched embankments may detract from the overall esthetics of the operation. Embankments should be removed and the site returned to its original grade.

Keep sludge left in place covered with water to prevent its aerobic decomposition with the potential release of nutrients to surface and ground water.

Disassembled structural facilities may be suitable for assembly at another site. Care should be taken during closure to minimize damage to the pieces of the facility, particularly coatings that prevent corrosion of metal pieces.

PLANS AND SPECIFICATIONS

Plans and specifications for closure of abandoned waste treatment lagoons and waste storage facilities shall be in keeping with this standard and shall describe the requirements for applying the practice to achieve its intended purpose. The plans and specifications shall also be consistent with the requirements of that standard.

OPERATION AND MAINTENANCE

The proper closure of a waste treatment lagoon or waste storage facility should require little or no operation and maintenance; however, if it is converted to another use, such as a fresh water facility, operation and maintenance shall be in accordance with the needs as set forth in the appropriate NRCS conservation practice standard for the intended purpose.

APPENDIX C - ID NRCS IDAW

United States Department of Agriculture
Natural Resource Conservation Service

IDAWM
Computer Program

Version 4.00 DECEMBER 2000

Computer Program for Animal Waste Computations
Title: IDAWM Version: 4.00
Date: May 1991 Last Revision: December 2000

Programmed by: Bruce D. Wilson
NRCS Assistant State Conservation Engineer
Portland, Oregon

Modified for Idaho by: Clare J. Prestwich, NRCS
Idaho State Irrigation Engineer

References:

- Oregon Department of Agriculture, Natural Resources Division, Oregon Animal Waste Installation Guidebook, Salem, Oregon, March, 1991

- USDA NRCS, Agricultural Waste Management Field Handbook, US Government Printing Office, Washington, D.C., 1991.

- Economic Worksheet for Animal Waste Utilization, Hal Gordon, NRCS State Economist, Portland, OR, 1992

- Idaho Department of Health and Welfare, Division of Environmental Quality, Idaho Waste Management Guidelines for Confined Feeding Operations, 1993.

- USDA, NRCS, Idaho FOTG Practice Standards 313, 359 and 590.

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Idawm

A. PROGRAM DESCRIPTION

This program can be used as a tool for computing animal waste volumes, nutrient amounts, sizing storage facilities, and/or determining nutrient application area requirements based upon plant uptake. The program uses data and procedural guidelines from the Idaho Waste Management Guidelines for Confined Feeding Operations (IDWMG) and the NRCS Agricultural Waste Management Field Handbook. The data input screens will display reference page numbers in the IDWMG where a description of data and procedures used can be found.

The program was created using version 4.5 of the Microsoft QuickBASIC interpreter. The program consists of 13 executable modules. Each module represents an input screen of the program. Since the program consists of executable modules, the program requires the BRUN45.EXE program file be in the same directory as the program modules in order to run properly.

Four data files are also needed to run the program. The data files consist of animal, crop, climatic and default information. The information in the data files from the OAWG (Oregon Animal Waste Guidebook) was modified for Idaho and can be updated as needed. The default data file has been created but can be altered to save the following information:

--landowner/operator
--climatic station
--type of operation
--animal descriptions
--animal weights
--months of animal confinement
--days animals are confined
--days animals are grazed
--liquid storage period
--solid storage period
--crops selected for nutrient uptake
--nutrient on which to base acreage calculations
--dollar value of nutrients
--selected printer for printing data
--data path and disk drive and path where data is to be stored.

The economics of determining the break even cost and nutrient balance of waste application was develop by Hal Gordon, NRCS Oregon State Economists, and adapted to this program.

B. EQUIPMENT

This program is designed to run on the AT&T PC 6300 series computer or compatible with 640K or RAM memory and running MS-DOS version 2.11 or higher. A single disk drive is required to run the program and a printer is required to print a paper copy of the program output. The program can be provided on 360K, 1.2 MB 5 1/4 inch diskettes or 720K/1.44MB 3 ½ inch diskettes.

C. INSTRUCTIONS TO LOAD AND RUN PROGRAM

If your computer is equipped with a hard disk, you can load the program onto the hard disk by creating a subdirectory and copying all the files from the diskette or diskettes into the subdirectory created on the hard disk or by downloading the program from the NRCS Idaho web page <http://id.nrcs.usda.gov> and clicking on "TECHNICAL RESOURCES", "ENGINEERING TECHNICAL RESOURCE DOWNLOAD PAGE", "COMPUTER PROGRAMS", then "idawm". To run the program from the subdirectory, simply use the change directory command (CD) to change to the subdirectory and type Idawm followed by the enter key. To avoid problems loading or saving data files add the following to the auotexec.bat file in the c:\ directory " path=c:\subdirectory where you loaded the program". If the path statement already exists just add it on to the end of the line. This can be done using any text editor.

If you wish to run the program using the floppy drive, insert diskette number one into the A: or B: disk drive, type

A: or **B:** for the drive the diskette is located in and press the enter key. Type Idawm followed by the enter key to run the program. If you are prompted to "Input run-time module path:", type **A:** or **B** for the disk drive containing the program diskette and press the enter key.

Important-- The first time you run the program;

1. Press the [F3] key to save the default settings.
2. Follow the instructions on page 13 to customize the data for the default screens paying special attention to the printer type and data storage disk drive and data path. Save the defaults by pressing the [PgDn] key at the last input screen so the next time you run the program the defaults will be set up the way you want them for your computer.

The program is initially set up to use the Genicom Dot Matrix printer for printouts and the A: disk drive for data storage.

If you have trouble running the program on your computer, call your IRM staff to insure you have the proper equipment and MSDOS version described in section B.

D. USER INSTRUCTIONS

The Idawm program is "user friendly" to the extent that all the input data needed is asked for in a logical manner. The data field that is activated for the user to enter new or to change default data is identified by that data field being shaded. The entire data field is shaded when the data field is empty and the length of the shaded area is reduced as each character is entered. If the data field is full, the program will provide one extra shaded space to indicate the current location for data input.

The following is a description of editing keys that can help enter and manipulate data in the program:

[ESC]	Pressing the escape key in any input field in the program will allow the user to save data entered and exit the program returning to the DOS operating system. See page 13 for instructions on saving data.
[DEL]	Pressing the delete key will clear all of the data from the data field in which the cursor is located .
[<---]	Pressing the backspace key will delete on character to the left of the shaded area.
[Tab]	Pressing the tab key will move the cursor from current data field to the next.
Shift [Tab]	Pressing the shift key along with the tab key will move the cursor from the current data field to the previous data field.
[PgDn]	Pressing the page down key will move the cursor to the next data entry screen in the program.
[PgUp]	Pressing the page up key will move the cursor to the previous data entry screen in the program.
[->]	Pressing the right cursor key will move the cursor to the next data field to the right.
[<-]	Pressing the left cursor key will move the cursor to the next data field to the left.
[UP]	Pressing the up cursor key will move the cursor to the next data field above the current data field.
[DOWN]	Pressing the down cursor key will move the cursor to the next data field below the current data field location.
[Enter]	Pressing the enter key or carriage return key (<CR>) will move to the next data field.
[Ctrl] [L]	Pressing the [Ctrl] and [L] keys together where indicated will provide a list of items from which to select.
[F1]	Pressing the [F1] function key will allow the user to load a previously saved data file. See page 13 for instructions on how to load a data file.
[F2]	Pressing the [F2] function key will allow the user to save entered data to a data file. See page 13 for instructions on how to save data to a file.
[F3]	Pressing the [F3] function key will allow the user to save data to a default data file that is used each time the program is run. See pages 13-15 for instructions on how to enter and save default data.
[F4]	Pressing the [F4] function key in the solids storage facility or liquid storage facility input screen allows the user to print the graphic display to a dot matrix printer. The user must have loaded the graphics print routine by typing **GRAPHICS** before running the program and selecting this option. If you are running the program through SIMULTASK on a UNIX operating system, this option may not give the desired results. This option is not available if you have specified a laser printer for the printer type in the default settings.

D. User Instructions Continued
The following provides a description of each data entry screen in the program:

SCREEN 1, PROGRAM DEVELOPMENT INFORMATION
The program will display information about the version of the program and a telephone number for help. No data entry is required on SCREEN 1. Press any key to proceed to SCREEN 2. The program will indicate that it is loading data from the default data file. The program will automatically proceed to SCREEN 2 once all of the necessary data is loaded. If the required data files are missing the program will not run.

SCREEN 2, ANIMAL WASTE MANAGEMENT PLANNING WORKSHEET
OPERATOR/LANDOWNER
Enter the name of the operator or landowner. As a default the file will be saved under this input. This data field will accept 1-40 characters. If manure for different animal groups is handled differently in storage or utilization you should make a separate idawm computer evaluation for the different groups. Example – milking cows manure stored and land applied, heifers and calves manure stored in corral in manure pack for several years; evaluate with separate analysis. Multiple computer runs can be used to evaluate alternatives for handling and/or utilizing the manure. Options for runs i.e. John Smith storage milkers, John Smith all animals.
LOCATION
Enter the location of the confined animal feeding operation (CAFO). This data field will accept 1-40 characters.
ASSISTED BY
Enter the name of the person providing assistance to the landowner. This data field will accept 1-40 characters.
CLIMATIC STATION
Enter the climatic station that best represents the location of the CAFO operation. Pressing [Ctrl] [L] will display an alphabetical list of 79 climatic stations to choose from (2 pages). Use the up and down cursor keys to choose the climatic station you want and press [Enter]. A correct entry in this data field is required to move to the next data entry screen. This data field will accept 1-20 characters. Other climatic station can be added by editing the file rf.awm with any text editor. The format is given at the top of the file. Data must be entered in this format. The 1 in 5 monthly precipitation is used for determining runoff from corrals/barns during the December through March period and the average monthly precipitation for the April through November period.
TYPE OF OPERATION
Enter the type of CAFO. Pressing [Ctrl] [L] will display a list of CAFO's to choose from. Use the up and down cursor keys to select the type of CAFO desired and press [Enter]. A correct entry is required in this data field to move to the next data field. This data field will accept 1-9 characters.
DATE
If the date displayed is not correct it may be edited to enter the correct month, day, and year. This data field will accept 1-2 characters.
DESCRIPTION
The animal descriptions displayed may be edited to reflect a more accurate description of the breed and other characteristics of the animals. Care must be taken to maintain similar descriptions or the related volume and nutrient production factors will not be correct. Press [Ctrl] [C] to copy the line of the current data field to the next line. Press [Ctrl] [D] to delete a line that has been copied. The default data lines may not be deleted. These data fields will accept 1-24 characters.
NUMBER
Enter the number of animals associated with each animal description. An entry into at least one of the data fields is required in order to move to the next data entry screen of the program. These data fields will accept 1-6 characters.
WEIGHT LBS
Enter the average weight of each animal described. An entry into at least one of the data fields is required in order to move to the next data entry page of the program. These data fields will accept 1-4 characters.
CONFINEMENT-START
Select the first month of confinement by pressing the [Shift] and the [<] or [>] keys together. If the animals are not confined, use the [Shift] and the [<] keys to select NONE. This data field will not allow data to be entered directly. . To copy the entry to the data field directly below, press [Ctrl] [C].
CONFINEMENT-END
Select the last month of confinement by pressing the [Shift] and the [<] or [>] keys. If the animals are not confined, use the [Shift] and the [<] keys to select none. This data field will not allow data to be entered directly. To copy the entry to the data field directly below, press [Ctrl] [C].

CONFINEMENT-DAYS
This is an automatic calculation by the program. For a JAN starting month and a DEC ending month of a confinement period of 365 days is used. If NONE is entered for both the starting and ending confinement period, 0 days are used for the confinement. Partial month confinement can be reflected by entering two lines for the animal group and adjusting the number of animals per line to reflect partial month conditions. As an example a Oct 15 to April 30 confinement period can be reflected by showing one-half of the animals being confined Oct-Apr and one-half confined Nov-Apr.
DAYS GRAZED
This is an automatic program calculation = 365 days – confinement days.
DAYS LIQUID STORAGE
Enter the planned liquid storage period in days not to exceed 365. To copy the current entry to the data field directly below, press [Ctrl] [C]. This data field will accept 1-3 characters.
DAYS SOLID STORAGE
Enter the planned solid storage period in days not to exceed 365. If all of the waste is handled as a liquid, enter 0. To copy the current entry to the data field directly below, press [Ctrl] [C]. This data field will accept 1-3 characters.

<u>SCREEN 3, DAILY BEDDING FACTOR</u>
This table shows typical daily bedding factors (first value) and calculates daily volume of bedding for the confined animal units (second value). When actual bedding use is known equate use to a daily animal unit rate. Bedding increases the size of the storage required for holding solid waste.
TYPE
Enter the type of bedding material used (informational description only). This description is printed on the output. This data field will accept 1-30 characters.
SELECTED FACTOR
Enter the appropriate bedding factor using the displayed list as a guide or enter an appropriate bedding factor for the type and volume of bedding used. Leave blank if a separator factor is to be entered which accounts for all solids and bedding separated. If bedding is planned to be used that will not be processed over the separator, enter the appropriate value. This data field will accept 1-5 characters.
SOLID SEPARATION FACTORS
SELECTED SEPARATOR FACTOR OR PERCENT OF TOTAL MANURE TREATED AS A SOLID
One of the first three lines is applicable if a separator structure is used. Enter the appropriate separator factor using the displayed list as a guide **<u>or</u>** manufacture ratings for separator type. Where manure is handle by scraping of waste to a stockpiled or allowed to accumulate in a corral move to the next data field and enter the total percentage of manure treated or handled as a solid. These data fields will accept 1-5 or 3 characters respectively. **The program will not allow entries into both data fields.** Refer to IWMG, Table 2 for general information on where manure is deposited.
Does Feed Seepage Enter Liquid Storage Facility (Y/N)-? YES If feed seepage enters the liquid storage facility, enter Y for yes. If feed seepage does not enter the liquid storage facility, enter “N” for no. Feed seepage is estimated by assuming 30 cubic feet of seepage per 1000-pound animal unit per year. This data field will accept 1-3 characters.

<u>SCREEN 3A, SOLID OPTIONS</u>
If the type of operation is a dairy, then another screen is shown to allow the user to designate how the manure is handled individually for milkers, dry cows, heifers and calves.

<u>SCREEN 4, VOLUME WASH WATER</u>
Note: If the type of operation is not a dairy, not all of the data entry fields described below will be displayed. For operations other than dairies simply refer to the data fields below displayed on the data entry screen. Refer to the IDWMG or the AWMFH for more information on volumes of wash water.
Cow Preparation Manual
If manual wash cow preparation is used, enter the daily wash volume per cow in gallons or cubic feet per day. These data fields will accept 1-6 characters.

Automatic Stall Wash
If automatic stall wash cow preparation is done, enter the daily wash volume per cow in gallons or cubic feet per day. These data fields will accept 1-6 characters.

Sprinkler
If automatic sprinkler wash cow preparation is done, enter the daily wash volume per cow in gallons or cubic feet per day. These data field will accept 1-6 characters.
Total Daily Volume= (number) **Cows X Total Selected Amount=**
The default number of cows for the daily volume of wash water is based on the animal numbers from screen 3, inventory data. If you wish to change the number of cows the daily volume of wash water is based on, simply press the left cursor key while in the sprinkler wash field and enter the desired number. Editing this field will not affect the numbers shown on data entry screen 3, inventory data. This data field will accept 1-6 characters. The program computes the total amount of wash water based on the number of cows washed per day and displays the amount.
Bulk Tank-Automatic
If a automatic bulk tank wash is used, enter the gallons or cubic feet used per wash. These data fields will accept 1-6 characters.
Manual
If a manual bulk tank wash is used, enter the gallons or cubic feet used per wash. These data fields will accept 1-6 characters.
Miscellaneous Equipment
Enter the daily amount of wash water used for miscellaneous equipment in gallons or cubic feet per wash. These data fields will accept 1-6 characters.
Pipelines
Enter the daily amount of wash water used for flushing pipelines in gallons or cubic feet per wash. These data fields will accept 1-6 characters.
Milkhouse And Parlor
Enter the daily amount of wash water used for the milkhouse and parlor in gallons or cubic feet per wash. These data fields will accept 1-6 characters.
Holding Area
Enter the daily amount of wash water used for washing the holding area in gallons or cubic feet per wash. These data fields will accept 1-6 characters.
Total Daily Volumes = {number} **Washes X Total Selected Amount** = If the number of washes shown is not correct, simply press the left cursor key while in the holding area data field and enter the correct number of washes used per day. This data field will accept 1-2 characters. The program will compute the total amount of wash water based on the number of washes per day and display the amount. When categories have different numbers of wash cycles per day, adjust the wash water per category to total water per day and change the number of washes to 1 per day.
LOT RUNOFF AREA
Roof
Enter the roof area, in square feet, that drains into the liquid storage facility. This data field will accept 1-7 characters.
Concrete Slab, Scraped Daily (Y/N) ? YES
Enter the unroofed concrete slab area, in square feet, that drains into the liquid storage facility. This data field will accept 1-7 characters. The default response for the unroofed concrete slab area being scrapped daily is yes. If the unroofed concrete slab area is not scraped daily, simply press the left cursor key while in the concrete slab area data field and press 'N" for no. If the concrete slab is scraped daily, the program will assume 100% of the monthly rainfall as runoff from the slab. If the concrete slab is not scraped daily, the program will apply concrete slab runoff factors to compute the runoff from the slab. This data field will accept 1-3 characters. Concrete and roof runoff have been disabled to match values given in IDWMG.
Unsurfaced Lot
Enter the unroofed unsurfaced lot area, in square feet, that drains into the liquid storage facility. This data field will accept 107 characters.
Total
The program will compute the total amount of surface area contributing to the liquid storage facility and display the amount. For the months of December through March the 1 in 5 year precipitation values are used to calculate runoff. Average Precipitation is used for April through November. Refer to pages 65-67 of the IDWMG.

<u>SCREEN 5, RUNOFF OPTIONS</u>
This screen allows the user to select whether to use the maximum or just the winter precipitation for the design storage period. Use the right or left arrow keys to toggle back and forth and make a selection. Winter precipitation is the default value.

SCREEN 6, IDAHO ANIMAL WASTE OPTION PAGE

At this page the user can (1) recycle through inventory input (2) proceed to storage facility sizing screens (3) proceed to the nutrient evaluation screens. Arrow down to desired option and [Enter] or [PgDn].

SCREEN 7, SOLIDS STORAGE AREA

Width, W= FT

Enter the width of the solid storage facility desired in feet. **For in corral storage, W=0**. This data field will accept 1-3 characters.

Height, H= FT

Enter the total height of the solid storage stack in feet. **For in corral storage, H=0**. This data field will accept 1-4 characters.

Wall Height, h= FT

Enter the wall height of the solid storage facility desired in feet. This data field will accept 1-4 characters.

Stack Slope, z= 2;1

The default stack slope ratio is 2. If a different stack slope ratio is desired, delete the default value and enter the desired stack slope ratio. This data field will accept 1-3 characters.

Covered, (Y/N) ? NO

The default response to the question of whether the tank is covered or not is NO. If the solids storage facility is covered, enter "Y" for yes. If the response is NO, the program will add the surface area of the solids storage facility to the lot runoff area when computing the total runoff entering the liquid storage facility. This data field will accept 1-3 characters.

Note: Press [Ctrl] [X] keys at the same time to compute the length of the solids storage facility "L" in feet and required storage capacity in cubic feet. The program will add 1 gallon per day of seepage per 100-pound animal unit from the solids storage facility to the total seepage entering the liquid storage facility. Refer to page 35 of the IDWMG for more information on seepage from solid storage facilities.

SCREEN 8, SELECT LIQUID STORAGE FACILITY

1- ANAEROBIC LAGOON
2- WASTE HOLDING POND
3- TWO CELL WASTE HOLDING POND
4- CIRCULAR HOLDING TANK
5- EVAPORATION POND

Press the number associated with the type of liquid storage facility desired. If there is not enough annual evaporation to size an evaporation pond, the program will display NOT ENOUGH EVAPORATION TO DESIGN POND and return to this data input screen.

CHOICE->

OK-? (Y/N)

If you have previously made a liquid storage facility selection, the program will show the choice you have made. If you wish to select another type of liquid storage facility, press "N" and then the number of the storage facility desired. If the highlighted type of liquid storage facility is okay, press "Y", [PgUp] or [PgDn] to continue.

SCREEN 9A, ANAEROBIC LAGOON or WASTE HOLDING POND or EVAPORATION POND
SCREENS 9B and 9C, TWO CELL WASTE HOLDING POND

Side Slope, Z=3:1

The default side slope ratio is 3. If a different side slope ratio is desired, delete the default value and enter the side slope ratio desired. This data field will accept 1-3 characters.

Bottom Width, BW = ft

Enter the bottom width planned or estimated for the holding pond. This data field will accept 1-3 characters.

Bottom Length = ft

Enter the bottom length planned or estimated for the holding pond. This data field will accept 1-4 characters.

Sludge Duration = 10 Yrs

The default duration for sludge accumulation is 10 years. If a different duration is desired, delete the default value and enter the desired duration for sludge accumulation in years. Sludge accumulation is based on a percentage of total solids produced annually per 1000-pound animal unit. This data field will accept 1-2 characters.

Existing Storage = O AF

The default value for the amount of existing storage available is 0 acre-feet. If there is existing storage available, delete the default value and enter the amount in acre feet of existing storage. This data field will accept 1-5 characters.

Surface Area = O SF
The default value for the surface area of the existing storage is 0 square feet. If there is an existing storage facility that is not covered, delete the default value and enter the surface area in square feet of the existing storage facility. This data field will accept 1-7 characters.
Note: Press the [Ctrl] [X] keys to compute the capacity in acre feet, depth of pond needed, "d" in feet, the top width "TW" in feet, and the top length in feet.

SCREEN 9D, CIRCULAR HOLDING TANK
Diameter, DIA= FT
Enter the desired inside diameter of the circular holding tank in feet. This data field will accept 1-4 characters.
Tank Covered (Y/N) ? YES
The default value for the tank being covered is yes. If the tank is not covered, enter "N" for no. If the tank is not covered, the amount of rainfall storage needed in inches and feet will be displayed. This data field will accept 3 characters.
Existing Storage = O CF
The default value for the amount of existing storage available is 0 cubic feet. If existing storage exists, enter the amount in cubic feet. This data field will accept 1-7 characters.
Surface Area = O SF
The default value for the surface area of the existing storage is 0 square feet. If there is an existing storage facility that is not covered, delete the default value and enter the surface area in square feet of the existing storage facility. This data field will accept 1-7 characters.
NOTE: press the [Ctrl] [X] keys to compute the depth of the circular holding tank "d" in feet and the volume of the tank in cubic feet. If the tank depth is greater than 20 feet, the program will indicate that the tank depth computed is unrealistic.

SCREEN 10, IDAHO ANIMAL WASTE OPTION PAGE
This is a repeat of SCREEN 7. At this page the user can (1) recycle through inventory input (2) proceed to storage facility sizing screens (3) proceed to the nutrient evaluation screens. Arrow down to desired option and [Enter] or [PgDn].

SCREEN 11, NUTRIENT LOSSES DURING STORAGE FOR XXXXX
SELECTED VALUES
***LIQUIDS>>>**
SOLIDS>>>
GRAZING>>>
Use the up and down cursor keys to select the storage method category for the type of waste indicated by the asterisk (*LIQUIDS>>>). Pressing the key that represents the first letter of the type of waste stored displays the storage loss category for that type of waste (e.g. [L] for liquids, [S] for solids). There are no storage losses for grazing. Pressing the [Enter] key while selecting a storage method category will allow the user to edit the percent retained values for nitrogen, phosphorous and potassium. These data fields will allow up to 3 characters. The program will not allow the data fields for grazing to be edited. To return to the loss category selection process, use the up cursor key.

SCREEN 12, NUTRIENT LOSSES DURING APPLICATION
SELECTED VALUES;
***LIQUIDS>>>**
SOLIDS>>>
GRAZING>>>

Use the up and down cursor keys to select the application category for the application method for the type of waste indicated by an asterisk (*LIQUIDS>>>). Pressing the key that represents the first letter of the type of waste stored displays the storage loss category for that type of waste (e.g. [L] for liquids, [S] for solids). The application category for grazing cannot be edited. Pressing the [Enter] key while selecting a application method category will allow you to edit the percent retained values for nitrogen, phosphorous and potassium. These data fields will allow up to 3 characters. To return to the loss category selection process, use the up cursor key.

SCREEN 13, DENITRIFICATION LOSSES FOR XXXXX
SELECTED VALUES;
***LIQUIDS>>>**

SOLIDS>>>
GRAZING>>>
In the Soil Drainage Class**,** section use the up and down cursor keys to select the soil drainage class for the type of waste indicated by a asterisk (*LIQUIDS>>>). Pressing the key that represents the first letter of the type of waste stored displays the storage loss category for that type of waste (e.g. [L] for liquids, [S] for solids, [G] for grazing). Pressing the [Enter] key while selecting a soil drainage class will allow you to edit the percent retained values for nitrogen. These data fields will allow up to 3 characters. To return to the drainage class selection process, use the up cursor key.

SCREEN 14, CROP INVENTORY AND TARGET YIELDS FOR XXXXX

Crop
If the crops grown are not displayed, press the [Ctrl] [L] keys to display the crop selection list. The hay/pasture crops include options for evaluating the nutrients based upon stage of growth at harvest. Use the up and down cursor keys to move through the list to find the crops desired. The [PgDn] and [PgUp] keys can be used to go from page to page of the crop list. A crop can be selected by pressing the [Enter] key. A selected crop is indicated by it being highlighted and can be unselected by pressing the [Ctrl] [D] keys. The last page of the crop selection list allows you to enter additional crops that are not listed in the *Idawm*. Be careful to enter nutrient uptake values in their elemental form for any additional crops added. Refer to NRCS Agricultural Waste Management Field Handbook, Chapter Six for information on the crops listed. To return to the data input screen once all of the desired crop shave been selected, press the [Ctrl] [X] key. For some crops several values are shown. Use the values which represent the planned harvest time in relation to stage of growth/maturity of crop. Only include grain straw as a crop when the straw is exported from the farm (not reused in the corrals and recycled back to the fields). The crops applicable to the utilization of the nutrients from the liquids, solids and grazing are entered separately for each of these categories.

Target Yield
Move to the data field adjacent to the crop desired and enter the yield in the units for the crop selected. This data field will accept 1-5 characters.

Years In Rotation
The program defaults to a rotation of 1 year for each crop listed. Edit year of respective crops to reflect the actual crop rotation. The nutrient utilization is based upon the crop, yield and years in the rotation.

SCREEN 15, CONTROLLING NUTRIENTS AND ECONOMICS

Nutrient-
Use the left and right arrow keys to select the nutrient on which the nutrient balance will be computed and press enter. Phosphorous is the default nutrient for the nutrient budget. The nutrient selected is used to compute application management data and acres needed for the crops previously selected for nutrient utilization. For information on nutrient uptake data, refer the NRCS Agricultural Waste Management Field Handbook, Chapter Six.

Value in Dollars-
If the default dollar values for nitrogen, phosphorous and/or potassium are incorrect, use the left and right arrow keys to move to the proper input field and enter the correct dollar value. The data field will accept 1-5 characters.

Fertilizer Application Cost-
If the default value for fertilizer application cost is incorrect, enter the correct dollar value. This data filed will accept 1-5 characters.

Manure Application Cost-
If the default value for manure application cost is incorrect, enter the correct dollar value. This data field will accept 1-5 characters.

System Life-
If the default value for the overall waste management system life is incorrect, enter the correct value for the expected life of the waste management system. This data field will accept 1-5 characters.

Annual Percentage Rate-
If the default value for the annual percentage rate at which money can be borrowed is incorrect, enter the correct annual percentage rate. This data field will accept 1-5 characters.

SCREEN 16, ACRES NEEDED FOR UTILIZATION BASED UPON XXXXX

The program calculates the required acres for the crop rotation specified to utilize the nutrients in the liquid and solid wastes and waste deposited from grazing animals. This computation is based on the utilization of the nutrient indicated. The default analysis proportions the nutrients by the number of years that each crop is in the rotation. **The manure distribution can be altered or adjusted for numerous management/cropping alternatives.**

The break even cost value for dollars invested into a waste management system and nutrient balance will be computed and displayed. The break even cost value is based on nutrient dollar values as they relate to commercial fertilizer costs needed to produce the target yields for the crop grown and take into account differences in application costs for commercial fertilizer and manure.

A nutrient balance will be computed for the nutrient selected and the total acres needed, nutrients utilized, nutrients in excess or still needed will be displayed along with cost data. Negative values indicate excess nutrients are available and positive values indicate additional nutrients may be needed to meet target yields.

SCREEN 17, WHICH TYPE OF IRRIGATION SYSTEM DO YOU USE
Use the arrow key to select the appropriate type of sprinkler, center pivot, Big Gun, wheel line, hand line. This screen appears when sprinkler application of liquid waste is selected in SCREEN 12, if broadcast application is selected SCREEN 19B will appear.

SCREEN 18A, XXXXXX
Enter requested data for the type of sprinkler system being used and/or planned.

SCREEN 19A, MANAGEMENT CRITERIA FOR SPRINKLING APPLICATION OF LIQUIDS
XXXXX Concentration in Storage = XXX PPM or X.XX LBS/ 1000 GAL
The program will compute and display the nutrient concentration in parts per million and pounds per thousand gallons in storage for the nutrient specified for uptake calculations. If the nutrient concentration in storage is known in either parts per million or pounds per 1000 gallons, move to the appropriate data field, delete the displayed value and enter the known value. These data fields will accept 1-5 characters.
Application
(LBS)
XXX
The maximum pounds to be applied of the nutrient specified for uptake calculations will be displayed along with other application data. If the pounds applied per application is incorrect, delete the amount displayed and enter the correct amount in pounds. This data field will accept 1-4 characters.

SCREEN 19B, MANAGEMENT CRITERIA FOR Broadcast APPLICATION OF LIQUIDS
Tank Wagon Capacity = 4000 Gallons
The default value for the tank wagon capacity is 4000 gallons. If the default value is incorrect for the equipment used, delete the default value and enter the correct capacity in gallons. This data field will accept 1-5 characters.
Spread Width = 15 Feet

The default value for the spread width of a tank wagon is 15 feet. If the default value is incorrect for the equipment being used delete the default value and enter the correct spread width in feet. This data field will accept 1-3 characters.

XXXXX Concentration in Storage = XXX PPM or X.XX LBS/1000 Gal
The program will compute and display the nutrient concentration in parts per million and pounds per thousand gallons in storage for the nutrient specified for uptake calculations. If the nutrient concentration in storage is known in either parts per million or pounds per 1000 gallons, move to the appropriate data field, delete the displayed value and enter the known value. These data fields will accept 1-5 characters.
Application
(LBS)
XXX
The maximum pounds to be applied of the nutrient specified for uptake calculations will be displayed along with other application data. If the pounds applied per application is incorrect, delete the amount displayed and enter the correct amount in pounds. This data field will accept 1-4 characters.

SCREEN 20, MANAGEMENT CRITERIA FOR XXXXXXXX APPLICATION OF SOLIDS
Management data will be presented for the application method chosen for solids.
For Tractor Spreader Application of Solids

Tractor Spreader Capacity = 160 Bushels or 199 Cubic Feet
The default value for the tractor spreader capacity is 160 bushels or 200 cubic feet. If the default values are incorrect for the equipment used, move to the appropriate data field, delete the default value and enter the correct capacity in bushels or cubic feet. These data fields will accept 1-4 characters.

Spread Width = 15 Feet
The default value for the spread width of the tractor spreader is 15 feet. If the default value is incorrect for the equipment being used, delete the default value and enter the correct spread width in feet. This data field will accept 1-3 characters.

XXXXX Concentration in Storage = XXX PPM or X.XX LBS/1000 Gal
The program will compute and display the nutrient concentration in parts per million and pounds per thousand gallons in storage for the nutrient specified for uptake calculations. If the nutrient concentration for uptake calculations. If the nutrient concentration in storage is known in either parts per million or pounds per 1000 gallons, move to the appropriate data field, delete the displayed value and enter the known value. These data fields will accept 1-5 characters.

Application
(LBS)
XXX
The maximum pounds to be applied of the nutrient specified for uptake calculations will be displayed along with other application data. If the pounds applied per application is incorrect, delete the amount displayed and enter the correct amount in pounds. This data field will accept 1-4 characters.

SCREEN 21, IDAHO ANIMAL WASTE OPTION PAGE
This is a repeat of SCREEN 7. At this page the user can (1) recycle through inventory input (2) proceed to storage facility sizing screens (3) proceed to the nutrient evaluation screens. Arrow down to desired option and [Enter] or [PgDn].

SCREEN 22, PRINT OUT OPTIONS
Press [I] To print only the Inventory
Press [S] To print Inventory plus Sizing
Press [N] To print Inventory plus Nutrient Use
Press[A] To print All

SCREEN 23, Printed Output-
Press [S] To Send Output to Screen
Press [P] to Send Output to Printer
Press [F] to Send Output to a File

To send the output to the screen, press the [S] key. Use the [PgUp] and the [PgDn] keys to move between output screens.

To send the output to an attached printer, press the [P] key. The type of printers the program supports will be display with the default printer highlighted. If you wish to print to a printer other than the default printer highlighted, use the up and down cursor keys to select the printer desired and press the [Enter] key.
To send the output to a file, press the [F] key. Indicate the data path the program will use to store the output file to. The output file will have a .OUT extension and will be formatted as an ASCII file.

[F1] DATA FILE RETRIEVAL-
Note: The program may automatically go to the save input data screen on page 13 if the input data had not been previously saved before selecting to retrieve data.
SCREEN #1, ENTER DISK DRIVE AND PATH TO RETRIEVE DATA FROM:
DATA FILE PATH . . .
The default disk drive and data path where data files are stored is displayed. If the data files are not stored in the default data path, enter the disk drive and data path where data files are to be retrieved from. Press the [Enter] key to retrieve the data files.
SCREEN #2, FILE NAME
Use the [PgDn] and [PgUp] keys to search for the data file to retrieve input data from and use the [Up] and [Down] cursor keys to move between data files. Press the [Enter] key to select the highlighted data file for data retrieval.

The program will indicate that it is loading data and return to input data screen 3.

[F2] SAVE INPUT DATA-
SCREEN#1, ENTER DATA PATH AND FILE NAME TO STORE DATA TO:
DATA FILE PATH . . .
The default data path is displayed. To save the input data to a data path other than the default data path, delete the default data path and enter the disk drive and path desired. Press the [Esc] key to exit this data entry screen without making changes or saving data.
DISK FILENAME . . .
To change the displayed disk filename, press the [,--] key to remove the unwanted characters or the [Del] key to clear the entire data entry field. This data field will accept 8 characters. Press the [Esc] key to exit this data entry screen without making changes or saving data.
LANDOWNER/OPERATOR . . .
To accept the landowner/operator name displayed and save data, press the [PgDn] key. To change the landowner/operator name displayed, press the [Backspace] key to remove unwanted characters or the [Del] key to clear the entire data entry field and enter the landowner/operator name desired. This data field will accept 40 characters. Press [Esc] to exit this data entry screen without making changes or saving data. Press the [PgDn] key to save the input data to a data file.
Saving Data . . .
The program will indicate it is saving the data and return to the input data screen from which the [F2] key was pressed or continue to the operation selected if the input data had not previously been saved.

[F3] DEFAULT DATA ENTRY-
Note: Press the [PgDn] and [PgUp] keys to move between default data entry screens. The program may automatically go to the save input data screen if the input data had not been previously saved before pressing [F3] to save defaults.
SCREEN #1, ENTER AND/OR SELECT DEFAULTS
ASSISTED BY:
Enter the name of the person who will be using the program the most. This data field will accept 1-40 characters.
CLIMATIC STATION:
Enter the climatic station that best represents the location of the CAFO operation to be assisted as shown on page 150 of the IDAWM. Pressing [Ctrl] [L] will display a list of climatic stations to choose from. Use the up and down cursor keys to choose the climatic station you want and press [Enter]. A correct entry in this data field is required to move to the next data entry screen. This data field will accept 1-20 characters.
TYPE OF OPERATION:
Enter the type of CAFO as describe on pages 71 of the IDWMG that best represents the majority of CAFO's to the assisted. Pressing [Ctrl] [L] will display a list of CAFO's to choose from. Use the up and down cursor keys to choose the type of CAFO you want and press [Enter]. A correct entry is required in this data field to move to the next data entry screen. This data field will accept 1-9 characters.
DESCRIPTION
The animal descriptions displayed may be edited to reflect a more accurate description of the breed and other characteristics of the CAFO. Care must be taken to maintain similar descriptions as described on page 71 in the IDWMG or the related volume and nutrient production factors will not be correct. Press [Ctrl] [C] to copy the line of the current data field and insert it directly below the current line. Press [Ctrl] [D] to delete a line that has been copied. The default data lines may not be deleted. These data fields will accept 1-24 characters.
WEIGHT LBS
Enter the average weights desired for the defaults of each animal described. These data fields will accept 1-4 characters.
CONFINEMENT-START
Select the first month of confinement by pressing the [Shirt] and the [<] or [>] keys. If the animals are not confined, select NONE. This field will not allow data to be entered directly.
CONFINEMENT-END
Select the last month of confinement by pressing the [Shift] and the [<] or [>] keys. If the animals are not confined, select NONE. This field will not allow data to be entered directly.
DAYS LIQUID STORAGE
Enter the planned liquid storage period in days not to exceed 365. To copy the current entry to the data field directly below, press [Ctrl] [C]. This data field will accept 1-3 characters.
DAYS SOLID STORAGE

Enter the planned solid storage period in days not to exceed 365. If all of the waste is handled as a liquid, enter 0. To copy the current entry to the data field directly below, press [Ctrl] [C]. This data field will accept 1-3 characters

SCREENS #2, 3, 4,5, SELECT CROPS FOR NUTRIENT DISPOSAL

Use the up and down cursor keys to move through the crop list to find the crops to be used as the defaults. The [PgDn] and {PgUp] keys can be used to go from page to page of the crop list. A crop can be selected by pressing the [Enter] key. A selected crop is indicated by it being highlighted and can be unselected by pressing the [Ctrl] [D] keys together. The last page of the crop selection list allows you to enter additional crops that are not listed in the IDWMG. Be careful to enter nutrient uptake values in their elemental form for any additional crops added. Refer to NRCS Agricultural Waste Management Field Handbook, Chapter Six for information on the Crop Uptake Nutrient.

CROP

Enter the crop names for the crops planned as defaults that are not listed on the previous screens. This data field will accept 1-25 characters.

CONDITION

Enter the condition of the crops planned to be used as defaults. This data field will accept 1-15 characters.

YIELD UNITS

Enter the yield units (ton, bu) for each crop entered as a default. This data field will accept 1-3 characters.

N

Enter the elemental nitrogen uptake value in pounds per yield unit previously entered for each default crop. This data field will accept 1-5 characters.

P

Enter the elemental phosphorous uptake value in pounds per yield unit previously entered for each default crop. Make sure the value entered is in the elemental form as the value entered will be converted to P_2O_5 by the program. This data field will accept 1-5 characters.

K

Enter the elemental potassium uptake value in pounds per yield unit previously entered for each default crop. Make sure the value entered is in the elemental for as the value entered will be converted to K_20 by the program. This data field will accept 1-5 characters.

SCREEN 6, ENTER CROP DATA FOR NUTRIENT DISPOSAL NOT ON LIST

Input items listed above for screens 2-5 for crop, condition, yield units, N, P and K.

SCREEN #7, ENTER DEFAULT NUTRIENT FOR THE NUTRIENT BALANCE AND COST FACTORS

Nutrient

Use the left and right arrow keys to select the nutrient on which the nutrient balance and management data will be computed and press enter. Phosphorous is the typical default nutrient.

Value in Dollars

Use the left and right arrow keys to move to the proper input field and enter the default dollar value to be used for the corresponding nutrient. The data fields will accept 1-5 characters.

Fertilizer Application Cost

Enter the default dollar value to be used for fertilizer application cost. This data field will accept 1-5 characters.

Manure Application Cost

Enter the default dollar value to be used for manure application cost. This data field will accept 1-5 characters.

System Life

Enter the default value to be used for the overall waste management system life. This data field will accept 1-5 characters.

Annual Percentage Rate

Enter the default value to be used for the annual percentage rate at which money can be borrowed. This data field will accept 1-5 characters.

SCREEN #8, CHOOSE PRINTER

Select Printer

Use the up and down cursor keys to move through the list to find the printer that best represents the printer to be used to get printouts from the program. Press the [Enter] key to select the highlighted printer as the default.

Data File Path . . .

Enter the default disk drive and data path where data files are to be saved. Press the [PgDn] key to save the default data as entered.

Saving Data . . .

The program will indicate it is saving the default data and return to the screen where the [F3] key was selected.

E. PROGRAM LIMITS

SCREEN 2 -

A valid climatic station, a valid type of operation and at least one animal number data field must have data in order to proceed to the next data entry screen.

Only a total of 10 different animal descriptions may be entered.

The program uses the either the maximum or winter rainfall period based on the liquid storage days entered to compute storage requirements. The program also computes the seepage storage requirements based on the maximum liquid storage days entered. Per State of Idaho requirements a 1 in 5 year winter precipitation is used instead of the average precipitation for the months of Dec through March.

SCREEN 3 -
If a separator factor is entered, the program assumes that the factor includes manure and bedding separated. If a bedding factor is also included, the program will add the bedding volume to the separated volume for the solids produced during the storage period selected on screen 3.

SCREEN 7
A reduction of approximately 30 percent in total sludge volumes is made when a separator factor is used. For anaerobic lagoons, no consideration for a reduction in total solids is made when a solid separator factor is used. If the tank depth computed exceeds 20 feet a warning statement will be displayed indicating that the depth is not practical.

SCREEN 14
Only 10 crops may be selected for nutrient utilization.

F. Example #1

Animal Waste Management System Inventory Worksheet for Dairies

Name of Landowner/Operator Don Green

Street Address P.O. Box 5000

City Meridian, or Zip Code 00000

Phone Number 208 555-1212

Assisted by Ed Helpful Date Sometime very soon

General Description of Operation

Current Mr. Green is currently milking 200 Holstein cows and has 40 dry cows, 40 heifers and 50 calves. Concrete slabs are scraped daily. He has 400 acres available for waste application which is in corn for silage and irrigated grass legume pasture and hayland. Alfalfa hay typically cut early bloom.

Planned Mr. Green would like to expand his herd size to 300 Holstein milking cows and improve on his waste management system. He would like a waste holding pond for storing liquid wastes and a solid stack area for solids.

Problems Roofs are not guttered, roofs and open lot areas contribute runoff to liquid storage facility.

Livestock Data Current-

Description	Number	Average Weight Pounds	Days Confined	Days Grazed	Days Storage Liquids	Days Storage Solids
Milkers	200	1400	365	0	10	10
Dry	40	1200	365	0	10	10
Heifers	40	850	212	153	10	10
Calves	50	250	365	0	10	10

Livestock Data Planned-

Description	Number	Average Weight Pounds	Days Confined	Days Grazed	Days Storage Liquids	Days Storage Solids
Milkers	300	1400	365	0	180	120
Dry	40	1200	365	0	180	120
Heifers	50	850	212	153	180	120
Calves	60	250	365	0	180	120

Storage Component Volumes

Cow Prep (Auto Single Cow: 5-15 gal/milker/day)
(Auto Multiple Cow: 25-40 gal/milker/day)
(Manual: 3-7 gal/milker/day) Manual - 4

Bulk Tank (Manual: 30-50 gal/wash)
(Auto: 60-110 gal/wash) __Manual - 50__ No. Washes __2__
Pipeline (75-150 gal/wash) ______150______ No. Washes __2__
Miscellaneous (25-35 gal/wash _____30_____________ No. Washes __2__
Milkhouse (300-700 gal/wash) ______300________ No. Washes __2__
Holding Area (500-1200 gal/wash) ________________ No. Washes __2__
Contributing Drainage Area, Acres
Contributing Roof Runoff Area, Sq. Ft. ___O, All building will be guttered
Contributing Lot Runoff Area, Sq. Ft Surfaced _____2,000 roof, 1000 concrete (scraped daily)
Unsurfaced ___15000
Type of Bedding ___________Sawdust
Volume, CY/Day _Current-150 CF/day Planned-160 CF/day

From milking and dry cows 95 % of waste to be handled as a solid from heifers and calves 100% of waste handled as a solid.

General Notes

Soils in the utilization area consist of moderately well drained silt loam soils.

Mr. Green uses a traveling “Big Gun” to apply liquids to the fields for utilization. The “Big “Gun operates at 300 GPM with a wetted diameter of 250 feet.

Mr. Green uses a 160 Bushel tractor spreader to spread solids in 15 foot wide strips to field for utilization.

Mr. Green stated he may apply for EQIP.

Assumptions for nutrient evaluations: for liquids a storage pond > than 50% dilution, for solids unroofed storage area, sprinkler application of liquids, spreader application of solids with incorporation within 3 days.

Animal Waste Management

Planning Worksheet

G. Example #2

Animal Waste Management System Inventory Worksheet for Beef

Name of Landowner/Operator Mr. White

Street Address P.O. Box 6000

City Council, Idaho , or Zip Code 83-----

Phone Number 208 555-1212

Assisted by Ed Helpful Date Sometime very soon

General Description of Operation

Current Mr. White has a beef operation in which he feeds approximately 100 – 850 pound ave wt steers. He has 500 acres of alfalfa hay and wheat for disposal of wastes. During summer months animals are grazed or not on property. Alfalfa hay cut when mature.

Planned Mr. White is not planning to expand his herd, but would like to improve on his waste management system. He would like to add some type of waste storage facility to stop storm runoff onto neighbor. Solid wastes will be manure pack in corral. Wants to use a big gun sprinkler for applying liquids. Concrete pad is not scraped on a daily basis. Does not plan on using any wash water.

Problems The existing waste management system does not have any storage. Storm water in winter spring flows into nearby stream.

Livestock Data Current-

Description	Number	Average Weight Pounds	Days Confined	Days Grazed	Days Storage Liquids	Days Storage Solids
Feeders-forage	100	850	243	122	0	0
Feeders					0	0
Cows					0	0
Calves					0	0

Livestock Data Planned-

Average Days

Description	Number	Weight Pounds	Days Confined	Days Grazed	Storage Liquids	Storage Solids
Feeders-forage	100	850	243	122	180	243
Feeders					0	0
Cows					0	0
Calves					0	0

Storage Component Volumes

Holding Area (500-1200 gal/wash) ________________ No. Washes

Contributing Drainage Area, Acres None

Contributing Roof Runoff Area, Sq. Ft. None

Contributing Lot Runoff Area, Sq. Ft Surfaced 1500 SF roofs, 1000 SF concrete slab

Unsurfaced 18000

Type of Bedding Wheat Straw

Volume, CY/Day 142 CF/day Currently and Planned

Utilization Area

Field Number	Crop	Acres	Yield Units/Acre Present	Yield Units/Acre Target	(Good, Fair, Poor) Crop Condition	(Good, Fair, Poor) Management Level
1 & 2	Grass/Legume Past	50	4 ton	4 ton	Good	Good
4 &6	Alfalfa, Hay	60	4 ton	5 ton	Good	Good
3	Wheat	50	75 bu	75 bu	Good	Good

General Notes

Soils in the utilization area consist of moderately well drained silt to silty loam soils. Depth to water table is greater than 4 feet.

No seepage entering liquid storage facility from feed storage area.

Mr. White has a “Big Gun” sprinkler that can be used to apply liquid waste to the utilization area. The “Big Gun” sprinkler has a flow rate of 165 gallons per minute and a wetted diameter of 200 feet. Mr. White also uses a 160 bushel spreader that spreads the solid waste in 20 foot wide strips to the utilization area.

APPENDIX D - WA NRCS ENGINEERING TECHNICAL NOTE #23

TECHNICAL NOTES

U.S. DEPARTMENT OF AGRICULTURE NATURAL RESOURCES CONSERVATION SERVICE

ENGINEERING #23 **SPOKANE, WASHINGTON**

January, 2013

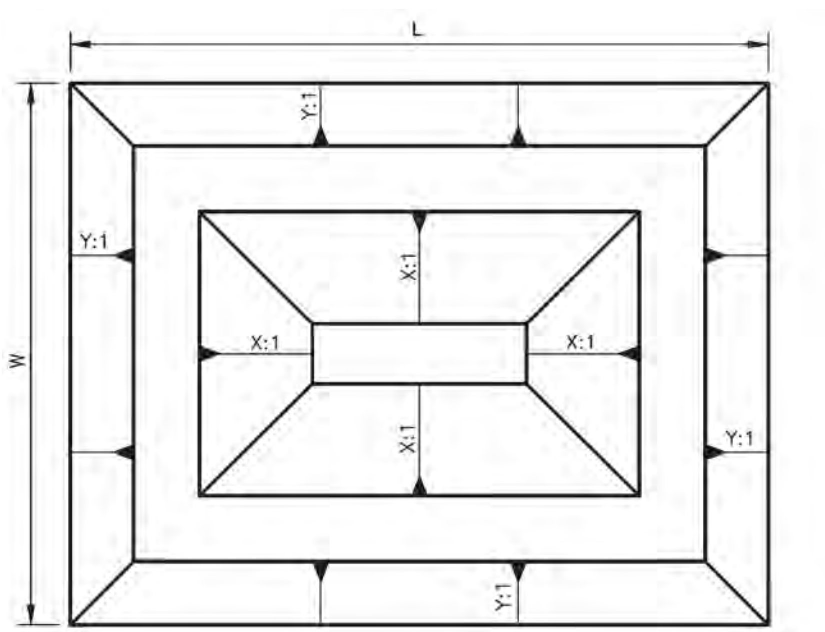
NRCS ASSESSMENT PROCEDURE

FOR

EXISTING WASTE STORAGE PONDS (WSP)

This Technical Note prescribes a consistent review and assessment process for assigning one of four rating categories and subcategories to a waste storage pond (WSP) according to observed factors that may contribute to the risk of contamination of water resources.

The NRCS assessment should not be construed to provide **ANY** regulatory certainty from State regulatory agencies. State of Washington laws and rules prohibit pollution of waters of the state, including ground water. The state requires a permit for discharge of wastewater to waters of the state. This document does not supersede these requirements.



PLAN VIEW

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EXISTING WASTE STORAGE POND (WSP) ASSESSMENT PROCEDURE

INTRODUCTION

NRCS works with Dairy operators across Washington State to provide technical and financial assistance to further their effort in the implementation of practices that serve to protect water resources. Waste storage ponds (WSPs) encountered by NRCS staff, while providing assistance, may have been constructed to an outdated standard or constructed to no standard.

This technical note contains a site inventory and assessment procedure for evaluating existing WSPs. This procedure requires collecting existing WSP site information and conducting an assessment of the WSP and Site, to establish an overall assessment of a WSP according to observed factors that may contribute to the risk of water resources. The assessments in this technical note are qualitative in nature and are not intended to quantify seepage amounts occurring from existing WSP's.

BACKGROUND

Waste storage ponds (WSPs) are used in animal production agriculture for the purpose of containing liquid animal waste until such time that the waste can be utilized as a soil nutrient amendment for crop production. The Washington State Department of Agriculture (WSDA) is assigned the responsibility of statewide inspection and enforcement of Dairy facilities. If WSDA identifies a water quality concern, the operator is directed to NRCS and/or the local Conservation District (CD) for technical assistance. On a voluntary basis, NRCS and/or the CD collaborate with the Dairy operator to address the identified water quality concerns.

A WSP is a common component of a Dairy waste management system. Most often the existing WSP structure condition and performance is unknown. Information is needed in order to develop technically sound comprehensive nutrient management plan alternatives for the dairy operation. This technical note provides a standardized procedure for completing a assessment of, and recommendations for existing WSP's.

PROCEDURE

Through this procedure, NRCS personnel will establish an overall assessment category of a WSP according to observed factors that may contribute to the risk of water resource degradation. NRCS personnel will assign one of four rating categories and corresponding subcategory.

This Technical Note describes a three phase procedure that must be completed in order to assign an overall rating category to an existing WSP. Phase 1 consists of documenting the existing WSP and physical site features and includes a series of forms listed in the table below. Phase 2 documents whether the WSP complies with NRCS practice standard criteria. Phase 3 consists of assessment procedures.

The series of forms have been developed for conducting the assessment of the:

- Existing WSP
- Site
- The combined WSP/Site

Phases 1 and 2 must be completed before conducting Phase 3.

Table 1. Overview of Phase 1, 2 and 3 activities

Phase	Form	Name	Subparts
1	**SSIF**	WSP Site and Structure Inventory Forms	1. General Site Information Form 2. Site Soils Form 3. Site Attributes Form 4. Structure Attributes Form 5. Structure Condition Form 6. Operation and Maintenance Form 7. Structure Modification Form
2	**PSCRF**	Practice Standard Compliance Report Form	None
3	**AF**	Assessment Forms	1. Site Assessment Form 2. Structure Assessment Form 3. Overall Assessment Form

PHASE 1 – WSP SITE AND STRUCTURE INVENTORIES

*WSP Site and Structure Inventory Forms (**SSIF**)*

Purpose: These forms document the current WSP site and structure conditions.

1. General Site Information: This form is used to document the general information regarding the existing WSP (e.g.: landowner, Address, Location, etc.). General weather and field surface conditions are documented as the accuracy of the data collection effort may be hampered depending on these conditions.
2. Site Soils Form: This form is used to inventory and record the natural ground site soil properties and water table conditions.
3. Site Attributes Form: This form is used to collect and document the WSP site information.
4. Structure Attributes Form: This form is used to document the physical characteristics of the existing WSP. Information collected for this step include a measure of the; embankment height, side slopes, top width, pond depth, etc. It may be necessary to utilize survey equipment to gather this information. The review person should document how the data was collected so that the users of the information can determine if further data collection would be needed in the future.
5. Structure Condition Form: This form is used for the “Near Full” or “Near Empty” condition to document waste storage pond observations made during a site visit such as; erosion, liner and embankment condition.
6. Operation and Maintenance Inventory Form: This form is used for the “Near Full” or “Near Empty” condition to document waste storage pond O&M activities and the resulting effectiveness. Document whether or not there are minor or major repair needs.
7. Structure Modification Form: This form is used to document modifications that have been made to the WSP either through visual inspection or conversation with the operator.

PHASE 2 – PRACTICE STANDARD COMPLIANCE

*Practice Standard Compliance Report Form (**PSCRF**)*

Purpose: This form is used to compare the existing WSP or the most recent structure modification against NRCS criteria in place at the time of construction. The current NRCS design criteria for this practice is found in the NRCS Practice Standard 313-Waste Storage Facility. The preceding standard for this practice was the NRCS Practice Standard 425 - Waste Storage Pond. A table listing critical changes to the NRCS Practice Standard design criteria for all of the pertinent revisions is located in Appendix 1.

When completing the form, document whether or not the WSP is performing in accordance with NRCS practice standard in place at the time of construction.

PHASE 3 – ASSESSMENT

*Assessment Forms (**AF**)*

Purpose: These series of forms are used to complete the Site, Structure and Overall assessments.

1. Site Assessment Form: The Site Assessment takes into consideration the existing saturated hydraulic conductivity, presence of wells, distance to the nearest body of water, EPA Region 10 sole source aquifer designations and the WSDA Aquifer Susceptibility Maps. Risk ratings of “Low”, “Medium” or “High” are assigned and are defined as:

   “Low Risk” - Located in an area that is highly unlikely to have water resources affected by the WSP.

   “Medium Risk” - Located in an area that may have water resources that could be affected by the WSP, however the site could be modified to protect water resources.

   “High Risk” - Located in an area where water resources are highly vulnerable to contamination and the site cannot be easily modified to protect water resources.

2. Structure Assessment Form: The Structure Assessment takes into account compliance with the NRCS practice standard in place at the time of construction and the inherent associated risk to the protection of water resources. Risk ratings of “Low”, “Medium” or “High” are assigned and are defined as:

   “Low Risk” - Waste Storage Pond complies with the NRCS practice standard in use at the time when constructed.

   “Medium Risk” - Waste Storage Pond complies with the NRCS practice standard in use at the time when constructed, however there are minor corrective actions necessary in order to restore the WSP to full functionality.

   “**High Risk”** - Waste Storage Pond does not comply with the NRCS practice standard in use at the time when constructed. Major corrective actions are necessary in order to restore the WSP to full functionality.

3. Overall Assessment Form: The Overall Assessment takes into account the Site and Structure assessment. There are four Categories with subcategories that are defined as:

   Category 1A - NRCS recommends utilizing the WSP for the purpose of waste storage.

   Category 1B - NRCS recommends utilizing the WSP for the purpose of waste storage, however the site may benefit from additional practices to reduce discharge potential in the situation of a structure failure.

   Category 2A - NRCS recommends utilizing the WSP for the purpose of waste storage, however the site would benefit from additional practices to reduce discharge potential in the situation of a structure failure.

   Category 2B - NRCS recommends discontinued use of the WSP for the purpose of waste storage until minor repairs and/or improvements have been completed in accordance with the NRCS practice standard in place at the time of construction and the site may benefit from additional practices to reduce discharge potential in the situation of a structure failure.

   Category 2C - NRCS recommends discontinued use of the WSP for the purpose of waste storage until minor repairs and/or improvements have been completed in accordance with the NRCS practice standard in place at the time of construction.

   Category 3A - NRCS recommends discontinued use of the WSP for the purpose of waste storage until major repairs or possible replacement of the existing WSP meeting the current NRCS Conservation Practice Standard – 313, Waste Storage Facility.

   Category 3B - NRCS recommends discontinued use of the WSP for the purpose of waste storage until major repairs or possible replacement of the existing WSP meeting the current NRCS Conservation Practice Standard – 313, Waste Storage Facility and the site may benefit from additional practices to reduce discharge potential in the situation of a structure failure.

   Category 3C - NRCS recommends discontinued use of the WSP for the purpose of waste storage until minor repairs and/or improvements have been completed for the waste storage pond structure and the site would benefit from additional practices to reduce discharge potential in the situation of a structure failure with structure relocation being considered.

   Category 4 - NRCS recommends discontinued use of the WSP for the purpose of waste storage until major repairs or possible replacement of the existing WSP meeting the current NRCS Conservation Practice Standard – 313, Waste Storage Facility and the site would benefit from additional practices to reduce discharge potential in the situation of a structure failure with structure relocation being considered.

OTHER CONSIDERATIONS/ CRITERIA

An existing WSP that stores more than 10 acre-feet above the ground surface must also be evaluated in accordance with the Washington Department of Ecology (DOE), Dam Safety Office (DSO) regulatory requirements. The DOE Dam Safety Office schedule regular review and inspection of jurisdictional WSP projects focused on configuring the WSP to survive suitable design floods and earthquakes. The DSO does not evaluate the adequacy of jurisdictional WSP's in meeting ground water quality performance requirements.

This Technical Note does not evaluate compliance with WA DOE Dam Safety criteria. If the WSP is a state regulated structure the DSO criteria will need to be met in addition to NRCS criteria.

REFERENCES:

1. "Earthen Manure Storage Seepage: A Study of Five Typical Sites," Prepared by: Principal investigator, Bill MacMillan with Study Summary by, Robert Borg and Peter Llewellyn, Agri-Facts, Practical Information for Alberta's Agriculture Industry, July 2001, Agdex 729-1

2. "Seepage Evaluation of Older Swine Lagoons in North Carolina," By R.L. Huffman, 2004 American Society of Agricultural Engineers, Vol. 47(5): pp 1507-1512.

3. "Measurement of Seepage from Earthen Waste Storage Structures in Iowa", T.D. Glanville, J.L. Baker, S.W. Melvin and M.M. Agua, 1999, Department of Agricultural & Biosystems Engineering, Iowa State University, Ames, Iowa 50011

4. DISCUSSION OF "Literature Review and Model (COMET) for Colloid/Metals and Transport in Porous Media", By W. B. Mills, S. Liu, and F.K. Fong, Groundwater, March-April 1991 issue, v. 29, no. 2, pp 199-208.

5. "Geologic and Ground Water Considerations," Chapter 7, Agricultural Waste Management Field Handbook, National Engineering Handbook (NEH),Part 657.07, Natural Resources Conservation Service, June, 1999.

6. "Agricultural Waste Management System Component Design," Chapter 10, Agricultural Waste Management Field Handbook, Amendment 31, National Engineering Handbook (NEH),Part 657.07, Natural Resources Conservation Service, August 2009.

7. "Design and Construction Guidelines for Impoundments Lined with Clay or Amendment-treated Soil," Appendix 10D, Agricultural Waste Management Field Handbook, Amendment 31, National Engineering Handbook (NEH),Part 657.07, Natural Resources Conservation Service, August 2009.

8. "Ground Water/Surface Water Interactions and Quality of Discharging Ground Water in Streams of the Lower Nooksack River Basin, Whatcom County, Washington", Stephen E. Cox, USGS; William Simonds, USGS; Llyn Doremus, Nooksack Indian Tribe, et. al. Scientific Investigations Report 2005-5255, U.S. Department of the Interior, U.S. Geological Survey.

9. "Liquid Animal Waste System Operation & Inspection Guide", Alabama Cooperative Extension System, BSEN – 01C4 (REV JUN 03), By Ted W. Tyson, P.E., C.I.D., Extension Biosystems Engineer & Professor, Auburn University.

10. "Guidance for the Evaluation of Existing Storage Structures", Michigan Department of Environmental Quality, Water Bureau, December 2, 2005.

11. "Subsurface Investigations for Waste Storage Facilities", 04/22/2009, Michigan NRCS, Animal Waste Management website. http://www.mi.nrcs.usda.gov/technical/engineering/animal_waste.html

12. "An AEM Tool for the Evaluation of Un-Designed Waste Storage Facilities", Agricultural Environmental Management, New York State, Soil & Water Conservation Committee, Department of Agriculture and Markets.

13. "Evaluation of Existing Waste Storage Facilities", William Reck PE, Darren Hickman PE, William Boyd PE, USDA-NRCS National Technical Service Center(s), 2006.

14. "Water Quality Indicator Tools", Water Quality Technical Note 1, Washington State NRCS, July 2000.

15. "Waste Storage Facility, Conservation Practice Standard, Code 313", USDA-NRCS, Washington State.

16. EPA Region 10 Sole Source Aquifer Maps, http://yosemite.epa.gov/r10/water.nsf/Sole+Source+Aquifers/ssamaps

SITE AND STRUCTURE INVENTORY FORMS (SSIF)

INSTRUCTIONS: The Site and Structure Inventory Forms are used to document the existing condition, physical features, evidence of operation / maintenance activities and the physical attributes of the WSP. The information collected through this process is used to complete the assessments for an existing WSP.

GENERAL SITE INFORMATION FORM:

Step 1: Document the landowner/farm name, address and the specific WSP location.

Step 2: Check the appropriate box for the review being completed, "WSP is near FULL or "WSP is near EMPTY".

Step 3: Complete the climatic condition section. This data is very important as it conveys the limitations present during the inventory process.

SITE SOILS FORM:

The Site Soils Form is used to document the existing WSP Site Soils. If there are different site soil types, it may be necessary to complete multiple reports.

SITE ATTRIBUTES FORM:

Information is either measured in the field, from maps, appendices of this technical note or from other previously completed forms of this technical note.

STRUCTURE ATTRIBUTES FORM:

Information is measured during the site visit or gathered from as-built documents. Provide comments pertinent to the site or structure for consideration during the assessment phase.

STRUCTURE CONDITION FORM:

Responses are either yes, no or N/A. The form was set up to address the Full or Empty condition, some of the questions may not apply depending on which condition is being evaluated.

SITE AND STRUCTURE INVENTORY FORMS (SSIF)

INSTRUCTIONS: (Continued)

OPERATION AND MAINTENANCE INVENTORY FORM:

Read each question and provide the appropriate response. Responses are either yes, no or N/A. The form was set up to address the Full or Empty condition, some of the questions may not apply depending on which condition is being evaluated.

WSP - MODIFICATIONS:

All WSP modifications shall be documented and an impact assessment shall be included.

SIGNATURE BLOCK:

The technically responsible staff person completing the forms shall print and sign their name. The Engineering Job Approval Authority for PS 313, “Design” will be included when completed by NRCS staff.

NRCS (SSIF - 3/10)

SITE AND STRUCTURE INVENTORY FORMS (SSIF)

GENERAL SITE INFORMATION FORM

LANDOWNER/FARM NAME: ____

ADDRESS:__________________________________ STATE:______ ZIP: __________

WSP LOCATION: Sec _________ T ____ R ____ **(or)** Lat ___________ Long __________

NRCS JOB CLASS: _____________

CHECK REVIEW CONDITION BELOW:

☐ WSP is FULL (Typically late winter or early spring)

☐ WSP is near EMPTY (Typically late summer or early fall)

MANURE/ EFFLUENT LEVEL and Other Observations: _________________________

____

TODAY: Liquid Level BELOW Top of Embankment or Spillway Elevation: ________ FT.

CLIMATIC CONDITIONS	
Weather:	Temperature:
Soil Surface Conditions (circle all that apply): Dry / Moist / Wet / Saturated / Standing Water/ Frozen/ Snow Covered	
Additional Information:	

SITE AND STRUCTURE INVENTORY FORMS (SSIF)

SITE SOILS FORM

INSTRUCTIONS: The Site Soils Report Form is used to document the existing WSP Site Soils. If there are different site soil types within the footprint of the structure or nearby it may be necessary to complete multiple reports.

Step 1: The landowner/farm name, address as well at the specific WSP location shall be documented.

Note: Attaching a soils map with the WSP location for documentation purposes is recommended.

Step 2: The soil type and soil profile propertied are retrieved from the NRCS Web Soil Survey (WSS). Aerial photos may also be used to document the surface water section of the site soils report.

It will be necessary to document the USCS classification for soils below the pond bottom surface. If there are two or more soil permeability rate values below the pond bottom surface, it is recommended to use the greatest permeability rate.

Step 3: Upon conducting a site visit it is recommended to verify any data obtained electronically when at the site. This is completed by digging soil pits or using a hand held soil auger.

SITE SOILS COMMENTS / NOTES

SITE AND STRUCTURE INVENTORY FORMS (SSIF)

Site Soils Report

Dominant Soil Type

Soil Survey Area Name	
Map Unit Symbol	
Map Unit Name	

Soil Profile

Top Depth (in)	Bottom Depth (in)	Unified Soil Classification	K_{sat} low (μm/sec)	K_{sat} high (μm/sec)

Maximum Hydraulic conductivity (K_{sat}) below WSP bottom surface (μm/sec)	
Depth to water table (in)	

SITE AND STRUCTURE INVENTORY FORMS (SSIF)

WSP - SITE ATTRIBUTES FORM	
SITE INVENTORY QUESTIONS	**RESPONSE**
1. Saturated Hydraulic Conductivity (K_{sat}) of the Existing WSP site soils below the WSP surface **(Refer to SSRF)**	
2. Distance from the nearest edge of WSP to the nearest groundwater water supply wells	
a. Depth to groundwater source if distance is less than 100 feet from the nearest edge of the WSP. **(Refer to DOE well log data sheet or estimate from the landowner)**	
3. Distance from nearest toe of WSP to nearest surface water flow or body	
a. If distance is less than 300 feet is there a natural secondary barrier or containment dike between the WSP and the Surface water of concern?	
4. WSP located within an EPA Region 10 Sole Source Aquifer or Source Area? **(Refer to Appendix 3 for Regional Map. For more detailed maps visit EPA Region 10 website at:** http://yosemite.epa.gov/r10/water.nsf/Sole+Source+Aquifers/ssamaps)	(Circle One) **Yes / No**
5. WSDA Aquifer Susceptibility Rating? **(Refer to Appendix 2 for State Map.)**	(Circle One) **Very Low** **Low** **Medium** **High**

SITE AND STRUCTURE INVENTORY FORMS (SSIF)

WSP - STRUCTURE ATTRIBUTES FORM	
WSP STRUCTURE ATTRIBUTES	**NOTES**
1. WSP - Inside Top – Average Width (ft)	
2. WSP - Inside Top – Average Length (ft)	
3. WSP Storage Capacity (cu ft)	
4. Embankment - Inside SS (X:1)	
5. Embankment - Outside SS (Y:1)	
6. Embankment – Top Width (ft)	
7. Combined Side Slope (Outside SS + Inside SS)	
8. Embankment – Maximum Fill Height (ft)	
9. Maximum Excavation Depth (ft)	
10. Total Pond Depth (ft)	
11. Liner Type and Thickness (in)	
12. Inlet Type and Location	
13. WSP Interior-Outlet Ramp Slope (z:1)	
14. Distance to Nearest Well / Water Depth in well(ft)	
15. Failure Impacts; Farm Building, Homes, Roads, Water Course	
16. Emptying Feature is provided to protect against accidental release. (yes/no) If yes please describe in the note section.	
17. Distance to Nearest Home/Dwelling (ft)	
18. Distance to Nearest Water Course (ft)	
WSP – STRUCTURE COMMENTS / NOTES	

SITE AND STRUCTURE INVENTORY FORMS (SSIF)

WSP - STRUCTURE CONDITION FORM

If any boxes checked **"YES"**; make notes of items for concern, possible extent of damage, identify options to repair, stabilize or address in the **REPORT** section.

SITE INVENTORY QUESTIONS		YES	NO	NA
Liner	Liner type: None / Compacted Clay / Flexible Membrane / Bentonite Amendment **(Circle One)**			
Liner	Evidence of liner slumps, bulges, boils, or whales?			
Liner	If applicable; Are perimeter drain(s) plugged or blocked?			
Embankment – Crest, Exterior Slope and Toe[1]	Evidence of cracks in embankment soils?			
	Damp, soft, or slumping areas?			
	Evidence of seepage on the embankment slope?			
	Evidence of seepage around pipes through berm?			
	Evidence of differential (uneven) settlement?			
	Evidence of seepage at the toe of the embankment?			
	Evidence of sand boils on the slope, along the toe or near the toe?			
WSP – Interior Surface	Interior erosion due to wave action?			
	Interior erosion from rainfall?			

[1] Complete inventory questions appropriate to structure, *if no embankment, as in a pit pond, show NA.*

NOTES:

SITE AND STRUCTURE INVENTORY FORMS (SSIF)

WSP - OPERATION AND MAINTENANCE INVENTORY FORM

If any boxes checked **"YES"**; make notes of location and identify O & M task to improve management in **REPORT** section.

SITE INVENTORY QUESTIONS		YES	NO	NA
Embankment – Crest, Exterior Slope and Toe[1]	Damage from burrowing animals?			
	Evidence of overtopping of embankment?			
	Evidence of soil erosion or gully on embankment?			
	Pond transfer pipe/structure is obstructed?			
	Presence of trees or woody vegetation?			
	Waste storage pond access is not fenced and properly marked? If not required for structure then n/a.			
WSP Interior/Liner	Interior erosion in vicinity of waste inlet structure?			
	Interior erosion near agitation equipment access points?			
	General erosion of liner material?			
	Damaged liner material (holes, tears, seams)?			
Waste Transfer	Any pumps or transfer pipes are not functional?			
	Any recycling pumps or transfer pipes are not functional?			
Odor	Downwind odor from WSP is strong or unbearable?			

[1] Complete inventory questions appropriate to structure, *if no embankment, as in a pit pond, show NA.*

NOTES:

STRUCTURE and O&M CONDITION CONCERNS	YES	NO
Was any abnormal condition or practice observed that requires corrective action (If yes then answer 1 and 2 below):		
1. Minor repair or change in practice would bring the WSP into compliance with accepted practice.		
2. Major repair or change in practice would bring the WSP into compliance with accepted practice.		

SITE AND STRUCTURE INVENTORY FORMS (SSIF)

WSP - STRUCTURE MODIFICATION FORM				
			Yes	**No**
HAS THE WSP BEEN STRUCTURALLY MODIFIED? ***(If "Yes" complete 1 through 5 below)***				
1	Was the WSP modification designed by a qualified individual?			
	Date design of modification			
	Designer (If applicable)			
2	Date of modification construction			
3	<u>Description of structural modification:</u>			
	Did the modification meet the NRCS practice standard in place at the time of construction?			
4	<u>Describe impact of the modification on structural integrity:</u>			
5	<u>Describe impact of the modification on storage depth and storage volume:</u>			
WSP Inventory Completed by				
Name:		JAA		
Signature:		Date:		

PRACTICE STANDARD COMPLIANCE REPORT FORM (PSCRF)

INSTRUCTIONS: The Practice Standard Compliance Report Form compares the WSP inventory data to the benchmark condition.

PRACTICE STANDARD COMPLIANCE REPORT FORM:

Step 1: Document the landowner/farm name, address as well at the specific WSP location.

Step 2: Fill in all fields if applicable otherwise place N/A.

Step 3: Complete the physical attributes table for "Current Conditions" by copying forward information from the "WSP Physical Attributes Table".

Step 4: Complete the NRCS Practice Standard Criteria section referring to Appendix 1, NRCS practice standard criteria for WSP's. Place the relative NRCS criteria based on the year the WSP was constructed or when the last modification was completed. If the WSP was constructed prior to 1979, then the 1979 criteria shall apply.

SIGNATURE BLOCK:

The technically responsible staff person completing the forms shall print and sign their name. The Engineering Job Approval Authority for PS 313, "Design" will be included when completed by NRCS staff.

NRCS (PSCRF -2/3)

PRACTICE STANDARD COMPLIANCE REPORT FORM (PSCRF)

LANDOWNER/FARM NAME: ____________________

ADDRESS: ____________________ STATE: ______ ZIP: __________

WSP LOCATION: Sec __________ T _____ R _____ **(or)** Lat __________ Long __________

DATE ORIGINAL WASTE STORAGE POND or MODIFICATION COMPLETED: __________

NRCS Practice Standard 313 Compliance Check			
PHYSICAL WSP ATTRIBUTES	**CURRENT CONDITIONS**	**NRCS Practice Standard criteria[1]**	**Complies NRCS Practice Standard Criteria? (Circle One)**
1. Embankment height. (Ref SSIF 7/10 – 8.0)			Yes - No - N/A
2. Failure of WSP would result in damages limited to farm buildings, ag-land, or country roads. (Ref SSIF 7/10 - 15.0)			Yes - No - N/A
3. WSP embankment elevation above 25 yr. floodplain. (Estimated)			Yes - No - N/A
4. Inlet permanent and resists; corrosion, plugging, freeze damage and is UV protected. (Ref SSIF 7/10 - 12.0)			Yes - No - N/A
5. Emptying features are provided and are protected against erosion and accidental release. (Ref SSIF 7/10 - 16.0)			Yes - No - N/A
6. Slurry or solid storage ramp slope. (Ref SSIF 7/10 – 13.0)			Yes - No - N/A
7. Fencing necessary for protection of humans and livestock. (Ref SSIF 9/10)			Yes - No - N/A
8. WSP embankment protected against erosion. (Ref SSIF 8/10 & 9/10)			Yes - No - N/A
9. Separation distance from WSP bottom and SHGWT. (Ref SSIF 5/10)			Yes - No - N/A
10. Liner. (Ref SSIF 8/10 & 9/10)			Yes - No - N/A
11. Liner type (Ref PS 521). (Ref SSIF 8/10)			Yes - No - N/A
12. If no liner, foundation soils permeability. (Ref SSIF 5/10)			Yes - No - N/A

[1] Appendix 1: Refer to the NRCS practice standard design criteria by date of adoption for current and archived NRCS practice standards used for Waste Storage Pond design and construction in WA State.

NRCS (PSCRF -3/3)

PRACTICE STANDARD COMPLIANCE REPORT FORM

NRCS Practice Standard 313 Compliance Check (***Continued***)				
PHYSICAL WSP ATTRIBUTES	**CURRENT CONDITIONS**	**NRCS Practice Standard criteria[2]**	**Complies NRCS Practice Standard Criteria?**	
13. Embankment inside side slope. (Ref SSIF 7/10 – 4.0)			Yes - No - N/A	
14. Embankment outside side slope. (Ref SSIF 7/10 – 5.0)			Yes - No - N/A	
15. Combined embankment side slope. (Ref SSIF 7/10 – 7.0)			Yes - No - N/A	
16. WSP above ground volumetric storage. (Estimated)			Yes - No - N/A	
17. Minimum distance to dwellings. (Ref SSIF 7/10 – 17.0)			Yes - No - N/A	
18. Embankment top width. (Ref SSIF 7/10 – 6.0)			Yes - No - N/A	
19. Minimum distance to water well. (Ref SSIF 7/10 – 14.0)			Yes - No - N/A	
20. Minimum distance to water course. (Ref SSIF 7/10 – 18.0)			Yes - No - N/A	
Compliance Check Results			**YES**	**NO**
Does the WSP comply with NRCS practice standards at the time of construction or modification?				

WSP Compliance Review Completed by (Print): ______________________ JAA: _____

Signature ____Date:_____________

[2] Appendix 1: Refer to the NRCS practice standard design criteria by date of adoption for current and archived NRCS practice standards used for Waste Storage Pond design and construction in WA State.

WSP ASSESSMENT FORMS (AF)

INSTRUCTIONS: The assessment forms provide a standardized procedure for assigning a category that ranks a WSP according to observed factors that may contribute to the risk of degradation to water resources.

SITE ASSESSMENT FORM:

The information that is utilized for the Site Assessment is the completed data located on the Site and Structure Inventory Form.

Step 1: Carefully read each question and check corresponding box.

Step 2: Record the score points in the right hand column for each question.

Step 3: Total the score points and assign the corresponding risk rating.

STRUCTURE ASSESSMENT FORM:

The information that is utilized for the Structure Assessment is the completed data located on the Site and Structure Inventory Form and the Practice Standard Compliance Report Form.

Step 1: Carefully read each question and check corresponding box.

Step 2: Record the score points in the right hand column for each question.

Step 3: Total the score points and assign the corresponding risk rating.

OVERALL ASSESSMENT FORM:

The Overall Assessment Form is completed utilizing the results on the Site and Structure Assessment Forms.

Step 1: On the “Risk Probability Matrix for Water Resource Degradation” plot the “Site Risk” rating and the “Structure Risk” rating.

Step 2: Circle the resulting combined risk factor on the matrix.

Step 3: From the Risk Probability Matrix for Groundwater Degradation check the corresponding box to document recommended actions for the Existing Waste Storage Pond.

SIGNATURE BLOCK:

The technically responsible staff person completing the forms shall print and sign their name. The Engineering Job Approval Authority for PS 313, “Design” will be included when completed by NRCS staff.

NRCS

WSP ASSESSMENT FORMS

SITE ASSESSMENT FORM				
Consideration	**Categories (Check appropriate box for each consideration and record points in the right hand column)**			**Score**
Saturated Hydraulic Conductivity (K_{sat}) of the soils below the WSP bottom surface	Less than 2 µm/sec	Between 2 and 20 µm/sec	Greater than 20 µm/sec	
	☐ **0 points**	☐ **1 points**	☐ **3 points**	
Shallow (< 145 feet deep) groundwater water supply wells within 100 feet of the nearest edge of the WSP	No	Yes, but it **is** technically feasible to decommission or relocate the shallow groundwater well	Yes, but it **is not** technically feasible to decommission or relocate the shallow groundwater well	
	☐ **0 points**	☐ **1 points**	☐ **3 points**	
Distance from the nearest surface water flow or body to the toe of the WSP	Greater than 300 ft	Less than 300 ft. but technically feasible to construct a secondary barrier or containment dike between the WSP and the surface water of concern.	Less than 300 ft. but not technically feasible to construct a secondary barrier or containment dike between the WSP and the surface water of concern.	
	☐ **0 points**	☐ **1 points**	☐ **3 points**	
Location with respect to an EPA Region 10 Sole Source Aquifer or Source Area **and** Medium to High Aquifer Susceptibility according to the WSDA Aquifer Susceptibility Map	Not located in either	Located in one, but not the other	Located in both.	
	☐ **0 points**	☐ **3 points**	☐ **6 points**	
			Total Score	
			Risk	

Total Score	**Risk Rating**
2 points or less =	**Low Risk**
3 to 5 points =	**Medium Risk**
6 points or more =	**High Risk**

WSP ASSESSMENT FORMS

STRUCTURE ASSESSMENT FORM				
Consideration	**Categories (Check appropriate box for each consideration and record points in the right hand column)**			**Score**
WSP complies with NRCS practice standard criteria (PSCRF 3/3)	Yes		No	
	☐ **0 points**	**N/A**	☐ **6 points**	
Earthen structural condition questions (SSIF 8/10)	All questions answered "NO" or "NA"	One or more of the questions answered "YES"; repairs require **minor** restoration effort[1].	One or more of the questions answered "YES"; repairs require **major** restoration effort[2].	
	☐ **0 points**	☐ **3 points**	☐ **6 points**	
Operation and maintenance questions (SSIF 9/10)	All questions answered "NO" or "NA"	One or more of the questions answered "YES"; repairs require **minor** restoration effort[1].	One or more of the questions answered "YES"; repairs require **major** restoration effort[2].	
	☐ **0 points**	☐ **2 points**	☐ **4 points**	
Structural modifications	Constructed in accordance with NRCS practice standard criteria	Not constructed in accordance with NRCS practice standard criteria in place at the time; repairs require **minor** restoration effort[1].	Not constructed in accordance with NRCS practice standard criteria in place at the time; repairs require **major** restoration effort[2].	
	☐ **0 points**	☐ **3 points**	☐ **6 points**	

Total Score	
Risk Rating	

Total Score	**Risk Rating**
2 points or less =	**Low Risk**
3 to 5 points =	**Medium Risk**
6 points or more =	**High Risk**

1. Minor restoration effort – Restorative activities can be completed without significant disturbance to the WSP.

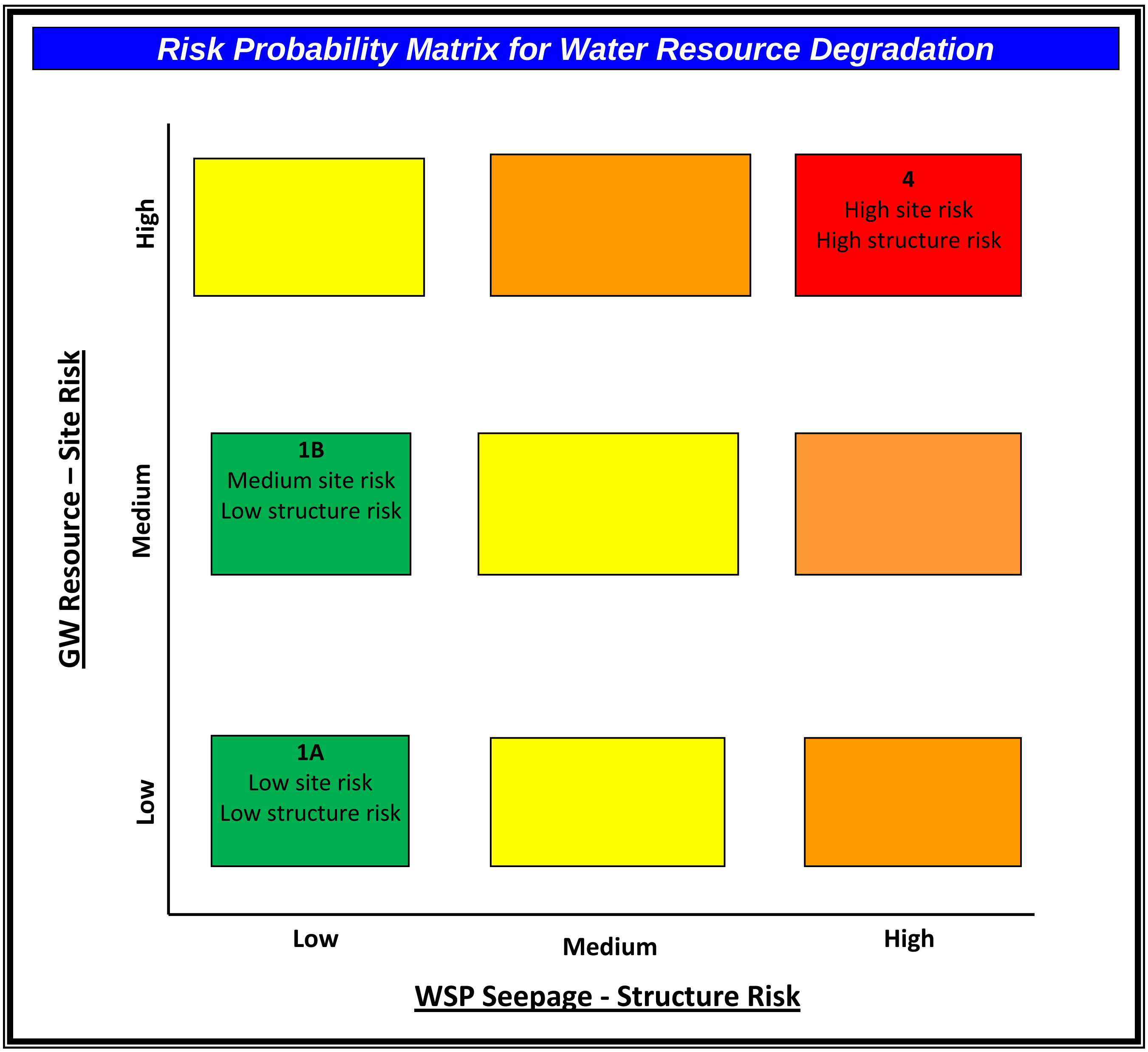
2. Major restoration effort – Restorative activities cannot be completed without significant disturbance to the WSP.

WSP ASSESSMENT FORMS

OVERALL ASSESSMENT FORM

Instructions: On the “Risk Probability Matrix for Water Resource Degradation” plot the following factors and circle the resulting combined risk factor on the matrix.

1. ***Ground Water Resource - Site Risk*** on the Y axis
2. ***WSP Seepage - Structure Risk*** on the X axis



WSP ASSESSMENT FORMS

Instructions: From the Risk Probability Matrix for Water Resource Degradation check the corresponding box to document recommended actions for the existing Waste Storage Pond.

Category 1

☐

A	B
Low site risk Low structure risk	Medium site risk Low structure risk

Category 1A - NRCS recommends utilizing the WSP for the purposes of waste storage.

Category 1B - NRCS recommends utilizing the WSP for the purposes of waste storage, however the site may benefit from additional practices to reduce discharge potential in the situation of a structure failure.

Category 2

☐

A	B	C
High site risk Low structure risk	Medium site risk Medium structure	Low site risk Medium structure risk

Category 2A - NRCS recommends utilizing the WSP for the purposes of waste storage, however the site would benefit from additional practices to reduce discharge potential in the situation of a structure failure.

Category 2B - NRCS recommends discontinued use of the WSP for the purposes of waste storage until minor repairs and/or improvements have been completed in accordance with the NRCS practice standard in place at the time of construction and the site may benefit from additional practices to reduce discharge potential in the situation of a structure failure.

Category 2C - NRCS recommends discontinued use of the WSP for the purposes of waste storage until minor repairs and/or improvements have been completed in accordance with the NRCS practice standard in place at the time of construction.

CONTINUED NEXT PAGE

WSP ASSESSMENT FORMS

CONTINUED FROM PREVIOUS PAGE

Category 3

	A	B	C
☐	Low site risk High structure risk	Medium site risk High structure risk	High site risk Medium structure

Category 3A - NRCS recommends discontinued use of the WSP for the purposes of waste storage until major repairs or possible replacement of the existing WSP meeting the current NRCS Conservation Practice Standard – 313, Waste Storage Facility.

Category 3B - NRCS recommends discontinued use of the WSP for the purposes of waste storage until major repairs or possible replacement of the existing WSP meeting the current NRCS Conservation Practice Standard – 313, Waste Storage Facility and the site may benefit from additional practices to reduce discharge potential in the situation of a structure failure.

Category 3C - NRCS recommends discontinued use of the WSP for the purposes of waste storage until minor repairs and/or improvements have been completed for the waste storage pond structure and the site would benefit from additional practices to reduce discharge potential in the situation of a structure failure with structure relocation being considered.

Category 4

☐ High site risk
High structure risk

Category 4 - NRCS recommends discontinued use of the WSP for the purposes of waste storage until major repairs or possible replacement of the existing WSP meeting the current NRCS Conservation Practice Standard – 313, Waste Storage Facility and the site would benefit from additional practices to reduce discharge potential in the situation of a structure failure with structure relocation being considered.

SIGNATURE BLOCK

THE WSP INTEGRITY ASSESSMENT REPORT WAS COMPLETED BY:

Evaluating Personnel: ______________________________ **Date:** ____________

Agency: ____

PS 313 Assigned Job Approval Authority for "WSP Review Assessment": ____________

Appendix 1

WSP Practice Standard Criteria Reference Documents

Table outline for – NRCS Practice Standard Criteria Revisions and WA State Supplements

Waste Storage Pond, PS-425, Dated: 1979 -1994

Waste Storage Facility, PS-313, Dated 2000 - Current

Washington State NRCS REVISION and Supplement Dates:

- April 1979 -
- February 1987 – State Supplement
- January 1994 – State Supplement
- February 2000
- June 2001
- December 2004

Earth pond construction dimension criteria for all WSP practices and all revisions: April 1979 to December 2004

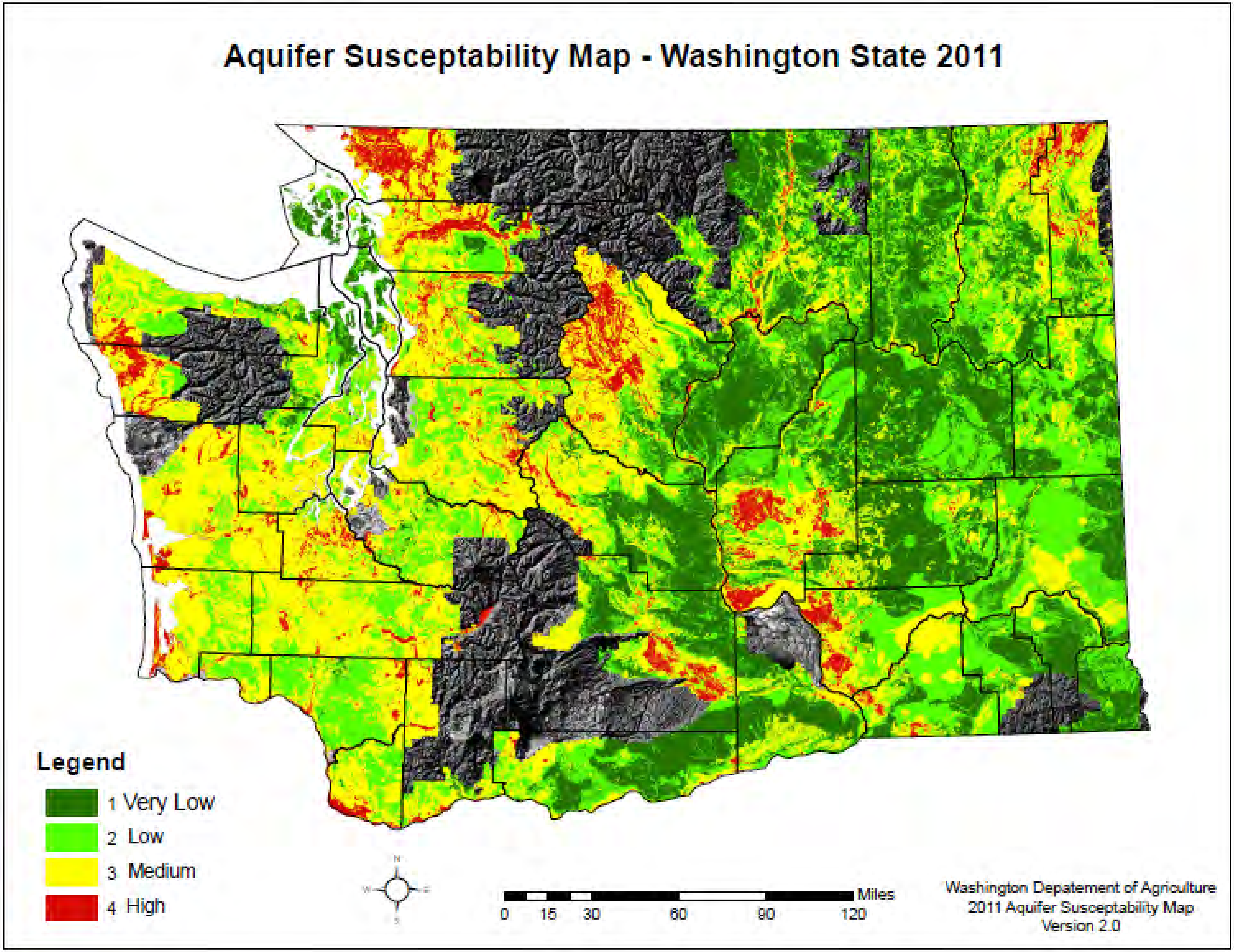
Practice Standard Code/Name	PS 425 Waste Storage pond			PS 313 Waste Storage Facility		
Release Date	1979, April			2000, February	2001, June	2004, December
Supplement Release Date		1987, February	1994, January			
1. Embankment Height.	35 feet or Less	35 feet or Less	35 feet or Less	35 feet or Less	35 feet or Less	35 feet or Less
2. Failure of WSP would result in damages limited to farm buildings, Ag-Land, or country roads.	N/A	N/A	N/A	Yes	Yes	Yes
3. WSP Embankment Elevation above Floodplain?	25 Yr	25 Yr	25 Yr	25 Yr	25 Yr	25 Yr
4. Inlet permanent and resists; corrosion, plugging, freeze damage and is UV protected?	Yes	Yes	Yes	Yes	Yes	Yes
5. Emptying features are provided and are protected against erosion and accidental release?	Yes	Yes	Yes	Yes	Yes	Yes
6. Liquid Storage Ramp slope.	4:1	4:1	4:1	4:1	4:1	4:1
7. If the WSP creates a safety hazard fencing is necessary for protection of Humans and livestock.	Yes	Yes	Yes	Yes	Yes	Yes
8. WSP Embankment protected against erosion.	Yes	Yes	Yes	Yes	Yes	Yes
9. Separation distance from WSP Bottom and SHGWT.	0 Inches	6 inches	6 inches	24 inches	24 inches	24 inches
10. Liner	Only if Self Sealing is not anticipated	Required for all foundation material, except glacial till, when closer than 300 feet to a domestic well.	Required for all WSP's	Required for all WSP's	Required for all WSP's if wetted surface permeability rate is less than $1x10^{-6}$ cm/s	Required for all WSP's if wetted surface permeability rate is less than $1x10^{-6}$ cm/s

Earth pond construction dimension criteria for all WSP practices and all revisions: April 1979 to December 2004						
Practice Standard Code/Name	PS 425 Waste Storage pond			PS 313 Waste Storage Facility		
Release Date	1979, April			2000, February	2001, June	2004, December
Supplement Release Date		1987, February	1994, January			
11. Liner type (Ref PS 521)	If Required	Minimum <u>Requirements</u> GM – 12" thick GC – 9" thick SM – 12" thick SC – 9" thick ML – 12" thick CL – 6" thick CH – 6" thick	12" Minimum thickness & soils requirement GM-w/20% fines GC-w/20% fines SM-w/20% fines SC-w/20% fines (or Amended) ML MH CL CH	12" Minimum thickness & soils requirement GM-w/20% fines GC-w/20% fines SM-w/20% fines SC-w/20% fines (or Amended) ML MH CL CH	12" Minimum thickness & soils requirement of permeability rate is less than $1x10^{-6}$ cm/s	12" Minimum thickness & soils requirement of permeability rate is less than $1x10^{-6}$ cm/s
12. If no liner, foundation soils permeability.	Low to Moderate	Low to Moderate	Must be equivalent to liner requirement	Must be equivalent to liner requirement	Must be equivalent to liner requirement	Must be equivalent to liner requirement
13. Maximum operating level marker	N/A	N/A	N/A	N/A	Yes	Yes
14. Embankment Top Width (minimum)	8 feet	8 feet	8 feet	8 feet	Embankment <u>Height / Width</u> 15' or Less / 8' 15'-20' / 10' 20'-25' / 12' 25'-30' / 14' 30'-35' / 15'	Embankment <u>Height / Width</u> 15' or Less / 8' 15'-20' / 10' 20'-25' / 12' 25'-30' / 14' 30'-35' / 15'
15. Embankment Inside Side Slope	N/A	N/A	N/A	No Steeper Than 2:1	No Steeper Than 2:1	No Steeper Than 2:1
16. Embankment Outside Side Slope	N/A	N/A	N/A	No Steeper Than 2:1	No Steeper Than 2:1	No Steeper Than 2:1
17. Combined Embankment Side Slope (minimum)	5:1	5:1	5:1	5:1	5:1	5:1
18. WSP Above Ground Volumetric Storage[3]	If over 10 ac-ft above ground storage refer to DOE Dam Safety Criteria	If over 10 ac-ft above ground storage refer to DOE Dam Safety Criteria	If over 10 ac-ft above ground storage refer to DOE Dam Safety Criteria	If over 10 ac-ft above ground storage refer to DOE Dam Safety Criteria	If over 10 ac-ft above ground storage refer to DOE Dam Safety Criteria	If over 10 ac-ft above ground storage refer to DOE Dam Safety Criteria
19. Minimum Distance to Dwellings	100 feet	100 feet	100 feet	N/A	N/A	N/A
20. Minimum Distance to water well	N/A	100 ft., 200 ft. for unconfined aquifers	300 feet	300 feet	300 feet	100 feet
21. Minimum distance to water course	N/A	25 feet	25 feet	N/A	N/A	N/A

[3] The storage threshold is the theoretical volume contained in the WSP with the fluid level at the top of the embankment, not at the operating level.

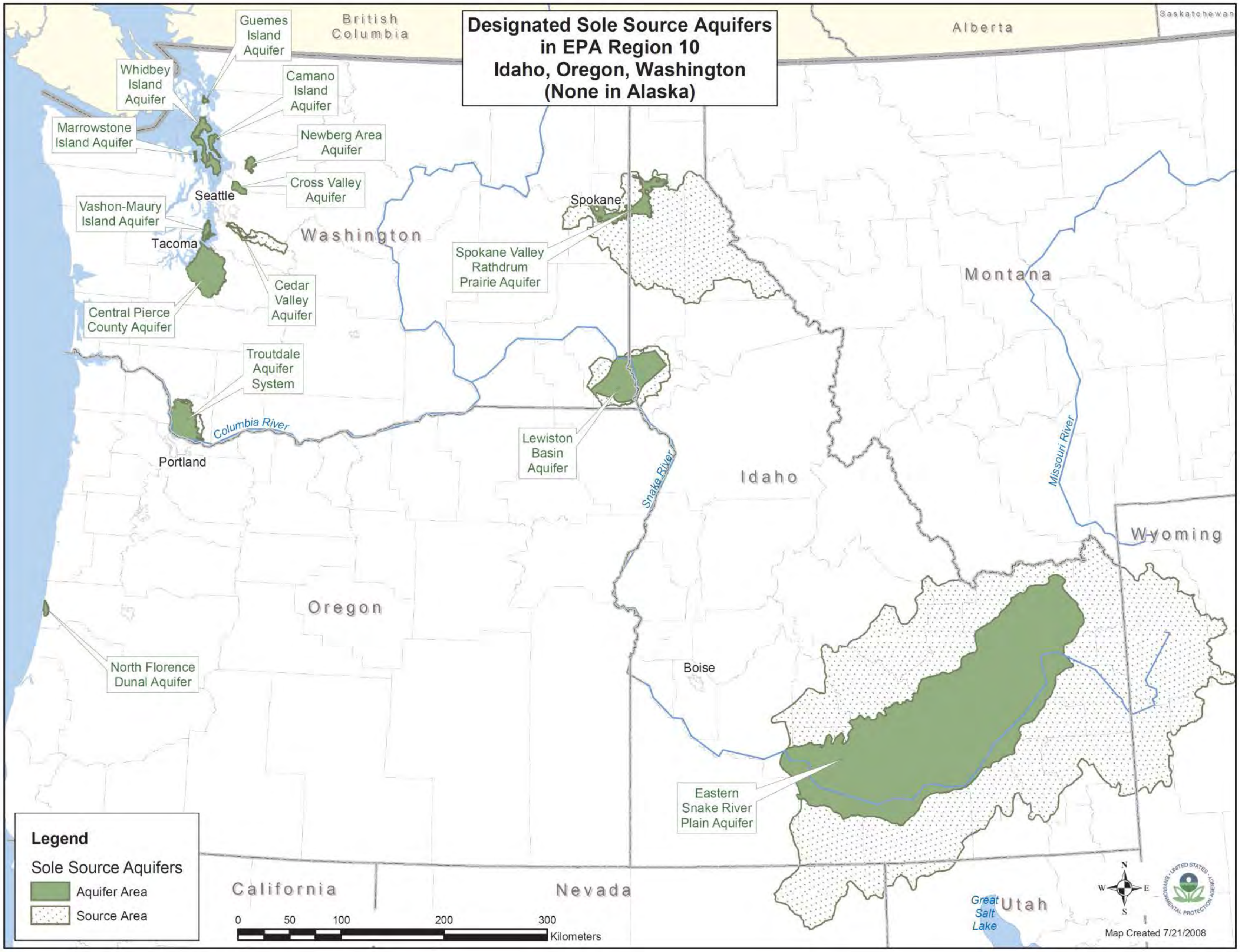
Appendix 2

WSDA Aquifer Susceptibility Map


Aquifer Susceptability Map - Washington State 2011
Legend
1 Very Low
2 Low
3 Medium
4 High
Miles
0 15 30 60 90 120
Washington Depatement of Agriculture
2011 Aquifer Susceptability Map
Version 2.0

Appendix 3

Designated Sole Source Aquifer Map for EPA Region 10


Designated Sole Source Aquifers in EPA Region 10 Idaho, Oregon, Washington (None in Alaska)
British Columbia
Alberta
Saskatchewan
Guemes Island Aquifer
Whidbey Island Aquifer
Camano Island Aquifer
Marrowstone Island Aquifer
Newberg Area Aquifer
Cross Valley Aquifer
Seattle
Vashon-Maury Island Aquifer
Tacoma
Washington
Spokane
Spokane Valley Rathdrum Prairie Aquifer
Cedar Valley Aquifer
Central Pierce County Aquifer
Montana
Troutdale Aquifer System
Columbia River
Portland
Lewiston Basin Aquifer
Snake River
Idaho
Missouri River
Wyoming
Oregon
North Florence Dunal Aquifer
Boise
Eastern Snake River Plain Aquifer
Legend
Sole Source Aquifers
Aquifer Area
Source Area
California
Nevada
0
50
100
200
300
Kilometers
Great Salt Lake
Utah
Map Created 7/21/2008

Appendix 4

WSP Volume Estimating Spreadsheet

INSTRUCTIONS

A spreadsheet has been developed to calculate the estimated volume of a square or rectangular WSP.

SPREADSHEET INPUTS

The spreadsheet requires six inputs in order to compute the approximate volume of the WSP.

L1 and L2 are Top of Pond dimensions as shown in feet.

W1 and W2 are Top of Pond dimensions as shown in feet.

h = Depth of WSP measured from crest to pond bottom surface in feet.

SS = Internal side slope of WSP.

h_{out} = Depth of WSP above ground measured from crest to lowest outside toe in feet

SPREADSHEET COMPUTATIONS

The spreadsheet computes the volume utilizing the prismoidal formula. All formula variables can be computed from the inputs and the intermediate results are shown in the output window of the spreadsheet.

$$V = h/6\,(A_t + 4M + A_b)$$

Where:

- *V - Volume of the truncated pyramid*
- *h - WSP Depth (Crest to Bottom)*
- *A_t - Top Surface Area, WSP Crest*
- *M - Cross Section Area, Mid-Depth*
- *A_b - Bottom Surface Area, WSP Base*
- *h_{out} - Depth of pond above ground from lowest outside toe to top of crest*
- *$V_{ab\text{-}gnd}$ - Volume stored above ground*
- *SS - Internal Sideslope of the WSP*
- *L_1 and L_2 are Top of Pond dimensions as shown*
- *W_1 and W_2 are Top of Pond dimensions as shown*

SPREADSHEET OUTPUTS

The spreadsheet provides a quick assessment of the estimated WSP volume. Three examples are provided for review.

See Example #1: The user inputs the information that is captured during the SSIF forms. The volume is computed and displayed in the output window. The estimated volume can be used to populate the “WSP Structure Attributes” field for waste storage capacity on SSIF page 7/10.

See Example #2: The user inputs the information that is captured during the SSIF forms. The volume is computed and displayed in the output window. The estimated volume can be used to populate the “WSP Structure Attributes” field for waste storage capacity on SSIF page 7/10.

In addition, a note is displayed when the computed volume is greater than 10 ac-ft. If the above ground storage is greater than 10 ac-ft, the WA State Dam Safety Office has regulatory authority over the facility and the State Dam Safety Standards prevail. NRCS Technical Note 23 does not determine compliance with WA State regulated dams.

See Example #3: The user inputs the information that is captured during the SSIF forms. In this case the volume cannot be computed or displayed in the output window. If the computed length or width of the bottom of the pond is less than zero (0), the results in the intermediate computation field for l or w reports “n.g.”. Either a different method will need to be utilized to compute the volume or the depth may be in error. It is recommended to verify that all of the input fields are correct.

Example 1: **Determine the estimated WSP volume**

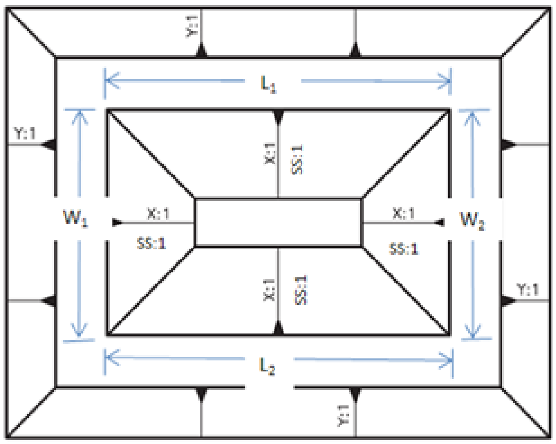
Computation Sheet

WA NRCS-ENG-Computation

U.S. Department of Agriculture
Natural Resources Conservation Service

State	Project			
Washington	Example #1			
By NRCS	**Date** 1/4/2013	**Checked By**	**Date**	**Job No.**
Subject Estimated WSP Prismoidal Volume				Sheet ____ of ____

Waste Storage Pond



PLAN VIEW

Volume of a Truncated Pyramid Prism with a Rectangular Base

with two parallel polygonal bases joined to one another by straight edges

$$V = h/6\ (A_t + 4M + A_b)$$

Where:

- V - *Volume of the truncated pyramid*
- h - *WSP Depth (Crest to Bottom)*
- A_t - *Top Surface Area, WSP Crest*
- M - *Cross Section Area, Mid-Depth*
- A_b - *Bottom Surface Area, WSP Base*
- h_{out} - *Depth of pond above ground from lowest outside toe to top of crest*
- $V_{ab\text{-}gnd}$ - *Volume stored above ground*
- SS - *Internal Sideslope of the WSP*

L_1 and L_2 are Top of Pond dimensions as shown
W_1 and W_2 are Top of Pond dimensions as shown

Definitions	Inputs		
ft. = Feet	$L_{side\ 1}$ =	210	ft.
s.f. = Square Feet	$L_{side\ 2}$ =	185	ft.
c.f. = Cubic Feet	$W_{side\ 1}$ =	100	ft.
a.f. = Acre-Feet	$W_{side\ 2}$ =	125	ft.
n.g. = Results are No Good	h =	11	ft.
	SS =	2.5	
	h_{out} =	5	

Data Input Field

Outputs					
Intermediate Computations			**Estimated WSP Volume**		
			$V = h/6\ (A_t + 4M + A_b)$		
A_t =	22,219	s.f.	V_{total} =	161,723	c.f.
M =	14,450	s.f.	V_{total} =	3.7	a.f.
A_b =	8,194	s.f.	and		
$M_{ab\text{-}gnd}$ =	18,500	s.f.	$V_{ab\text{-}gnd}$ =	92,760	c.f.
$A_{b\ ab\text{-}gnd}$ =	15,094	s.f.	$V_{ab\text{-}gnd}$ =	2.1	a.f.

Pond Storage Volume

Above Ground Pond Storage Volume

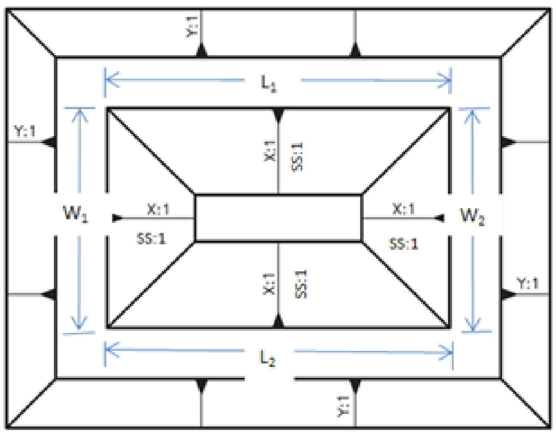
Example 2: Determine the estimated WSP volume

Computation Sheet
WA NRCS-ENG-Computation

U.S. Department of Agriculture
Natural Resources Conservation Service

State	Project			
Washington	Example #2			
By: NRCS	Date: 1/4/2013	Checked By	Date	Job No.
Subject: Estimated WSP Prismoidal Volume			Sheet ____ of ____	

Waste Storage Pond



PLAN VIEW

Volume of a Truncated Pyramid Prism with a Rectangular Base

with two parallel polygonal bases joined to one another by straight edges

$$V = h/6\,(A_t + 4M + A_b)$$

Where:

- *V* - *Volume of the truncated pyramid*
- *h* - *WSP Depth (Crest to Bottom)*
- A_t - *Top Surface Area, WSP Crest*
- *M* - *Cross Section Area, Mid-Depth*
- A_b - *Bottom Surface Area, WSP Base*
- h_{out} - *Depth of pond above ground from lowest outside toe to top of crest*
- $V_{ab\text{-}gnd}$ - *Volume stored above ground*
- *SS* - *Internal Sideslope of the WSP*

L_1 and L_2 are Top of Pond dimensions as shown
W_1 and W_2 are Top of Pond dimensions as shown

Definitions	Inputs		
ft. = Feet	$L_{side\,1}$ =	300	ft.
s.f. = Square Feet	$L_{side\,2}$ =	325	ft.
c.f. = Cubic Feet	$W_{side\,1}$ =	250	ft.
a.f. = Acre-Feet	$W_{side\,2}$ =	200	ft.
n.g. = Results are No Good	h =	15	ft.
	SS =	2.5	
	h_{out} =	7.5	

Data Input Field

Outputs			
Intermediate Computations		Estimated WSP Volume	
A_t =	70,313 s.f.	$V = h/6\,(A_t + 4M + A_b)$	
M =	51,563 s.f.		
A_b =	35,625 s.f.	V_{total} =	780,469 c.f.
$M_{ab\text{-}gnd}$ =	60,586 s.f.	V_{total} =	17.9 a.f.
$A_{b\ ab\text{-}gnd}$ =	51,563 s.f.	and	
		$V_{ab\text{-}gnd}$ =	455,273 c.f.
		$V_{ab\text{-}gnd}$ =	10.5 a.f.
		NOTE: Exceeds 10 Acre-Feet stored above ground	

Pond Storage Volume

This notification is displayed when the above ground volume is greater than 10 ac-ft

Example 3: Determine the estimated WSP volume

Computation Sheet
WA NRCS-ENG-Computation

U.S. Department of Agriculture
Natural Resources Conservation Service

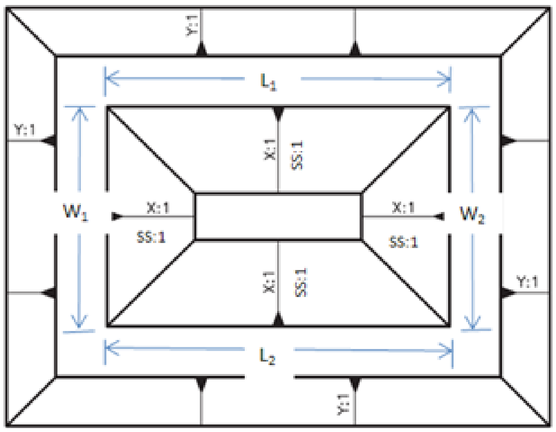
State	Project			
Washington	Example #3			

By	Date	Checked By	Date	Job No.
NRCS	1/4/2013			

Subject: Estimated WSP Prismoidal Volume

Sheet ________ of ________

Waste Storage Pond



PLAN VIEW

Volume of a Truncated Pyramid Prism with a Rectangular Base

with two parallel polygonal bases joined to one another by straight edges

$$V = h/6\ (A_t + 4M + A_b)$$

Where:

- *V - Volume of the truncated pyramid*
- *h - WSP Depth (Crest to Bottom)*
- *A_t - Top Surface Area, WSP Crest*
- *M - Cross Section Area, Mid-Depth*
- *A_b - Bottom Surface Area, WSP Base*
- *h_{out} - Depth of pond above ground from lowest outside toe to top of crest*
- *$V_{ab\text{-}gnd}$ - Volume stored above ground*
- *SS - Internal Sideslope of the WSP*
- *L_1 and L_2 are Top of Pond dimensions as shown*
- *W_1 and W_2 are Top of Pond dimensions as shown*

Data Input Field

Definitions	Inputs		
ft. = Feet	$L_{side\ 1}$ =	100	ft.
s.f. = Square Feet	$L_{side\ 2}$ =	90	ft.
c.f. = Cubic Feet	$W_{side\ 1}$ =	50	ft.
a.f. = Acre-Feet	$W_{side\ 2}$ =	50	ft.
n.g. = Results are No Good	h =	9	ft.
	SS =	3	
	h_{out} =	4	

Outputs					
Intermediate Computations			Estimated WSP Volume		
A_t =	4,750	s.f.	$V = h/6\ (A_t + 4M + A_b)$		
M =	1,564	s.f.			
A_b =	n.g.	s.f.	V_{total} =	n.g.	c.f.
$M_{ab\text{-}gnd}$ =	3,154	s.f.	V_{total} =	n.g.	a.f.
$A_{b\ ab\text{-}gnd}$ =	1,846	s.f.	and		
			$V_{ab\text{-}gnd}$ =	12,808	c.f.
			$V_{ab\text{-}gnd}$ =	0.3	a.f.

Output field displays "n.g." when the pond bottom length or width is <0 ft.

APPENDIX E - ID NRCS WATER QUALITY TECHNICAL NOTE #6

TECHNICAL NOTES

USDA-Natural Resources Conservation Service
Boise, Idaho

TN - Water Quality No. 6 ***July 2006***

IDAHO NUTRIENT TRANSPORT RISK ASSESSMENT (INTRA)
A Water Quality Risk Assessment Tool for Conservation Planning

The Idaho Nutrient Transport Risk Assessment (INTRA) uses a limited number of landform, site and management characteristics to determine the probability of off-site transport of nutrients (primarily nitrogen and phosphorus). The purpose of the Risk Assessment is to provide planners with a tool to evaluate the various landforms and management practices for potential risk of nutrient movement to surface and ground water. The assessment tool is used during the planning process to determine if surface and/or ground water quality concerns exist. The tool is similar to the risk assessment within ONEPLAN, but is modified to use with conservation management units, not individual fields. The tool was field-tested in both northern and southern Idaho in a number of different landuse-operation scenarios. The tool provides recommendations to assist the planner in selecting appropriate conservation practices that address individual and multiple risk factors to protect or enhance water quality. These mitigating practices are required in order to meet quality criteria for nutrients and organics in surface and ground water if the final risk level is greater than LOW. A brief summary of nutrient movement in agricultural systems, primarily phosphorus and nitrogen, follows. For a more detailed description, refer to *Idaho Water Quality Technical Notes No. 4 and 5.*

Summary of Nutrient Movement in Agricultural Systems

Phosphorus

Phosphorus movement in runoff occurs as particulate P and dissolved P. Particulate P is attached to mineral and organic sediment as it moves with the runoff. Dissolved P is in the water solution. In general, particulate P is the major portion (75-90%) of the P transported in runoff from cultivated land. Dissolved P makes up a larger portion of the total P in runoff from non-cultivated lands such as pastures and fields with reduced tillage.

As runoff moves from the landscape toward surface water, phosphorus may become more bioavailable by the sorption and desorption processes, and by the preferential transport of clay-sized material as sediment moves over the landscape (enrichment). The interaction between the particulate and dissolved P in the runoff is very dynamic and the mechanism of transport is complex. Additionally, dissolved P can move laterally towards surface water bodies as subsurface flow, or downwards, as the soil reaches P saturation. Therefore, it is difficult to predict the transformation and ultimate fate of P as it moves through the landscape (Sharpley et al. 2003).

<u>Nitrogen</u>
Nitrogen is one of the most dynamic and mobile nutrients in the plant-soil-air continuum, with many pathways for loss. There is a large reservoir of N in soil, but most of this is in the organic form. It is estimated that only 2-3% of organic N is mineralized annually. The mineralized form of N (nitrate and ammonium) is readily available for uptake by plants. The N cycle is both spatially and temporally variable within agricultural systems. Variability of soil properties impacts nitrogen movement and loss within agricultural operations, including soil organic matter, residual nitrate, crop residue amount, crop yield variability, and changes in soil chemical and physical properties across the field. The primary loss mechanism of nitrogen in agricultural systems is leaching of nitrate below the root zone. However, losses of nitrogen to the air and by overland flow also occur.

Management plays a critical role in reducing N loss to the environment, and management is <u>the</u> dominant factor influencing long-term nitrate leaching (Shaffer and Delgado 2002). Soil, climate, watershed and aquifer characteristics must also be taken into account in order to minimize nitrate leaching. Loss of nitrate from agricultural systems can range from 0 - 60% of N applied (Meisinger and Delgado 2002). Leaching loss is dependent on the concentration of N in soil solution and the volume of water leached. Over-irrigation can lead to nitrate leaching, especially with shallow rooted crops. Effective management is therefore aimed at reducing transport through proper irrigation water management, and optimizing N application amounts and timing in concert with crop uptake. Crop type and cultivation are also important considerations.

<u>The Idaho Nutrient Transport Risk Assessment: Risk Factors</u>
The main factors influencing nutrient movement in agricultural systems can be separated into transport, source and management factors. Transport factors include the mechanisms by which nutrients move within the landscape. These are rainfall, irrigation, erosion and runoff, and deep percolation. Factors which influence the source and amount of nutrients available for transport include soil nutrient content and form of nutrient applied. Management factors include the method of application, timing and placement in the landscape as influenced by the management of application equipment and tillage.

When the factors of the assessment are analyzed, it will be apparent when an individual factor (or factors) is influencing the assessment disproportionately. These identified factors are the basis for planning corrective soil and water conservation practices and management techniques.

The soil, hydrology, climate and land management site characteristics that have a major influence on nutrient availability, retention, management and movement are listed below. The number in parentheses after each factor is the relative weighting factor.

- Soil test P (available phosphorus in soil laboratory test units relative to the 0-12" soil layer *Phosphorus Threshold* per Idaho Nutrient Management Practice Standard 590) (1.0)
- P fertilizer application rates (in pounds available phosphate per acre) (0.75)
- P fertilizer application methods (0.5)
- Organic P source application rates (in pounds available phosphates per acre) (1.0)

- Organic P source application methods (0.75)
- N fertilizer application rate (1.0)
- N application timing (1.00 if non-irrigated, 0.75 if irrigated)
- N fertilizer application method (0.75)
- Irrigation runoff index (0.5)
- Runoff class (0.5)
- Runoff conservation practices (-1.0)
- Sheet and rill and/or irrigation-induced soil erosion (in tons per acre per year) (1.0)
- Distance to the nearest receiving water body (1.0)
- Irrigation index (for deep percolation) (1.5)
- Leaching index (0.5 irrigated, 1.5 not irrigated)
- Water table depth, geologic features, and hydrologic group (1.00 if irrigated, 1.5 if non-irrigated)

Field-specific data for the site characteristics selected for this version of the Risk Assessment (Table 1) are readily available at the conservation management unit level. Some analytical testing of the soil and organic material is required to determine the rating levels. This soil and organic material analysis is considered essential as a basis for the assessment.

The factors (described below) used in the assessment are rated as VERY LOW, LOW, MEDIUM, HIGH, or VERY HIGH (and some use CRITICAL) by determining the range for each category. The sum of the site characteristic rankings provides an index for surface water quality (Table 2) and an index for ground water quality (Table 3).

Soil P Test
A soil sample (0-12”) from the site is necessary to assess the relative level of "plant available P" in the surface layer of the soil. The plant available P is the level customarily given in a soil test analysis by the Cooperative Extension Service or commercial soil test laboratories. The Assessment uses ranges of soil test P. The Olsen (bicarbonate), Bray I, or Morgan (sodium acetate) soil test P methods are required by the NRCS Idaho Nutrient Management Standard depending upon the soil pH. The soil test level for "plant available P" does not ascertain the total P in the surface soil. Rather, it gives an indication of the relative amount of total P that may be present because of the general relationship between the forms of P (organic, adsorbed, and labile P) and the solution P available for plant uptake. If a soil test P result is above the phosphorus threshold as identified in the Idaho Nutrient Management Standard (590), the rating automatically defaults to CRITICAL.

P Fertilizer Application Rate
The P fertilizer application rate is the amount, in pounds per acre (lbs/ac), of commercial phosphate fertilizer (P_20_5) applied to the soil. This phosphate fertilizer does not include phosphorus from organic sources that are recorded in Organic P Sources Application Rate.

P Fertilizer Application Method
The manner in which P fertilizer is applied to the soil affects potential P movement. Incorporation implies that the fertilizer P is buried below the soil surface. If fertilizer is surface applied on a field with surface runoff (natural or from irrigation) and there is no incorporation, it is considered a significant risk and therefore the rating automatically defaults to CRITICAL.

Organic P Source Application Rate
The organic P application rate is the amount, in pounds per acre (lbs/ac), of potential phosphate (P_20_5) contained in the manure and applied to the soil. This organic phosphate source does not include phosphorus from fertilizer sources that are recorded in P Fertilizer Application Rate.

Organic P Source Application Method
The manner in which organic P material is applied to the soil can determine potential P movement. Incorporation implies that the organic P material is buried below the soil surface. If manure is surface applied on a field with surface runoff (natural or from irrigation) and there is no incorporation, it is considered to be a discharge and a violation of existing regulations. Because of this, the rating automatically defaults to CRITICAL.

Runoff Class and Irrigation Runoff Index

Runoff Class: The runoff class of the site is used to determine the risk of runoff from storm events. One method to determine the runoff class is based on the soil permeability and the percent slope of the site (USDA-NRCS Soil Survey Manual, Agricultural Handbook 18, 1993). The matrix relating soil permeability class and slope (Table 4) provides the appropriate value category. This information is available in the SSURGO soils database (physical properties report).

Runoff Index: The irrigation runoff index of the site is used for irrigated lands. For sprinkler irrigated lands, the runoff index is simply based on a user supplied assessment of whether or not runoff (overland flow) exists and, if so, whether or not it leaves the field. For surface irrigated lands, the runoff index is based on the typical percent of the irrigation set time that runoff from the furrow/field occurs; the user enters whether it is more or less than 50%.

Runoff Conservation Practices
Runoff conservation practices include any conservation practices which serve to reduce runoff and the movement of soil, thereby reducing potential for dissolved and particulate phosphorus movement across the landscape toward a receiving water body. Credit (negative point value) is applied depending on the number of conservation practices implemented, so multiple practices receive greater credit than a single practice. Also, runoff conservation practices that filter or trap nutrients (such as buffers, borders, filter strips, and grassed waterways) receive greater credit than those that simply reduce runoff. Certain practices (e.g., tail-water recovery systems with sediment basins) eliminate runoff and sediment loss from the field.

Soil Erosion (Total Water-Induced Soil Erosion)
Soil erosion is defined as the loss of soil along the slope or unsheltered distance caused by the processes of water and wind. Soil erosion is estimated from erosion prediction models including the Revised Universal Soil Loss Equation (RUSLE/RUSLE2) for water erosion from non-irrigated lands (and sprinkler irrigated lands if runoff exists) and the Surface Irrigation Soil Loss equation (SISL) for water erosion from surface irrigated lands. The Wind Erosion Equation (WEQ) is not used in this assessment. The value category is given in tons of soil loss per acre per year (ton/ac/yr). These soil loss prediction models do not predict sediment delivery rates from the end of a field to a water body. The prediction models are used in this assessment to

indicate the potential for sediment and attached nutrient movement across the slope or unsheltered distance toward surface waters.

Distance to Nearest Receiving Water Body
The distance to the nearest receiving water body is the distance in feet between the edge of the field and the nearest receiving water. This is typically a ditch, canal, waterway, drain, etc. – *any water body or water way which has connection (perennial or ephemeral) with a stream, river, pond or lake*. The closer the distance, the greater the likelihood nutrients lost from the field will reach the receiving water body.

Leaching Index
Deep percolation is dependent on numerous factors, including climate and soil type. The leaching index is based on the Nitrogen Leaching Index (Czymmek et al. 2003, Williams and Kissel 1991) which is essentially a water percolation index based on soil water storage. Slight modifications were made to some of the percolation index equations to adjust for low precipitation zones found in areas of Idaho. Total annual precipitation for specific locations is determined from local climate station data, as is winter precipitation. The percolation index is based on precipitation and hydrologic soil group. A seasonal index is calculated as the ratio of winter precipitation to annual precipitation. The leaching index is then calculated as the product of the percolation index and seasonal index. For irrigated lands, the leaching index is low if the irrigation index is low. If not, then the leaching index is based on amount of winter precipitation.

Irrigation Index
Managing irrigation water will minimize nutrient losses from leaching and surface runoff. Potential system application efficiency and irrigation water management have significant impacts on actual water movement through the root zone. Five different factors are used in the irrigation index to determine the potential for irrigation water to transport nutrients to ground water. The irrigation system is the primary rating factor, and the other variables modify that rating based on the level of management for each. These additional factors are water control and measurement, irrigation scheduling and soil moisture monitoring, use of pre- and/or post-season irrigation, and soil condition index (SCI).

N Application Index
Crop nitrogen requirement is determined based on crop yield and University of Idaho fertilizer recommendations. The nitrogen application rate is the percent nitrogen applied compared to the total crop nitrogen requirement according to the fertilizer guides prior to any credits or debits for previous crop and residual nitrogen.

N Application Timing
Timing of N application directly influences potential transport due to the high mobility of nitrate in soils. The appropriate timing of N application is complicated by the soil processes of nitrification, volitization, and mobilization, which affect N plant availability. Split applications of N throughout the growing season better match crop growth requirements, reducing the likelihood of loss. Fall application in most instances has the greatest potential for loss prior to the planting season; additional N applications are often required to meet crop demand when losses occur.

Water Table Depth/Soil Type
Soils can stop or slow nutrient movement depending on their chemical and physical characteristics. Depth of soils, depth to water tables and limiting layers such as hard pans will influence rooting depth, nitrogen movement, and leaching potential. Fine textured soils (Hydrologic Group D) have a lower potential for leaching due to reduced permeability and high water holding capacity, while coarse textured soils (Hydrologic Group A) have a higher likelihood of nitrate leaching due to low water holding capacity and the rapid infiltration and movement of water through the profile.

If a water table is present within five feet of the surface, the potential for ground water contamination is high regardless of the soil type.

Using the Idaho Nutrient Transport Risk Assessment

The Assessment applies on Cropland, Hayland, and Pasture where nutrients are applied. Use of the Risk Assessment for planning should begin during the initial field visit and interview with the producer. However, some of the information needed for the factors will be obtained from other planning tools (for instance, SISL or RUSLE2, soils database, etc.). **A field data sheet is provided in the spreadsheet, but required calculations and look-up information is performed by the spreadsheet, so entering information from the field data sheet into the spreadsheet (or taking the computer to the field) is required**. Steps for using the assessment tool are:

1) An assessment is developed for each land use, conservation management unit, or cropping system.

   Example: An operation includes 3 cropping systems or conservation management units:

   1. Hay in rotation with row crops and cereals, where commercial fertilizer is applied.
   2. Hay in rotation with row crops and cereals where animal waste is applied in addition to commercial fertilizer.
   3. Pasture where commercial fertilizer is applied.

   An assessment is required for each system/management unit.

2) Identify the critical crop in each system. The critical crop is the crop in which the highest potential for off-site transport of nutrients exists. For example, a rotation being evaluated includes winter wheat, spring barley and summer fallow. All the nitrogen for winter wheat is applied in the fall prior to planting the crop. The critical crop is winter wheat. The assessment is made using information which relates to the winter wheat crop.

3) The planner must obtain the following information from the producer.
   1. Typical rotation.
   2. For the critical crop:

a) Soil test data using the appropriate analysis method (Olson, Bray or Sodium Acetate). Note: If no soil test has been done in the last 5 years, the input value is automatically a VERY HIGH.
b) Phosphorus fertilizer application rate (lbs/ac/yr).
c) Phosphorus fertilizer application method.
d) Organic phosphorus application rate (lbs/ac/yr). Note: If the producer can not provide this information, the input value is automatically a VERY HIGH.
e) Organic phosphorus fertilizer application method.
f) Nitrogen application rate (% of Crop Requirement) requires 2 factors. The actual lbs/ac/yr of Nitrogen applied and the target yield. The program uses these 2 values to generate the rating.
g) Nitrogen fertilizer application method.
h) Runoff Index (Surface Irrigated). This value is qualitative. The planner determines the input by asking the producer whether water runs off less than or more than 50% of the set time.
i) Runoff Index (Sprinkler Irrigated). This value is qualitative. The planner determines the input with on site observation and/or asking the producer. Does water move across the field surface during irrigation? Does water leave the field via overland flow?

4) Other Information: Factors like hydrologic soil group, average field slope, permeability, soil erosion, and distance to surface waters are required and should be representative of the cropping scenario/conservation management unit being evaluated.

Requirements for Meeting Quality Criteria

- Quality Criteria is met when an overall rating of LOW is obtained. No mitigating practices are required.
- Quality Criteria is not met when an overall rating of MEDIUM or greater is obtained. Mitigating practices are required. If <u>all</u> possible mitigating practices have already been implemented, then Quality Criteria are considered met. <u>This must be documented in the plan.</u>

Identification of Mitigating Practices

The rating for each site characteristic (factor) is displayed on the Assessment Report. If any site characteristic has a MEDIUM or higher rating, then mitigating practices are required. Mitigating practices are not required for any site characteristic which has a rating of LOW, however “Recommended” practices might be suggested. “Recommended” and “Required” practices are identified on the report in the column titled “Mitigating Practices”.

References

Czymmek, KJ, QM Ketterings, HM van Es, and SD DeGloria. 2003. The New York Nitrate Leaching Index. Cornell University, Department of Crop and Soil Sciences, Extension Publication E03-2.

Meisinger, JJ, and JA Delgado. 2002. Principles of managing nitrogen leaching. J. Soil and Water Conservation 57: 485 - 498.

Shaffer, MJ, and JA Delgado. 2002. Essentials of a national nitrate leaching index assessment tool. J. Soil and Water Conservation 57: 327 – 335.

Sharpley, AN, T Daniel, T Sims, J Lemunyon, R Stevens, and R Parry. 2003. Agricultural phosphorus and eutrophication (second edition). USDA-Agricultural Research Service, ARS-149.

USDA-NRCS Conservation Practice Standard, Nutrient Management, Idaho 590.

USDA-NRCS, Engineering Technical Note, Series 1901. A Phosphorus Assessment Tool, August 1994.

USDA-NRCS Soil Survey Manual, Agricultural Handbook 18, 1993.

Williams, JR, and DE Kissel. 1991. Water percolation: an indicator of nitrogen-leaching potential. pp 59-83 *IN*: RF Follet, DR Keeney, and RM Cruse (eds). Managing nitrogen for groundwater quality and farm profitability. Soil Science Society of America, Inc. Madison, WI

Table 1. Idaho Nutrient Transport Risk Assessment for Planning (Field Sheet). The weighting for each factor is incorporated into the point value.

Surface Water Quality							
Site Characteristic	**Rating and Point Value**						**SELECTED RATING**
	Very Low 0	Low 1	Medium 2	High 4	Very High 8	Critical 10	
Soil Test P (ppm) Olsen Method 0 – 12”	< 8	8 - 15	16 - 25	26 - 35	36 – 40 (or no soil test)	> 40	
Soil Test P (ppm) Bray Method 0 – 12”	< 10	10 - 20	21 - 40	41 - 50	51- 60 (or no soil test)	> 60	
Soil Test P (ppm) Morgan Method (NaOAc) 0 – 12”	< 1.0	1.0 – 2.0	2.1 – 4.0	4.1 – 5.0	5.1- 6.0 (or no soil test)	> 6.0	
Site Characteristic	**Rating and Point Value**						**SELECTED RATING**
	Very Low 0	Low 0.75	Medium 1.5	High 3	Very High 6	Critical	
Phosphorus Fertilizer Application Rate (lbs/ac P_2O_5)	0	< 60	60 - 150	151- 300	> 300		
Site Characteristic	**Rating and Point Value**						**SELECTED RATING**
	Very Low 0	Low 0.5	Medium 1.0	High 2	Very High 4	Critical 10	
Phosphorus Fertilizer Application Method	None applied	Placed with planter (banded) or injected > 2" or plowed	Incorporated > 3" by disking or chiseling, etc.	Chemigated, or incorporated < 3" by harrowing, etc.	Surface applied, no incorporation	Surface applied on a field with surface runoff (natural or from irrigation) and no incorporation	
Site Characteristic	**Rating and Point Value**						**SELECTED RATING**
	Very Low 0	Low 1	Medium 2	High 4	Very High 8	Critical	
Organic Phosphorus Application Rate (lbs/ac P_2O_5)	0	< 40	40 - 100	101 – 200	> 200 (or unknown)		

Site Characteristic	**Rating and Point Value**						**SELECTED RATING**
	Very Low 0	Low 0.75	Medium 1.5	High 3	Very High 6	Critical 10	
Organic Phosphorus Application Method	None applied	Placed with planter (banded) or injected > 2" or plowed	Incorporated > 3" by disking or chiseling, etc.	Chemigated, or incorporated < 3" by harrowing, etc.	Surface applied, no incorporation	Surface applied on a field with surface runoff (natural or from irrigation) and no incorporation	

Site Characteristic	**Rating and Point Value**						**SELECTED RATING**
	Very Low 0	Low 1	Medium 2	High 4	Very High 8	Critical	
Nitrogen Application Rate (% of Crop Requirement)	< 40	40 - 60	60 - 100	100 - 120	> 120		

Site Characteristic	**Rating and Point Value**						**SELECTED RATING**
	Very Low 0	Low 0.75	Medium 1.5	High 3	Very High 6	Critical 10	
Nitrogen Fertilizer Application Method (prior to critical runoff period)	None applied	Placed with planter (banded) or injected > 2" or plowed	Incorporated > 3" by disking or chiseling, etc.	Chemigated, or incorporated < 3" by harrowing, etc.	Surface applied, no incorporation	Surface applied on a field with surface runoff (natural or from irrigation) and no incorporation	

Site Characteristic	**Rating and Point Value**						**SELECTED RATING**
	Very Low 0	Low 0.5	Medium 1.0	High 2	Very High 4	Critical	
Runoff Index (Surface Irrigated)	No runoff occurs	-----	Water runs off the field less than 50% of the set time	-----	Water runs off the field 50% or more of the set time		
Runoff (Sprinkler Irrigated)	No runoff occurs	Water moves across the surface but not off the field	-----	Runoff leaves the field	----		
Runoff Class	Negligible	Very low or low	Medium	High	Very High		

Site Characteristic	**Rating and Point Value**						**SELECTED RATING**
	Very Low 0	Low -1	Medium -2	High -4	Very High -8	Critical	
Runoff BMPs (Only applies if runoff occurs)	No conservation practices	One or two on-field conservation practices that reduces runoff	Multiple conservation practices that reduce runoff <u>or</u> trap nutrients	Multiple conservation practices that reduce runoff <u>and</u> trap/filter pollutants	Conservation practice(s) that eliminates runoff		
Site Characteristic	**Rating and Point Value**						**SELECTED RATING**
	Very Low 0	Low 1	Medium 2	High 4	Very High 8	Critical	
Average Total Soil Erosion due to Water (tons/ac/year)	< 1 ton/acre	1 - 5 tons/acre	5 - 10 tons/acre	10 - 15 tons/acre	> 15 tons/acre		
Site Characteristic	**Rating and Point Value**						**SELECTED RATING**
	Very Low 0	Low 1	Medium 2	High 4	Very High 8	Critical	
Distance to Surface Water	> 2640 feet (> 0.5 mile)	2640 - 1320 feet	1319 - 600 feet	599 - 200 feet	< 200 feet		
TOTAL POINTS FOR SURFACE WATER QUALITY (Less than 12 is a LOW rating)							

Ground Water Quality							
Site Characteristic	**Rating and Point Value**						**SELECTED RATING**
	Very Low 0	Low 1	Medium 2	High 4	Very High 8	Critical	
Nitrogen Application Rate (% of Crop Requirement)	< 40	40 - 60	60 - 100	100 - 120	> 120		
Site Characteristic	**Rating and Point Value**						**SELECTED RATING**
Irrigated> **Not Irrigated>**	Very Low 0 0	Low 0.75 1	Medium 1.5 2	High 3 4	Very High 6 8	Critical	
Nitrogen Application Timing	None applied	Nitrogen applied in several applications during the primary growing season, the first application no greater than 30 days of start of primary growing season	Majority of nitrogen is applied within 30 days of, or during, the primary growing season. Nitrogen applied outside this time frame is less than 50 lbs and is applied with a nitrification inhibitor or when soil temperatures are less than 50 deg. F.	Nitrogen is applied as a single application within 90 days of the primary growing season OR a split application is made which does not meet the conditions described for LOW or MEDIUM.	Nitrogen is applied as a single application more than 90 days prior to the primary growing season.		

Site Characteristic	Rating and Point Value					SELECTED RATING
	Very Low 0	Low 1.5	Medium 3	High 6	Very High 12	Critical	
Irrigation Index	> 79	70 - 79	60 - 69	50-59	< 50		

This index requires information on the irrigation system type, water measurement and distribution, irrigation scheduling, SCI, and whether pre or post season irrigation is used. Circle the most appropriate selection in each category.

Irrigation System	**Irrigation Scheduling**	**Water Control and Measurement**
Surface - Graded Border	Use a set irrigation schedule each year	
Surface - Level Border (Basin)	Irrigation based on visual observation of crop stress	Poor - no water measurement AND poor control of water due to inadequate water control structures throughout the conveyance system
Surface - Graded Furrow or Corrugates	Soil moisture by NRCS feel method	
Surface - Surge	Check book scheduling, irrigation scheduler, etc.	
Surface - Controlled with contour ditch, turnouts, canvas dams, etc.	Irrigation scheduling via pan evaporation of atmometer in field	Fair - manually recorded water measurement at delivery point to farm AND poor control of water due to inadequate control structures throughout the conveyance system
Surface - Uncontrolled (wild flood, no control with turnouts, etc.)	Irrigation scheduling via regional weather network (e.g. AgriMet)	
Sprinkler - Big gun or boom	Soil moisture monitoring using Gypsum blocks, moisture probes, etc.	
Sprinkler - Periodic Move (hand line or wheel line)	Continuous measurement of soil moisture, water applied, and ET	Average - manual recordings somewhere in the system OR good control of water with effective water control structures throughout the conveyance system
Sprinkler - Solid set		
Sprinkler - Center pivot	**Pre/Post Irrigation**	
Sprinkler - Lateral/linear move	Pre- and post-season irrigations based on standard run time	Good - manual recordings somewhere in the system AND good control of water with effective water control structures throughout the conveyance system
Micro Irrigation - Sprays and Bubblers	Pre-season OR post-season irrigations based on standard run time	
Micro Irrigation - Tubing or tape w/ integrated or punched-in emitters	Pre- and post-season irrigations based on soil moisture assessment	
	Pre- OR post-season irrigations based on soil moisture assessment	Excellent - Continuous recording water measurement device(s) AND good control of water with effective water control structures throughout the conveyance system
	No irrigation outside crop growing season	

Leaching Index (Irrigated) (applies only if Irrigation Index > LOW)	< 9	9 - 12	13 - 16	17 - 20	> 20	[redacted]	
Leaching Index (Not Irrigated)	0	0 – 2	2 – 5	5 – 10	>10	[redacted]	
Site Characteristic	**Rating and Point Value**						**SELECTED RATING**
	Very Low 0	Low 1	Medium 2	High 4	Very High 8	Critical	
Water Table/Geologic Feature Depth and Soil Type	Water table or geologic feature > 5 feet from surface, Hydrologic Group D	Water table or geologic feature > 5 feet from surface, Hydrologic Group C	Water table or geologic feature > 5 feet from surface, Hydrologic Groups A, B	Water table or geologic feature < 5 feet to surface, Hydrologic Groups C, D	Water table or geologic feature < 5 feet to surface, Hydrologic Groups A, B	[redacted]	
TOTAL POINTS FOR GROUND WATER QUALITY (Less than 9 is a LOW rating)							

Table 2. Surface Water Quality Nutrient Transport Risk Assessment Index rating and sit e vulnerability.

Surface Water Risk Assessment Rating	Total	Site Vulnerability Chart
LOW	< 12	Low potential for nutrient loss if current farming practices are maintained.
MEDIUM	12 - 20	Medium potential for nutrient loss. Some remediation measures should be undertaken to minimize the probability of nutrient loss.
HIGH	21 - 40	High potential for nutrient loss and adverse effects on surface and/or ground waters. Soil and water conservation measures and phosphorus management plans are needed to reduce the probability of nutrient loss.
VERY HIGH	> 40	Very high potential for nutrient loss and adverse effects on surface and/or ground waters. All necessary soil and water conservation measures and a nutrient management plan must be implemented to minimize nutrient loss.

Table 3. Ground Water Quality Nutrient Transport Risk Assessment Index rating and sit e vulnerability.

Ground Water Risk Assessment Index Rating	Total	Site Vulnerability Chart
LOW	< 9	Low potential for nutrient loss if current farming practices are maintained.
MEDIUM	9 - 16	Medium potential for nutrient loss. Some remediation measures should be undertaken to minimize the probability of loss.
HIGH	16 - 25	High potential for nutrient loss and adverse effects on ground water. Soil and water conservation measures and nutrient management plans are needed to reduce the probability of loss.
VERY HIGH	>25	Very high potential for nutrient loss and adverse effects on ground water. All necessary soil and water conservation measures and a nutrient management plan must be implemented to minimize loss.

Table 4. The surface RUNOFF CLASS site characteristic determined from the relationship of the soil permeability class and field slope. Adapted from NRCS Soil Survey Manual (1993) Table 3-10.

Slope (%)	Soil Permeability Class [1] *(in/hr)*				
	Very Rapid *(>20.00 in/hr)*	Moderately Rapid and Rapid *(2.00 – 20.00)*	Moderately Slow and Moderate *(0.20 – 2.00)*	Slow *(0.06 - 0.20)*	Very Slow *(< 0.06 in/hr)*
	Runoff Class [3]				
Concave [2]	N	N	N	N	N
< 1	N	N	N	L	M
1 - 5	N	VL	L	M	H
5 - 10	VL	L	M	H	VH
10 - 20	VL	L	M	H	VH
> 20	L	M	H	VH	VH

[1] Permeability class of the least permeable layer within the upper 39 inches (one meter) of the soil profile. Permeability classes for specific soils can be obtained from a published soil survey or from local USDA-NRCS field offices (soils database).
[2] Area from which no or very little water escapes by overland flow.
[3] RUNOFF CLASS: N = negligible, VL = very low, L = low, M = medium, H = high, VH = very high.

ATTACHMENT 1: Example for Conservation Planning

Benchmark condition is sprinkler irrigated potato-sugarbeet-winter wheat in southeast Idaho with manure application.

Site Characteristic and Ranking	Factor Weighting X Rating Value
Soil P test is 35 ppm using an Olsen Test =HIGH	1.0 x 4 = 4.0
P fertilizer application rate is 50 lbs/ac P_2O_5 =LOW	0.75 x 1 = 0.75
P fertilizer application method is placed with planter =LOW	0.5 x 1 = 0.5
Organic P source application rate is 210 lbs/ac =VERY HIGH	1.0 x 8 = 8.0
Organic P source application method is incorporated less than 3 inches by harrowing, etc. =HIGH	0.75 x 4 = 3.0
N fertilizer application rate is 80% of crop requirement prior to debits/credits =MEDIUM	1.0 x 2 = 2.0
N fertilizer application method is broadcast and incorporated greater than 3" =LOW	0.75 x 1 = 0.75
N fertilizer application timing is single application in spring, > 30 days prior to growing season =HIGH	0.75 x 4 = 3
Irrigation Runoff Index for sprinkler irrigated, no runoff occurs but overland flow within field does occur. = LOW	0.5 x 1 = .5
Runoff class from Table 3 is Medium =MEDIUM	0.5 x 2 = 1.0
No runoff conservation practices in place =VERY LOW	1.0 x 0 = 0

Soil erosion is 7.5 tons/ac/yr = MEDIUM	1.0 x 2 = 2.0
Distance to nearest receiving water body is 300 feet =HIGH	1.0 x 4 = 4.0
Irrigation Index calculated at 68 for center pivot with visual observation of crop stress, pre-season irrigation and average control of water =MEDIUM	1.5 x 2 = 3
Leaching Index for Pocatello =LOW	0.75 x 1 = 0.75
Water table/soils for Hydrologic Group C with no water table or geologic feature within 5 feet =LOW	1.0 x 1 = 1.0
Total Points for Surface Water Quality	**26.5**
Total Points for Ground Water Quality	**9.75**

Ranking for Surface Water - the site has a **HIGH** potential for nutrient loss and adverse effects on surface waters.

Ranking for Ground Water – the site has a **MEDIUM** potential for nutrient loss and impact to ground water.

Using the individual site characteristics, identify some factors of concern and management options that could be used to reduce this site vulnerability (mitigation):

Soil P Test – The soil P test was HIGH. Remember that the soil test level for "available P" does not ascertain the total P in the surface soil. It does, however, give an indication of the amount of total P that may be present because of the general relationship between the forms of P and the solution P available for crop uptake. Research has conclusively shown that the higher the soil test P level of a site, the proportionately higher the potential P loss will be from that site. Therefore the long-term goal should be to conduct a comprehensive soil testing program on the entire farm and implement nutrient management on individual fields using ONEPLAN. Estimates should be made to determine the time required to deplete the soil P to optimum levels.

Organic P Source Application Rate – The organic P source application rate was > 200 lbs/ac, falling in the VERY HIGH category. This particular site characteristic is especially important. Here we have a management unit with a soil test P level that is already high and very high rates of organic P are being applied. Considering the long-term management options discussed under

Soil P Test, the organic P application rate should either be reduced to crop P uptake or less, or no organic P should be applied ntil the soil P is depleted back to an optimal level. The ONEPLAN nutrient management program can help identify fields with lower soil P test and lower risk assessment values where the organic material could be applied.

Organic P Source Application Method – The organic P source application method was incorporated less than 3 inches with a harrow, etc. putting it in the HIGH category. Remember that the manner in which organic P material is applied to the soil can determine potential P movement. Since the organic P was only minimally incorporated, the organic P would still have a substantial surface exposure. Mechanical incorporation reduces the amount of nutrients in the thin mixing zone at the soil surface and/or on crop residue or foliage, thus reducing the interaction with and transfer of nutrients to runoff water. With incorporation, other environmental losses may also be reduced, and nutrient management may be improved. However, mechanical incorporation with tillage may reduce soil-protecting crop residue and increase erosion. Incorporated material may be subject to downward movement. Leaching losses may be increased, and the relative importance of the different loss pathways needs to be considered. The organic P material should be injected or plowed greater than 2 inches if possible, and applied immediately before the crop is planted.

Runoff Conservation Practices – No runoff practices are currently in place, so level of use is VERY LOW. Implementing irrigation water management and use of surface roughening (dam-dike) and buffers would help reduce runoff and sediment loss. (see Soil Erosion).

Soil Erosion – The soil erosion rate was 7.5 tons/ac/yr (MEDIUM category). Prediction models are used in the assessment to indicate a movement of soil, thus potential for sediment and attached phosphorus movement across the slope or unsheltered distance and to a water body. Conservation measures such as residue management or reduced tillage should be considered as a way to reduce erosion. In addition, other conservation measures like field borders or buffers should be considered as a means to mitigate off-site transport and improve the quality of runoff leaving the field.

Irrigation Index – Despite the use of a center pivot system, the irrigation index rated MEDIUM because of pre-season irrigation practices and a low level of irrigation scheduling. Following appropriate irrigation water management techniques could significantly improve efficient use of water and reduce the potential for leaching losses.

Nitrogen Application Timing – Applying nitrogen as a single application more than 30 days prior to the start of the growing season increases the risk of loss during spring. Apply the nitrogen closer to the growing season and consider splitting applications for better crop use efficiency.

APPENDIX F - UNIVERSITY OF IDAHO CIS 1139

University of Idaho
College of Agricultural and Life Sciences

CIS 1139

Manure and Wastewater Sampling

by Ron E. Sheffield and Richard J. Norell

Nutrient concentrations vary within most types of manure. A review of samples from 42 dairies in Idaho (Table 1) showed that nitrogen (N) and phosphorus (P) in wastewater lagoons vary greatly between farms. For example, on small open lot dairies (< 1,000 head), P can range from 16 to 28 pounds/per acre-inch while on large open lot dairies (> 1,000 head), the range is 12 to 20 pounds per acre-inch.

Phosphorus concentrations on freestall flush dairies ranged from 23 to 31 pounds per acre-inch, while scraped freestall dairies ranged from 17 to 39 pounds per acre-inch. This is a broad range of nutrient levels with the maximum and minimum values differing by more than a factor of two.

These numbers should send a clear message: Average nutrient estimates may be suitable for the purposes of developing a manure utilization plan, but these averages are not adequate for calculating proper application rates.

Do not base your application rates on laboratory test results from previous years because nutrient concentrations can change significantly, particularly when the manure has been exposed to the environment. For example, nutrient levels in a lagoon or storage pond can be greatly diluted by more rainfall than normal or concentrated due to excessive summertime evaporation.

Manure should be tested as close to the date of application as practical. Preferably, the sample should be taken as near the application time as possible prior to the manure application, or within 30 days of application. However, if you urgently need to pump down a full lagoon or storage pond, you should not wait until you can sample and obtain the results. Instead, you should sample the day of irrigation. The results can later be used to determine the nutrients applied to the fields and identify the need for additional nutrients to complete crop production.

Producers who do not test each manure source before or just after land application are faced with a number of questions they simply may not be able to answer:

- Am I supplying plants with adequate nutrients?
- Am I building up excess nutrients that may ultimately move to surface waters or groundwater?
- Am I applying heavy metals at levels that may be toxic to plants and permanently alter soil productivity?

Because environmental damage and losses in plant yield and quality often happen before visible plant symptoms, always have your manure analyzed by a competent lab. Certified labs in Idaho can analyze manure samples and may be able to make agronomic recommendations regarding the use of the manure as a fertilizer.

Manure sampling

Proper sampling is the key to reliable manure analysis. Although lab procedures are accurate, they have little value if the sample fails to represent the manure product.

Manure samples submitted to a lab should represent the average composition of the material that will be applied to the field. Reliable samples typically consist of material collected from a number of locations. Precise sampling methods vary according to the type of manure. The lab, county extension agent, or crop consultant should have specific instructions on sampling, including proper containers to use and maximum holding or shipping times. General sampling recommendations follow.

Preparing liquid manure for lab analysis. Liquid manure samples submitted for analysis should meet the following requirements:

- Place sample in a sealed, clean plastic container with about a 1-pint volume. Glass is not suitable because it is breakable and may contain contaminants.

Table 1. Average lagoon wastewater concentrations from various types of Idaho dairies.

Farm Type[1]	Ammonia (NH_3) lb/ac-in	Total Kjeldahl Nitrogen (TKN) lb/ac-in	Total Phosphorus (TP) lb/ac-in	Total Solids (TS) mg/l	Biochemical Oxygen Demand (BOD) mg/l
OL < 1,000 hd	40 +/- 2	119 +/- 29	22 +/- 6	29,291 +/- 12,098	21,067 +/- 20,240
OL > 1,000 hd	61 +/- 22	92 +/- 36	16 +/- 4	5,087 +/- 1,386	1,068 +/-192
FS Scrape	175 +/- 75	181 +/- 75	28 +/- 11	24,122 +/- 13,826	2,135 +/- 968
FS Flush	149 +/- 23	162 +/- 24	27 +/- 4	10,770 +/- 2,138	1,912 +/- 481

[1] Farm Type: OL = Open Lot Dairy; FS = Freestall Dairy; hd = head.
[2] Average values +/- standard error.

- Leave at least 1 inch of air space in the plastic container to allow for expansion caused by the release of gas from the manure material.
- Refrigerate or freeze samples that cannot be shipped on the day they are collected, minimizing chemical reactions and pressure buildup from gases.

Ideally, liquid manure should be sampled after it is thoroughly mixed. Because this is sometimes impractical, samples can also be taken in accordance with the suggestions that follow.

Lagoon liquid. Premixing the surface liquid in the lagoon is not needed, provided it is the only component that is being pumped. Growers with multistage systems should draw samples from the lagoon they intend to pump for crop irrigation.

Samples should be collected using a clean, plastic container similar to the one shown in **Figure 1.** One pint of material should be taken from at least eight sites around the lagoon and then mixed in the larger clean, plastic container. Effluent should be collected at least 6 feet from the lagoon's edge at a depth of about a foot. Shallower samples from anaerobic lagoons may be less representative than deep samples because oxygen transfer near the surface sometimes alters the chemistry of the solution. Floating debris and scum should be avoided. One pint of mixed material should be sent to the lab. Galvanized containers should never be used for collection, mixing, or storage due to the risk of contamination from metals like zinc in the container.

A University of Idaho study compared nutrient composition from two sampling locations: direct from storage and during land application. Nitrogen concentration averaged 15 pounds per acre-inch higher in storage samples than from land application samples. Conversely, phosphorus and potassium concentrations were similar between storage and land application samples. Nitrogen application rates may be overestimated if based on nutrient analysis from storage samples.

These recommendations are adequate for average irrigation volumes. If an entire storage structure is to be emptied by such means as furrow irrigation, more frequent sampling with many more sampling points is recommended.

Liquid slurry. Manure materials applied as a slurry (approximately 5 to 12 percent solids) from a pit, storage pond, or vacuumed from a feed alley should be mixed prior to sampling. If you agitate your pit or basin prior to sampling, a sampling device pictured in **Figure 1** can be used. If you wish to sample a storage structure without agitation, you must use a composite sampling device as shown in **Figure 2**. Manure should be collected from approximately eight areas around the pit or pond and mixed thoroughly in a clean, plastic container. An 8- to 10-foot section of 0.5- to 0.75-inch plastic pipe can also be used: extend the pipe into the pit with ball plug open, pull up the ball plug (or press your thumb over the end to form an air lock), and remove the pipe from the manure, releasing the air lock to deposit the manure in the plastic container.

Lagoon sludge. The best time to take a sludge sample is while measuring for volume of sludge in a lagoon. This allows samples to be collected from several points around the interior of the lagoon. How the sample is collected depends on how the sludge will be removed. Depending on the density and nutrient concentration of the lagoon effluent, the samples may differ by up to 100 percent from point to point.

To draw a sample, use the same type of sampler as described above for manure slurry (**Figure 2**) and lower the sampler until it almost reaches the bottom. Avoid using a commercial "sludge-judge," because experience has shown that these devices do not work well on thick manure sludge and settled solids.

Wearing plastic or latex gloves, collect a core or profile of lagoon effluent and sludge. Once the pipe is over a clean 5-gallon plastic bucket, slowly break the vacuum by removing your finger from the end of the pipe. If the entire lagoon is going to be agitated during sludge removal, the entire core of collected sludge and effluent should be sent to the laboratory. If the lagoon effluent is going to be drawn down and primarily only sludge pumped out, then just the collected sludge should be sent to the lab. If you are unsure how the sludge will be removed, take samples using both methods, label them separately, and have both analyzed.

Place several samples in the bucket and mix thoroughly before removing a sub-sample for analysis. Consider using a plastic, wide-mouth bottle when shipping samples to the laboratory.

Solid Manure. Solid manure samples should represent the manure's average moisture content. If the material varies

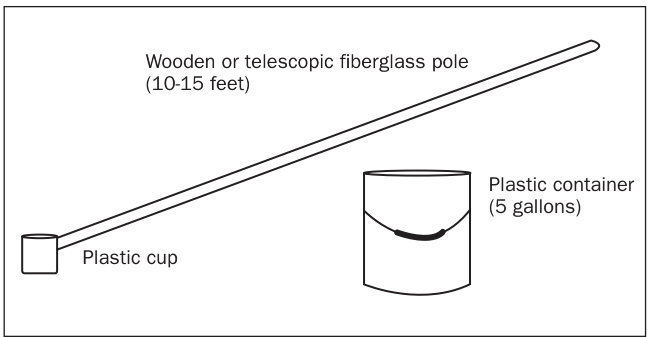


Figure 1. Liquid manure sampling devices like these can be purchased or made.

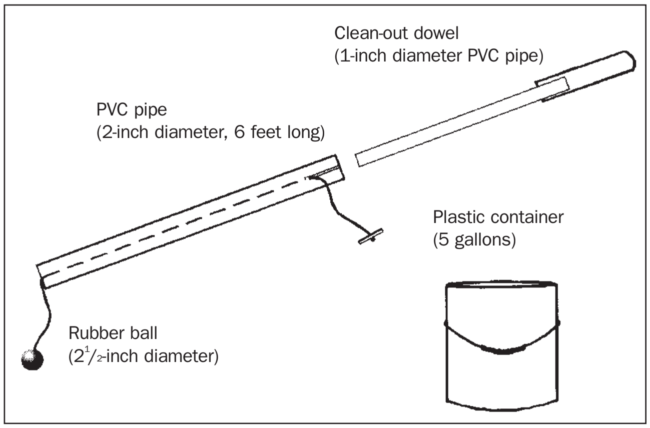


Figure 2. Composite sampler for slurries and lagoon sludge or settled solids includes a collecting PVC pipe and a clean-out dowel (smaller PVC pipe), string, and a rubber ball big enough to cover one end of the collecting pipe.

greatly in its moisture content, you should submit at least 3 samples to a laboratory and take an average of each analysis.

A 1-quart sample is adequate for analysis. Samples should be taken from approximately 8 different areas in the manure pile, placed in a clean plastic container, and thoroughly mixed. Samples should be taken wearing plastic or latex gloves and using a plastic or stainless steel hand shovel or trowel. Do not use galvanized trowels or buckets because they will likely contaminate the sample, rendering falsely high concentrations of metals like zinc in the analysis. Approximately 1 quart of the mixed sample should be placed in a plastic bag, sealed, and shipped directly to the lab. Samples stored for more than 1 day should be refrigerated.

Stockpiled manure or litter. Ideally, stockpiled manure and separated solids should be stored under cover on an impervious surface. The weathered exterior of uncovered waste may not accurately represent the majority of the material. Additionally, rainfall will move water-soluble nutrients down into the pile. If an unprotected stockpile is applied over an extended period, it should be sampled before each application.

Stockpiled manure should be sampled at a depth of at least 18 inches at 6 or more locations around the pile. The collected material should be combined in a plastic container and mixed thoroughly. The 1-quart lab sample should be taken from this mixture, placed in a plastic container or bag, sealed, and shipped to the lab for analysis. If the sample cannot be shipped within one day of sampling, it should be refrigerated.

Surface-scraped manure. Surface-scraped and piled materials should be treated like stockpiled manure. Follow the same procedures for taking samples. Ideally, surface-scraped materials should be protected from the weather unless they are used immediately.

Composted manure. Ideally, composted manure should be stored under cover on an impervious surface. Although nutrients are somewhat stabilized in these materials, some nutrients can leach out during rains. When compost is left unprotected, samples should be submitted to the lab each time the material is applied. Sampling procedures are the same as those described for stockpiled manure.

Who can analyze my manure sample?

Both public and private labs analyze manure samples. Use only labs that are certified or conduct their analysis according to the North American Proficiency Testing – Manure Assessment Program (NAPT-MAP) to test manure and wastewater, or the North American Proficiency Testing – Compost Assessment Program (NAPT-CAP) to test compost. Private labs can be found through local Cooperative Extension Service (CES) agents, state regulators, or on the NAPT-MAP Web site: *http://ghex.colostate.edu/map/*.

Deciding which lab to use depends on several factors:

- Is the lab certified or does it conduct its analysis according to NAPT-MAP or NAPT-CAP guidelines?
- What is the cost to run the sample?
- How long will it take to get your results?
- Does the lab offer all parameters needed for your operation?
- Can you get your sample to the lab in the required time?

When you have selected a lab to analyze the manure, you need to follow its specific sample requirements. Many labs offer sample containers that they ask you to use. Sample collection procedures, including holding times allowed and refrigeration and shipping requirements, must be closely followed to obtain accurate results. One standard that applies to all labs and sampling recommendations is to sample as close to the application time as possible.

Essential analyses include concentrations of essential plant nutrients, including nitrogen as ammonium (NH_4-N), and Total Kjeldahl Nitrogen (TKN), Total phosphorus (TP) and potassium (K). Additionally, you may consider sampling for nitrate (NO_3-N), dissolved phosphorus (PO_4-), calcium (Ca), magnesium (Mg), sulfur (S), iron (Fe), manganese (Mn), zinc (Zn), copper (Cu), boron (B), dry matter content or total solids (TS), pH, and electrical conductivity (for liquid samples). Where applicable, check your NPDES permit (National Pollutant Discharge Elimination System) for specific sampling requirements.

What does my manure analysis report tell me?

Lab results may be presented in a number of ways. The easiest to use is a wet, "as-is" basis in pounds of available nutrient (N, P, or K) (1) per ton; (2) per 1,000 gallons of manure or wastewater; or (3) per acre-inch of manure or wastewater.

If a lab reports results on a dry basis, you must have the moisture content of the manure to convert the results back to a wet basis. A lab may also give results as a concentration (parts per million [ppm] or milligram per liter [mg/l]), which likewise requires conversion factors to get the results into a usable form based on how you apply the manure. Finally, if a lab reports P and K as elemental P and K, you must convert them to the fertilizer basis of P_2O_5 or K_2O. This can be done with the following conversions:

P X 2.29 = P_2O_5
K X 1.20 = K_2O

Select a lab that reports an analysis on an "as-is" basis in the units of measure most useful to your operation.

Most useful information

The most useful information is predicted nutrients available for the first crop. Nutrient availability is predicted based on estimates of manure breakdown and nutrient loss according to application method. If the lab does not report plant-available nutrients, contact your nutrient management planner, a certified crop advisor, or your local extension office for assistance.

Of the total nutrients predicted to be available for the first crop, 50 to 75 percent will likely become available during the first month. It is, therefore, important to apply manure near the time nutrients are required by plants. The remaining nutrients gradually become available over the next three months. Nutrients not available for the first crop are slowly released to available forms over time. In soils that do not readily leach with heavy rainfall, nutrients may accumulate to significant quantities over time.

You should review the report to see if the analysis is within the expected ranges for your manure. It is common for manure analyses to vary between seasons, due to excess rainfall, drought, or changes in management practices. However, you should compare your results to the results from previous manure reports to ensure that they appear reasonable. If your results are significantly different from what you expected, it is advisable to resample the manure. The original sample may have been mislabeled or improperly collected, and thus not be representative of the manure.

To meet a specific plant nutrient requirement, nutrients listed in the report or calculated as "available for the first crop" should be used in determining the actual application rate. For the availability prediction to be reliable, you must have properly identified the type of manure and the application method on the information sheet submitted to the lab. It is important to understand that nutrient availability cannot be determined with 100 percent accuracy. Many variables, including the type of manure product and environmental factors (i.e., soil type, rainfall, temperature, and general soil conditions), influence the breakdown of the manure and nutrient loss. Remember, the worst sample of your manure is always better than the best book value.

About the authors

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University of Idaho Extension

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APPENDIX G - UNIVERSITY OF IDAHO BULLETIN #704 (REVISED)

Soil Sampling

Bulletin 704
(revised)

R. L. Mahler and
T. A. Tindall

College of Agriculture

University of Idaho
Cooperative Extension System

Soil Sampling

Environmental concerns have brought nutrient management in agriculture under increased scrutiny. A goal of sound nutrient management is to maximize the proportion of applied nutrients that is used by the crop (nutrient use efficiency). Soil sampling is a best management practice (BMP) for fertilizer management that will help improve nutrient use efficiency and protect the environment.

Soil sampling is also one of the most important steps in a sound crop fertilization program. Poor soil sampling procedures account for more than 90 percent of all errors in fertilizer recommendations based on soil tests. Soil test results are only as good as the soil sample. Once you take a good sample, you must also handle it properly for it to remain a good sample.

A good soil testing program can be divided into four operations: (1) taking the sample, (2) analyzing the sample, (3) interpreting the sample analyses, and (4) making the fertilizer recommendations. This publication focuses on the first step, collecting the soil sample.

Once you take a sample, you must send it to a laboratory for analysis. Then the Extension agricultural educator or fertilizer fieldman in your county can interpret the analysis and make specific fertilizer recommendations. Fertilizer guides from the University of Idaho Cooperative Extension System are also available to help you select the correct fertilizer application rate.

The soil sampling guidelines in this publication meet sampling standards suggested by federal, state, and local nutrient management programs in Idaho.

What is a soil test?

A soil test is a chemical evaluation of the nutrient-supplying capability of a soil at the time of sampling. Not all soil-testing methods are alike nor are all fertilizer recommendations based on those soil tests equally reliable.

Reliable fertilizer recommendations are developed through research by calibrating laboratory soil test values and correlating them with crop responses to fertilizer rates. These soil test correlation trials must be conducted for several years on a particular crop growing on a specific soil type. If soil test calibration is incomplete, fertilizer recommendations based on soil-test results still can only be best guesses.

A soil test does not measure the total amount of a specific nutrient in the soil. There is usually little relationship between the total amount of a nutrient in the soil and the amount of a nutrient that plants can obtain.

A soil test also does not measure the amount of plant-available nutrients in the soil because not all the nutrients in the soil are in a form readily usable by plants. Through research, however, a relationship can usually be established between soil test nutrient levels and the total amount of a nutrient in the soil.

What does a soil test measure?

Present soil-testing methods measure a certain portion of the total nutrient content of the soil. During testing, this portion is removed from the soil by an extracting solution that is mixed with the soil for a given length of time. The solution containing the extracted portion of the nutrient is separated from the soil by filtration, and then the solution is analyzed.

A low soil-test value for a particular nutrient means the crop will be unable to obtain enough of that nutrient from the soil to produce the highest yield under average soil and climatic conditions. A nutrient deficiency should be corrected by adding the nutrient as a fertilizer. The amount of nutrient that needs to be added for a given soil-test value is calculated based on results from the correlation research test plots.

Sampling timing

Because nutrient concentrations in the soil vary with the season, you should take soil samples as close as possible to planting or to the time of crop need for the nutrient. Ideally, take the soil samples 2 to 4 weeks before planting or fertilizing the crop. It usually requires 1 to 3 weeks to take a soil sample, get the sample to the testing laboratory, and obtain results.

Sampling very wet, very dry, or frozen soils will not affect soil test results though collecting soil samples under these conditions is difficult. Do not sample snow–covered fields. The snow makes it difficult to recognize and avoid unusual areas in the field, so you may not get a representative sample.

Sampling frequency

For best soil fertility management, especially for the mobile nutrients, sample each year and fertilize for the potential yield of the intended crop. Having an analysis performed for every nutrient each year is not necessary. Whether you need an analysis of a nutrient depends on such things as its mobility in the soil and the nutrient requirements of the crop.

Take soil samples at least once during each crop rotation cycle. Maintain a record of soil test results on each field to evaluate long-term trends in nutrient levels.

Sampling procedure

One of the most important steps in a soil testing program is to collect a soil sample that represents the area to be fertilized. If the soil sample is not representative, the test results and recommendations can be misleading.

The correct steps in soil sampling are illustrated in figure 1. Before sampling, obtain necessary information, materials, and equipment from the Extension agricultural educator or fertilizer fieldman in your county.

Use proper soil sampling tools. A soil auger or probe is most convenient, but you can use a shovel or spade for shallow samples. You will need a plastic bucket or other container for each sample to help you collect and mix a composite sample.

Be sure that all equipment is clean, and especially be sure it is free of fertilizer. Even a small amount of fertilizer dust can result in a highly erroneous analysis. Do not use a galvanized bucket when analyzing for zinc (Zn) or a rusty shovel or bucket when analyzing for iron (Fe). If the sample will be analyzed for Fe or manganese (Mn), do not dry the soil sample before shipping.

When sampling, avoid unusual areas such as eroded sections, dead furrows, and fence lines. If the field to be sampled covers a large area with

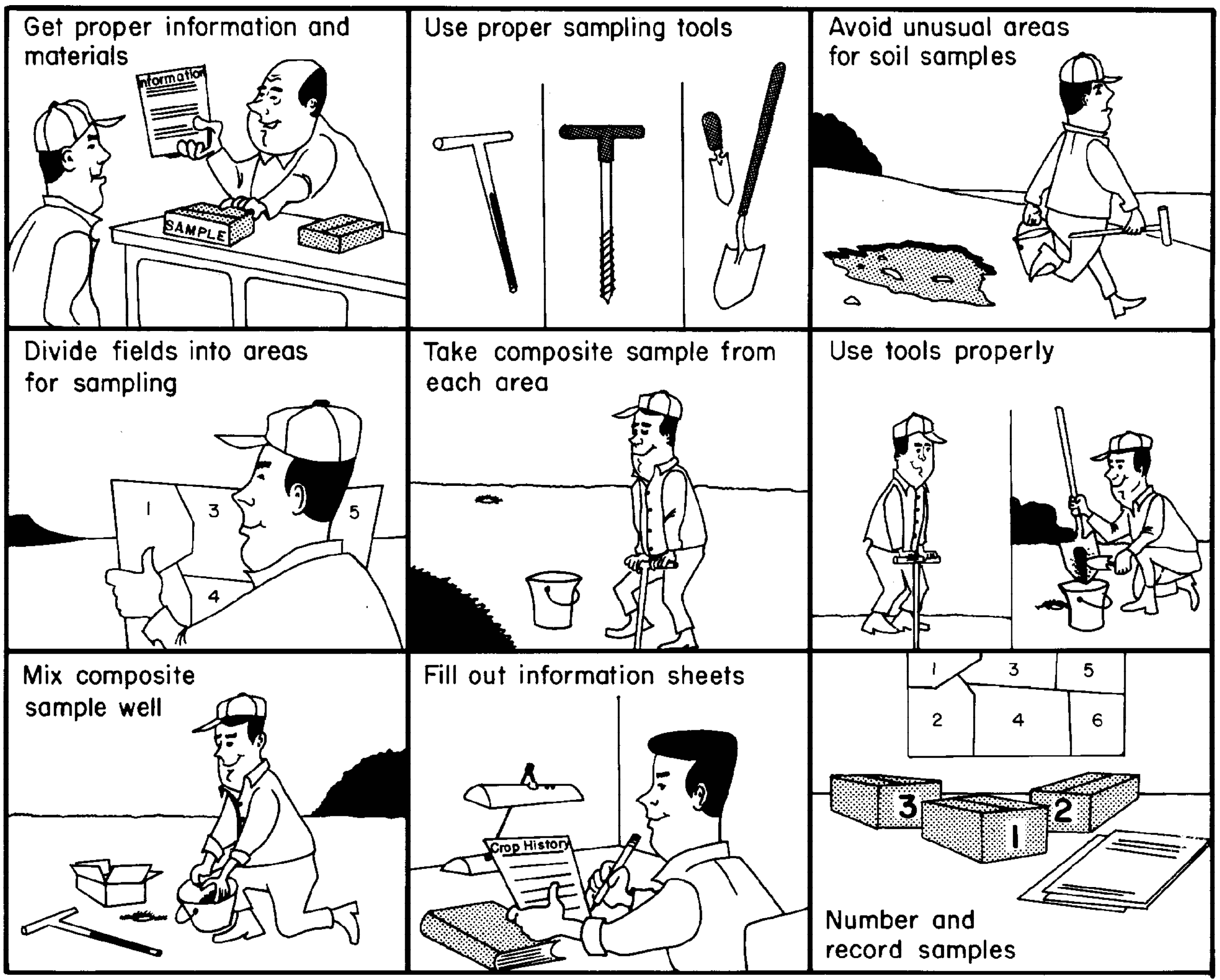

Fig. 1. Follow these steps to obtain a good sample for testing (redrawn courtesy of the National Fertilizer Institute).

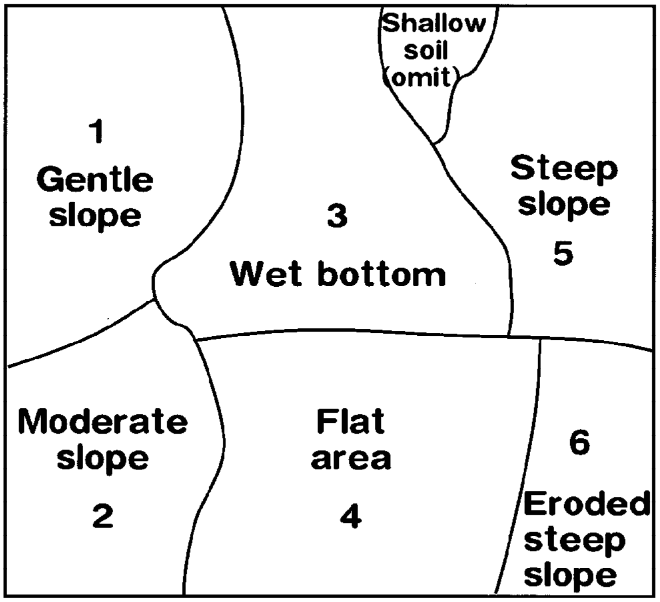

Fig. 2. A field with areas identified as sampling units.

Table 2. Effective rooting depth for some common Idaho crops.

Crop	Depth (feet)
Cereals (wheat, barley, oats)	5 to 6
Corn	5 to 6
Alfalfa, rapeseed	4 to 5
Hops, grapes, tree fruits	4 to 5
Sugarbeets	2 to 3
Peas, beans, lentils, onions, potatoes, mint	2
Vegetable seed	1 to 1 1/2

varied topography, subdivide it into relatively uniform sampling units (fig. 2). Sampling subdivision units that are too small to fertilize separately may be of interest, but impractical if you do not treat the small units differently from the rest of the field. Omit these areas from the sampling.

Within each sampling unit take soil samples from several different locations and mix these subsamples into one composite sample. The number of subsamples needed to obtain a representative composite sample depends on the uniformity and size of the sampling unit (table 1). Although the numbers of subsamples in table 1 give the best results, they may be unrealistic if you plan to take a great number of samples. An absolute minimum of 10 subsamples from each sampling unit is necessary to obtain an acceptable sample. The more subsamples you take, the better the representation of the area sampled.

Take all subsamples randomly from the sampling unit, but be sure to distribute subsample sites throughout the sampling unit. Meander or zig-zag throughout each sampling unit to sample the area. Special considerations are necessary in eroded areas, furrow irrigation, under no-till, and where fertilizer is banded (see "Special Sampling").

The total amount of soil you collect from the sampling unit may be more than you need for analyses. Mix the individual subsamples together thoroughly and take the soil sample from the composite mixture. The composite sample should be at least 1 pint—about 1 pound—in size.

Sampling depth

Depth of sampling is critical because tillage and nutrient mobility in the soil can greatly influence nutrient levels in different soil zones (fig. 3). Sampling depth depends on the crop. cultural practices, tillage depth, and the nutrients to be analyzed.

Because the greatest abundance of plant roots, greatest biological activity,

Table 1. Number of subsamples recommended for a representative composite sample based on field size.

Field size (acres)	Number of subsamples
fewer than 5	15
5 to 10	18
10 to 25	20
25 to 50	25
more than 50	30

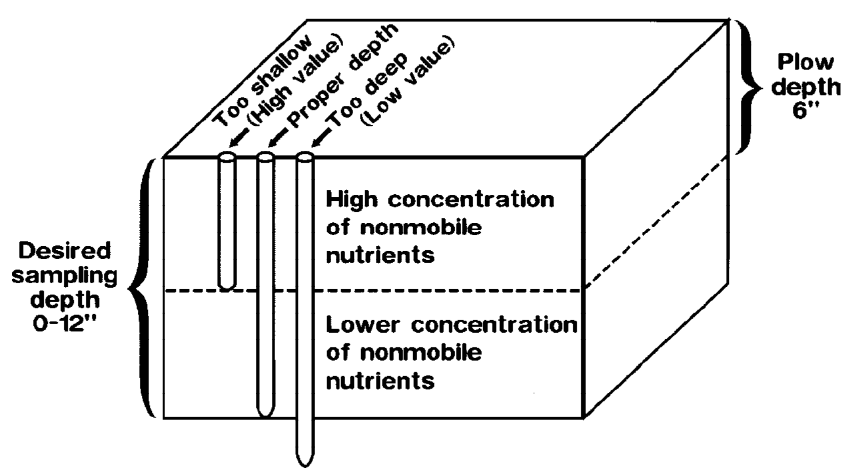

Fig. 3. Too deep or shallow a sampling depth can produce inaccurate soil test results. The plow layer is usually higher in nonmobile nutrients than the soil layers below it.

and highest nutrient levels occur in the surface layers, the upper 12 inches of soil are used for most analyses. The analyses run on the surface sample include soil reaction (pH), phosphorus (P), potassium (K), organic matter, sulfur (S), boron (B), zinc (Zn), and other micronutrients.

Sampling depth is especially critical for nonmobile nutrients such as P and K. The recommended sampling depth for nonmobile nutrients is 12 inches (fig. 3).

The tillage zone, typically 6 to 8 inches deep, usually contains a relatively uniform, high concentration of nonmobile nutrients. Below the tillage zone the concentration is usually lower. Therefore, a sample from the tillage zone will usually have a higher content of nonmobile nutrients than a sample from the desired 0- to 12-inch sample depth. This can lead to erroneous results.

Depth sampling

When sampling for mobile nutrients such as nitrogen (N), boron (B), and sulfur (S), take samples by 1-foot increments to the effective rooting depth of the crop (fig. 4). This can be a depth of 5 to 6 feet (table 2) unless the soil has a root-limiting layer such as bedrock or hardpan. For each foot depth, take 10 or more subsamples at random from the sampling unit.

If you plan to sample less than a year after banding or injecting fertilizer or if you have any question about fertilizer placement, use the sampling technique described under "Areas Where Fertilizer Has Been Banded." Irrigation or precipitation should disperse mobile nutrients over a period of a year.

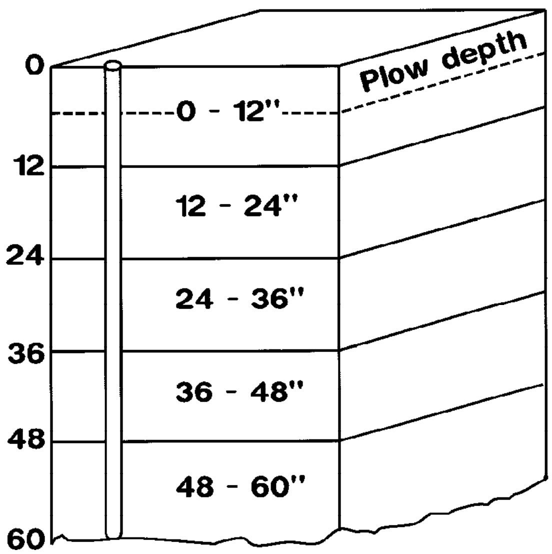

Fig. 4. Depth sampling (successive samples by 12-inch increments) for mobile nutrients (especially N) should be continued to rooting depth, which may be 5 to 6 feet for some crops.

Sample handling

Soil samples need special handling to ensure accurate results and minimize changes in nutrient levels because of biological activity. Keep moist soil samples cool at all times during and after sampling. Samples can be frozen or refrigerated for extended periods of time without adverse effects.

If the samples cannot be refrigerated or frozen soon after collection, air dry them or take them directly to the soil testing laboratory. Air dry by spreading the sample in a thin layer on a plastic sheet. Break up all clods or lumps, and spread the soil in a layer about 1/4 inch deep. Dry at room temperature. If a circulating fan is available, position it to move the air over the sample for rapid drying.

Caution: Do not dry where agricultural chemical or fertilizer fumes or dust will come in contact with the samples. Do not use artificial heat in drying. Ask the Extension agricultural educator or fertilizer fieldman in your county for more details concerning special handling of soil samples.

When the soil samples are dry, mix the soil thoroughly, crushing any coarse lumps. Take from the sample about 1 pint (roughly 1 pound) of well-mixed soil and place it in a soil sample bag or other container. Soil sample bags and soil test report forms are available from the Cooperative Extension System office in your county or from a fertilizer fieldman.

Label the bag carefully with your name, the sample number, sample depth, and field number. The field number should correspond with a field or farm map showing the areas

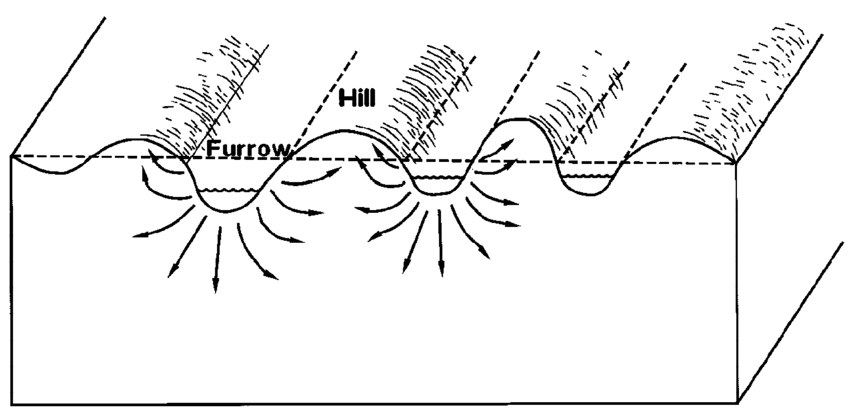

Fig. 5. Movement of mobile nutrients in furrow-irrigated fields.

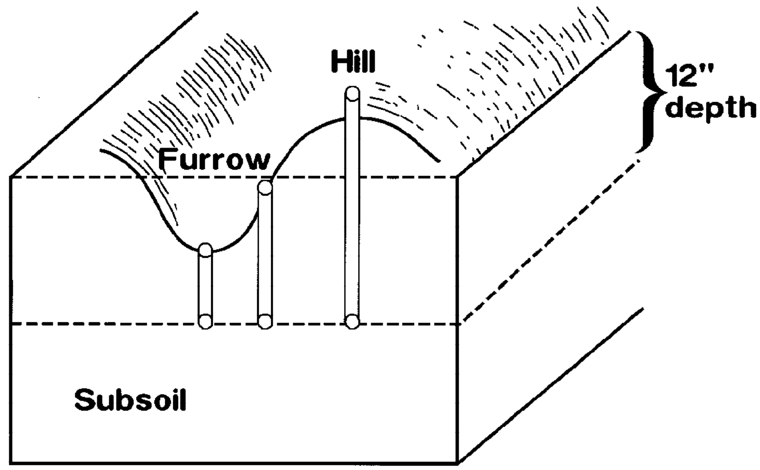

Fig. 6. Special sampling techniques are required when soil sampling furrow-irrigated fields. Take a sample from the hilltop, the furrow bottom, and at the midpoint between the hilltop and furrow bottom. The 12-inch sampling depth is based on the midpoint sampling location.

sampled. This will help you keep an accurate record of soil test reports. Provide information on crop to be grown, yield potential, recent history of crops grown, yields, fertilizer applied, and other information.

Sample analysis

Analyze regularly only for those nutrients that have been shown to be yield limiting in your area or for the crop to be grown. In general, all soils should be analyzed for N, P, K, and S . For determination of potential need for micronutrients, refer to PNW 276, *Current Nutrient Status of Soils in Idaho, Oregon, and Washington.* Occasional analyses for micronutrient concentrations may be advisable.

Special sampling

Special sampling problems occur in fields that have been leveled for irrigation, fields that have lost all or most topsoil as a result of erosion, fields that are surface (furrow) irrigated, fields that have had a fertilizer band applied, and fields that are not thoroughly tilled.

Land-leveled and eroded areas

Areas that have been eroded or artificially leveled for irrigation usually have little or no original topsoil. The soil surface may be exposed subsoil material. These areas should be sampled separately if they are large enough to be managed differently from where topsoil has not been removed. Subsoil material is usually low in organic matter and can be high in clay, calcium carbonate (lime), or both.

Furrow-irrigated fields

For a representative soil sample, sample furrow-irrigated fields before the furrowing operation. If furrowing has already been completed, follow the special sampling procedures described here.

The movement of water and dissolved plant nutrients can create unique nutrient distribution patterns in the hills between the furrows (fig. 5). To obtain a representative sample, you need to be aware of furrow direction, spacing, and location, and to take closely spaced soil samples perpendicular to the furrow (fig. 6).

Approximately 20 sites (with at least three samples per site) are needed for a representative composite soil sample. At each sampling site, take a sample from the hilltop, from the midpoint between the hilltop and furrow, and from the furrow bottom. The sampling depth at the midpoint between the hilltop and furrow bottom should be 12 inches. The bottom point of this sample should be the same as for the furrow and hilltop samples. Thus, the furrow sampling depth will be less than 12 inches, while the hilltop sampling depth will be more than 12 inches (fig. 6).

Mix the hilltop, midpoint, and furrow samples to make a composite sample for each site. Mix the site samples for a representative composite field soil

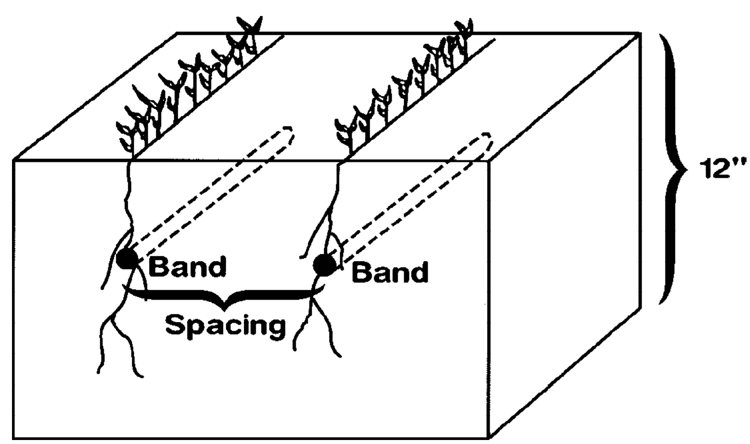

Fig. 7. Diagram of fertilizer location in soil where fertilizer has been banded.

sample to be analyzed for nonmobile nutrients (P, K, and micronutrients). Deeper profile sampling (depth sampling) is recommended for mobile nutrients (N and S).

Areas where fertilizer has been banded

Banding of fertilizers is becoming a more common practice (fig. 7). In fields where fertilizers have been banded and tillage has occurred before soil sampling, regular sampling procedures can be followed. However, if tillage has not adequately mixed the soil, special soil sampling is required. If a field has had a banded fertilizer application the previous growing season and has not been plowed, an ideal sample would be a continuous slice 1 to 2 inches thick and 12 inches deep extending from the center of one band to the center of the next band.

Little research has been conducted to determine the best method of sampling banded fields. Currently three different approaches are used widely. Each method produces a satisfactory representative sample, but the effort required to obtain these samples differs considerably.

Systematic sampling method. If you know the direction, depth, and spacing of the fertilizer band, you can obtain a representative soil sample with this sampling procedure. Take 5 to 10 soil samples perpendicular to the band row beginning in the edge of a fertilizer band and ending at the edge of an adjacent band (fig. 8). Follow this procedure on at least 20 sampling sites in each field or portion of a field being sampled. Mix and composite the soils collected from each site to obtain a representative soil sample.

Controlled sampling method. You also should know the direction, depth, and spacing of the fertilizer bands to obtain a representative soil sample with this method. Take 20 to 30 soil cores from locations scattered throughout the field or portion of the field. Avoid sampling directly in a fertilizer band.

The composite sample should adequately represent the area being sampled. This method may result in slightly lower soil test values of nonmobile nutrients (P, K, and micronutrients) than the systematic and random sampling methods.

Random sampling method. Use this sampling method when the location of the previous season's fertilizer bands is not known. Take 40 to 60 random soil cores to form a composite sample of the area being sampled.

Reduced tillage or no-till fields

You may need special approaches to soil sampling with reduced tillage or no-till fields because the soil has been disturbed so little that fertilizer, whether broadcast on the surface or banded below the surface, is not mixed into the soil. You need to know the history of fertilization, tillage, and other management practices to determine how to obtain a representative sample.

If nonmobile nutrients (P, K, and micronutrients other than B) have been surface broadcast and little or no tillage has been used since their application, remove the surface 1 inch of soil before sampling. Nutrients in the top inch of soil will probably not be available to the growing crop.

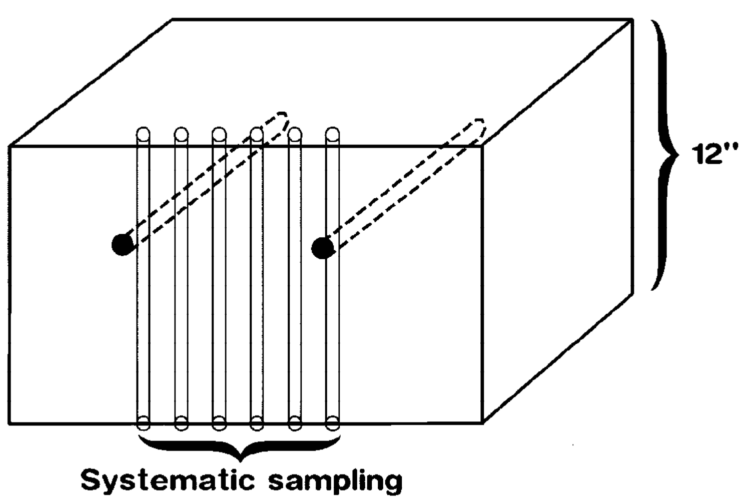

Fig. 8. Systematic soil sampling in a field where fertilizer has been banded (sampling method 1).

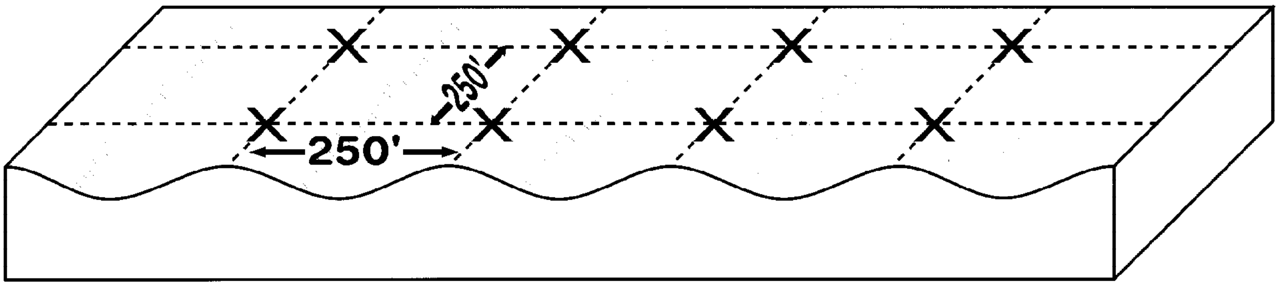

Fig. 9. Grid soil sampling pattern where samples are collected every 250 feet. Note that a complete soil sample is collected at each spot marked with an X.

If fertilizer has been banded with the no-till system, consider methods suggested in "Areas Where Fertilizer Has Been Banded." If a field has been under a continuous no-till system for a long time, determine the pH of the surface foot at 3-inch intervals (0 to 3, 3 to 6, 6 to 9, 9 to 12 inches) every 3 to 5 years. Soil pH will affect the availability of fertilizer nutrients as well as the activity of commonly used herbicides, insecticides, and fungicides.

Grid sampling in nonuniform fields

Many fields are not uniform and vary both horizontally and vertically across landscapes. Traditional soil sampling procedures average nutrient levels in soil subsamples to determine average nutrient levels in the field. The nutrient values obtained are good, but the manager must realize that many of the values in the field are either less than or greater than the values determined. When fields are broken into grids with shorter distances between the sampling points a more precise soil map can be developed to determine nutrient needs.

The technology is now available to combine grid sampling with variable rate fertilizer application to handle spatial variability within a field. These application techniques make fertilizer nutrient application more precise, resulting in greater nutrient use efficiency and reducing pollution potential.

Irrigated fields including individual pivots should be set up in a 200- to 300-foot grid for potato, sugarbeets, corn, and other potentially high-N-use crops (fig. 9). A wider grid of 400 feet may be used for small grains, beans, and other crops where N management is less intensive or under dryland conditions.

Soil nutrient needs for each segment of the grid are entered into a computer-driven system mounted on specialized commercial fertilizer application equipment. Variable rates of nutrients are then applied based on individual soil samples over the entire field.

A similar system designed for fertilizer applications through pivot sprinklers is being developed by the University of Idaho. This system has the potential to apply variable rates of nutrients and water specifically related to changes across individual fields.

The Soil Conservation Service has a digitized soil survey information system (SSIS), which when combined with the results of grid sampling provides specific information and recommendations for soils and soil types within a field. The SSIS can locate pockets of sandy or coarse-textured soils where leaching is a major concern or areas of finer-textured soils where pockets of residual N may occur. The SSIS also indicates where erosion or surface runoff may be high and where areas should be targeted for federal programs such as the Conservation Reserve Program.

Another computer-mapping technique, Geographic Information Systems (GIS), can be combined with the results of grid sampling to provide growers and land managers with information for land-use planning.

Additional information on proper soil sampling procedures can be obtained from the Extension agricultural educator or fertilizer fieldman in your county.

The authors—Robert L. Mahler, soil scientist, Moscow, and Terry A. Tindall, former Extension soil scientist, Twin Falls Research and Extension Center; both with the University of Idaho Department of Plant, Soil, and Entomological Sciences.

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APPENDIX H - ANNUAL REPORT TEMPLATE

CAFO ANNUAL REPORT FORM

Submit a copy of this form to the U.S. Environmental Protection Agency (EPA), Region 10, by March 1st of each year to report data for the previous calendar year:

EPA Region 10
Attn: NPDES Compliance Unit
Office of Compliance and Enforcement
1200 6th Avenue, Suite 900
Mail Stop: OCE-133
Seattle, WA 98101

Also submit a copy of the form to the Idaho State Department of Agriculture (ISDA):

ISDA
Division of Animal Industries
P.O. Box 790
Boise, ID 83701

The reporting period for the information list below is January 1 – December 31, _____________.

1. Facility Information

a. Name of CAFO (as listed in the facility's written notification of permit coverage)

____

b. Permit Number (as listed in the facility's written notification of permit coverage)

____

Contact Information (provide the name, telephone number, and email address of the person to be contacted about the information contained in this report)

c. Name: ____

d. Telephone: (____________)______________-_____________________________________

e. Email: ____

2. Animal Inventory

For each type of animal confined at this facility, whether in open confinement or housed under roof, list the type and maximum number confined during the year.

Animal Type	Number Confined

3. Manure, Litter, and Process Wastewater Generated and Transferred

Estimate the total amount of manure, litter, and process wastewater generated at this facility and transferred to other persons (i.e., for use on land not under the control of the permitted CAFO or other use or disposal not under the CAFO's control) during the reporting period. Indicate the units (tons or cubic feet) for manure and litter.

	Units	Amount Generated	Amount Transferred
Manure	☐ tons or ☐ ft^3		
Litter	☐ tons or ☐ ft^3		
Process Wastewater	☐ gallons or ☐ ft^3		

4. Production Area Discharges

For each discharge of manure, litter, or process wastewater from the production area during the reporting period, list the date, time, and approximate volume of the discharge.

Discharge date (mm/dd/yyyy)	Time (specify AM or PM)	Approximate volume (specify gallons or other units)

5. Nutrient Management Plan

Was the current version of the CAFO's NMP developed or approved by a certified nutrient management planner?

☐ Yes ☐ No

6. Acres for Land Application

a. Total number of acres for land application covered by the CAFO's nutrient management plan (NMP)

______________________ Acres

b. Total number of acres under the control of the CAFO used for land application of manure, litter, or process wastewater during the reporting period

______________________ Acres

7. Crops and Yields

For each field, list the field ID as listed in the CAFO's NMP, the actual crop(s) planted, and the actual yield for each crop harvested during the reporting period. Use multiple lines for double cropping or cover crops. In the last column, check the box to indicate whether the crop was seeded during the year prior to the period covered by this report. Use Table A.7 in Attachment A to list additional fields and crops if needed.

☐ Check here to indicate whether additional fields and crops are listed in Attachment A.

Field ID	Crop	Yield (specify units per acre, e.g., tons, bushels, cwt)	Seeded in previous year?
			▣
			▣
			☐
			☐
			☐
			☐
			☐
			☐
			☐
			☐
			☐
			☐

8. Manure, Litter, and Process Wastewater Application

Provide the total amount of manure, litter, and process wastewater applied to each field during this reporting period. Indicate the units used for manure and litter. Also list the amount of plant-available nitrogen and phosphorus from manure, litter, and process wastewater applied to each field during the reporting period. Use Table A.8 in Attachment A to list additional fields if needed.

☐ Check here to indicate whether additional fields are listed in Attachment A.

Field ID	Manure applied (☐ tons/acre or ☐ ft^3/acre)	Litter applied (☐ tons/acre or ☐ ft^3/acre)	Wastewater applied (gallons/acre)	Nutrients applied* (pounds/acre)	
				PAN	P

*Total pounds of plant-available nitrogen (PAN) and phosphorus (P) applied per acre. For PAN, include NO_3, NH_4, and the portion of organic N applied (if any) that is expected to be available to the current crop, determined consistent with the annual nutrient budget.

9. Soil Sample Analyses

For each field, list the analytical results for the most recent soil analysis for pH, soil organic matter (SOM), nitrate (NO_3-N), ammonium (NH_4-N), and phosphorus (P). Include units. Use Table A.9 in Attachment A to list additional fields if needed.

☐ Check here to indicate whether additional fields are listed in Attachment A.

Field ID	pH	SOM	NO_3 N	NH_4 N	P

10. Manure, Litter, and Process Wastewater Sample Analyses

For each source of manure, litter, or process wastewater land applied during the reporting period, list the analytical results for the most recent analysis. Include units.

Source of manure or wastewater (e.g., storage structure)		NH_4 N	TKN	NO_3 N	P	☐ Total Solids or ☐ Dry Matter
	Units:					

11. Nutrient Budgets

For each field provide the calculated amount manure, litter, and process wastewater, as well as plant-available nitrogen and phosphorus to be applied (in lbs/acre), based on the annual nutrient budget included in the NMP. Indicate the units for manure and litter. Use Table A.11 in Attachment A to list additional fields if needed.

☐ Check here to indicate whether additional fields are listed in Attachment A.

Field ID	Manure (☐ tons/acre or ☐ ft^3/acre)	Litter (☐ tons/acre or ☐ ft^3/acre)	Wastewater (gallons/acre)	Nutrients * (pounds/acre)	
				PAN	P

*Total pounds of plant-available nitrogen (PAN) and phosphorus (P) planned per acre. For PAN, include NO_3, NH_4, and the portion of organic N applied (if any) that is expected to be available to the current crop, from the annual nutrient budget.

12. Certification

Print the form and sign the certification statement below before submittal.

I certify under penalty of law that this document and all attachments were prepared under my direction or supervision in accordance with a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing violations.

____

Name of Certifying Official (print or type)

____

Signature

____

Date Signed

NOTE: This report must be signed and certified by a responsible corporate officer (corporation), a general partner (partnership), or the proprietor (sole proprietorship). The report may be signed by a duly authorized representative of the corporate officer, general partner, or proprietor if:

i. The authorization is made in writing by the corporate officer, general partner, or proprietor, and
ii. The authorization specifies either an individual or a position having responsibility for the overall operation of the regulated facility or activity, or an individual or position having overall responsibility for environmental matters for the company; and
iii. The written authorization is submitted to the Director of EPA Region 10’s Office of Compliance and Enforcement.

Attachment A – Additional Data Tables

Use the tables below if additional rows are needed to provide the information requested in the form.

Table A.7. Crops and Yields

Field ID	Crop	Yield (specify units per acre, e.g., tons, bushels, cwt)	Seeded in previous year?
			☐
			☐
			☐
			☐
			☐
			☐
			☐
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Field ID	Crop	Yield (specify units per acre, e.g., tons, bushels, cwt)	Seeded in previous year?
			☐
			☐
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			☐

A.8. Manure, Littler, and Process Wastewater Application

Field ID	Manure applied (☐ tons/acre or ☐ ft^3/acre)	Litter applied (☐ tons/acre or ☐ ft^3/acre)	Wastewater applied (gallons/acre)	Nutrients applied* (pounds/acre)	
				PAN	P

Field ID	Manure applied (☐ tons/acre or ☐ ft^3/acre)	Litter applied (☐ tons/acre or ☐ ft^3/acre)	Wastewater applied (gallons/acre)	Nutrients applied* (pounds/acre)	
				PAN	P

A.9. Soil Sample Analysis

Field ID	pH	SOM	NO_3 N	NH_4 N	P

Field ID	pH	SOM	NO_3 N	NH_4 N	P

A.11. Nutrient Budgets

Field ID	Manure (☐ tons/acre or ☐ ft^3/acre)	Litter (☐ tons/acre or ☐ ft^3/acre)	Wastewater (gallons/acre)	Nutrients * (pounds/acre)	
				PAN	P

Field ID	Manure (☐ tons/acre or ☐ ft^3/acre)	Litter (☐ tons/acre or ☐ ft^3/acre)	Wastewater (gallons/acre)	Nutrients * (pounds/acre)	
				PAN	P

APPENDIX I - IDAHO PHOSPHORUS SITE INDEX

The Phosphorus Site Index:

A Systematic Approach to Assess the Risk of Nonpoint Source Pollution of Idaho Waters by Agricultural Phosphorus

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2017

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INTRODUCTION

Why is phosphorus a concern for Idaho?

Water quality in Idaho has been negatively impacted by the inputs of nutrients from both point and nonpoint sources. The two nutrients of greatest concern are nitrogen (N) and phosphorus (P). Efforts to reduce nutrient enrichment of ground and surface waters have become a high priority for state and federal agencies and a matter of considerable importance to all nutrient users and nutrient generators in the state. Two actions in particular highlight the importance of this issue in Idaho:

- Total Maximum Daily Load (TMDL) Program: Section 303(d) of the Federal Clean Water Act (CWA) of 1972 requires states to develop a list of water bodies that need pollution reduction beyond that achievable with existing control measures. These water bodies are referred to as “Water Quality Limited” and are compiled by each state on a “303(d) list”. States are required to develop a “total maximum daily load (TMDL)” for a number of pollutants, including nutrients for these “water quality limited” waters. A TMDL is defined as “the level of pollution or pollutant load below which a water body will meet water quality standards and thereby allow use goals such as drinking water supply, swimming and fishing, or shellfish harvesting”. In ID, approximately 36% of streams were identified as not meeting water quality standards. The TMDL for the upper and middle Snake River was set at 0.075 mg total P L^{-1}.

- Idaho Statute Title 37 Chapter 4 Section 37-40, passed in 1999 requires that all dairy farms shall have a nutrient management plan approved by the Idaho State Department of Agriculture. The nutrient management plan shall cover the dairy farm site and other land owned and operated by the dairy farm owner or operator. Nutrient management plans submitted to the department by the dairy farm shall include the names and addresses of each recipient of that dairy farm’s livestock waste, the number of acres to which the livestock waste is applied and the amount of such livestock waste received by each recipient. The information provided in this subsection shall be available to the county in which the dairy farm, or the land upon which the livestock waste is applied, is located. If livestock waste is converted to compost before it leaves the dairy farm, only the first recipient of the compost must be listed in the nutrient management plan as a recipient of livestock waste from the dairy farm. Existing dairy farms were required to submit a nutrient management plan to the department on or before July 1, 2001, and plans are required to be updated every 5 years.

What is a Phosphorus Site Index?

In the early 1990's the U.S. Department of Agriculture (USDA) began to develop assessment tools for areas with water quality problems. While some models such as the Universal Soil Loss Equation (USLE) for erosion, and Groundwater Loading Effects of Agricultural Management Systems (GLEAMS) for ground water pollution, were already being used to screen watersheds for potential agricultural impacts on water quality, there was no model considered suitable for the field-scale assessment of the potential movement of P from soil to water. A group of scientists from universities and governmental agencies met in 1990 to discuss the potential movement of P from soil to water, and later formed a national work group (PICT: Phosphorus Index Core Team) to more formally address this problem. Members of the PICT soon realized that despite the many scientists conducting independent research on soil P, there was a lack of integrated research that could be used to develop the field scale assessment tool for P needed by USDA. Consequently, the first priority of PICT was a simple, field-based, planning tool that could integrate through a multi-parameter matrix, the soil properties, hydrology, and agricultural management practices within a defined geographic area, and thus to assess, in a relative way, the risk for P movement from soil to water. The initial goals of the PICT team were:

- *To develop an easily used field rating system (the* ***Phosphorus Site Index****) for Cooperative Extension, Natural Resource Conservation Service (NRCS) technical staff, crop consultants, farmers or others that rates soils according to the potential for P loss to surface waters*
- *To relate the P Site Index to the sensitivity of receiving waters to eutrophication.* This is a vital task because soil P is only an environmental concern if a transport process exists that can carry particulate or soluble P to surface waters where eutrophication is limited by P.
- *To facilitate adaptation of the P Site Index to site specific situations.* The variability in soils, crops, climates and surface waters makes it essential that each state or region modify the parameters and interpretation given in the original P Index to best fit local conditions.
- *To develop agricultural management practices that will minimize the buildup of soil P to excessive levels and the transport of P from soils to sensitive water bodies.*

The *P Site Index* is designed to provide a systematic assessment of the risks of P loss from soils, but does not attempt to estimate the actual quantity of P lost in runoff. Knowledge of this risk not only allows us to design best management practices (BMPs) that can reduce agricultural P losses to surface waters, but to more effectively prioritize the locations where their implementation will have the greatest water quality benefits.

It has long been known that P loss depends on not only the amount of P in or added to a soil but the transport processes that control soil and water movement from fields to waterways. Therefore, when assessing the risk of P loss from soil to water, it is important that we not focus strictly on measures of P, such as agronomic soil test P value. Rather a much broader, multi-disciplinary approach is needed; one that recognizes that P loss will vary among watersheds and soils, due to the rate and type of soil amendments used, and due to the wide diversity in soils, crop management practices, topography, and hydrology. At a minimum, any risk assessment process for soil P shall include the following:

- Characteristics of the P source (fertilizer, manure, biosolids) that influence its solubility and thus the potential for movement or retention of P once the source has been applied to a soil.

- The concentration and bioavailability of P in soils susceptible to loss by erosion.

- The potential for soluble P release from soils into surface runoff or subsurface drainage.

- The effect of other factors, such as hydrology, topography, soil, crop, and P source management practices, on the potential for P movement from soil to water.

- Any "channel processes" occurring in streams, field ditches, etc. that mitigate or enhance P transport into surface waters.

- The sensitivity of surface waters to P and the proximity of these waters to agricultural soils.

In summary, when resources are limited, it is critical to target areas where the interaction of P source, P management, and P transport processes result in the most serious risk of losses of P to surface and shallow ground waters. This is the fundamental goal of the *P Site Index*.

Phosphorus Site Index

The *P Site Index* has two separate components (Table 1). Part A characterizes the risk of P loss based on site-specific soil properties and hydrologic considerations. Part B characterizes the risk of P loss based on site-specific past and current nutrient management practices that affect the concentration of P in the soil (soil test P) and the potential for P loss due to management of inorganic (fertilizer) and organic (manures, composts, etc.) P sources. Parts A and B are summarized below, followed by a detailed discussion and descriptions of each component of the two parts. Generalized interpretations of the *P Site Index* values are given in Table 2.

Part A: Phosphorus Loss Potential Due to Site and Transport Characteristics

Surface transport mechanisms, i.e. soil erosion and runoff are generally the main mechanisms by which P is exported from agricultural fields to receiving waters. In some areas, leaching of P can also be a significant method of P export, especially in areas with artificial subsurface drainage (e.g. tiles, mole drains) high water tables, or shallow soils overlying basalt. Therefore, the considerations of the methods of P transport factors affecting these transport mechanisms are critical to an understanding of P losses from watersheds. Part A includes the following four factors: (i) soil erodibility; (ii) soil surface runoff index; (iii) leaching potential; and (iv) distance from edge of field to surface water.

Part B: Phosphorus Loss Potential Due to P Source and Management Practices

Phosphorus losses are also related to the amount and forms of P at a site which can potentially be transported to ground or surface waters. The main sources of P at any site that must be considered in assessing the risk of P loss are (i) soil P (particulate and dissolved), a reflection of natural soil properties and past management practices: and (ii) P inputs such as inorganic fertilizers and organic P sources (manures, composts, biosolids). Also of importance are the management practices used for all P inputs, such as the rate, method, and timing of fertilizer and manure applications, as these factors will influence whether or not P sources will have negative impacts on water quality. Part B includes the following three factors: (i) soil test P value; (ii) P applications rate; and (iii) P application method.

Table 1. The *Phosphorus Site Index* proposed for use in Idaho

Part A: Phosphorus loss potential due to site and transport characteristics

Characteristics	**Phosphorus Loss Rating**					**Field Value**
Soil Erodibility	Very Low **0**	Low **1**	Medium **2**	High **4**	Very High **8**	
Soil Surface Runoff Index – Surface Irrigated	No Runoff **0**	Water runs off less than 50% of the irrigation set time **4**		Water runs off more than 50% of the irrigation set time **8**		
Soil Surface Runoff Index – Sprinkler or Non-Irrigated	Very Low **0**	Low **1**	Medium **2**	High **4**	Very High **8**	
Leaching Potential	Low **1**		Medium **2**	High **4**		
Distance from Edge of Field to Surface Water	> 2,640’ **0**		200-2,640’ **2**	< 200’ **8**		

Part B: Phosphorus loss potential due to P source and management practices.

Characteristics	**Phosphorus Loss Rating**					**Field Value**
	Very Low	Low	Medium	High	Very High	
Soil Test P value	**0.05** x [Olsen Soil Test P (ppm)] **0.025** x Bray Soil Test P (ppm)]					
P Application Rate (lbs P_2O_5 applied per acre)	No Application **0**	< 60 **1**	60 – 150 **2**	151 – 300 **4**	>300 **8**	
P Application Method	None Applied **0**	Incorporated within 2 days or injected/banded below surface at least 3” **1**	Incorporated within 7 days of application **2**	Incorporated > 7 days or no incorporation when applied between February 16 and December 15 **4**	Application between December 16 and February 15 **8**	

Table 2. Generalized interpretations of the *P Site Index*.

P Site Index Value	Generalized Interpretation of the *P Site Index* Value
< 75	**LOW** potential for P movement from this site given current management practices and site characteristics. There is a low probability of an adverse impact to surface waters from P losses from this site. Nitrogen-based nutrient management planning is satisfactory for this site. Soil P levels and P loss potential may increase in the future due to N-based nutrient management planning.
75 - 150	**MEDIUM** potential for P movement from this site given current management practices and site characteristics. Phosphorus applications shall be limited to the amount expected to be removed from the field by crop harvest (crop uptake) or soil test-based P application recommendations. Testing of manure P prior to application is required.
151 – 225	**HIGH** potential for P movement from this site given the current management practices and site characteristics. Phosphorus applications shall be limited to 50% of crop P uptake. Testing of manure P prior to application is required.
> 225	**VERY HIGH** potential for P movement from this site given current management practices and site characteristics. No P shall be applied to this site.

Usage of the Idaho *Phosphorus Site Index*

The Phosphorus Site Index is a risk assessment tool to help determine the potential for off-site transport of phosphorus from agricultural fields. It is intended to be used as an integral and interactive part of the nutrient management plan to help guide applications of manure and fertilizers to minimize potential P losses from agricultural fields, and to identify fields that may require additional management to reduce P losses even when P applications are not planned. The PSI is also a valuable educational tool to assist producers in recognizing high risk areas, allowing them to focus conservation practices where they would be of most value.

A PSI rating shall be done for each field. Fields that do not receive manure and fertilizer shall only be assessed once until there is a planned application of P. The PSI shall be calculated prior to P application for each field using the planned management and P application rate along with current soil test P results. The risk rating will determine whether or not the P application on the field is allowable, given the current management. For example, if the risk assessment was completed with inputs for the field source factors (soil test P, planned P application rates, and planned application method and timing) and the field received a low rating, then application and management can continue according to plan. If, however, the risk rating is in a medium category, P application will be limited to crop uptake. If the risk rating is in a higher category, BMPs will need to be implemented on the field in order to reduce the potential for P loss, and/or the P application rates must be limited or prohibited in order to reduce the risk of P losses from the field. Producers can receive full credit for maximum of two (2) BPMs per field at any given time. In addition, testing of manure prior to application will be required for fields having a risk rating above low.

When a perennial crop such as alfalfa is part of the rotation, or when allowable manure application rates are below a reasonable application rate (<10 tons/acre for manure and <5 tons/acre for composted manure) then a producer may be allowed to apply up to a four year application rate at one time with no further application over the remainder of the time period that the nutrients have been allocated to. For example, a field with a medium rating beginning a four-year rotation of alfalfa could apply a maximum of four times the annual excepted crop P uptake rate in the first year with no additional P application for the next three years; or a field with a high rating beginning a four-year rotation of alfalfa could apply a maximum of two times the annual expected crop P uptake rate in the first year, and the following three years of alfalfa could receive no additional P.

Phosphorus Site Index:
Part A: Phosphorus Loss Potential Due to Site and Transport Characteristics

Soil Erosion

Phosphorus is strongly sorbed by soils, therefore erosion of soil materials dominates the movement of particulate P in landscapes (Bjorneberg et al., 2002; Leytem and Westermann, 2003). Up to 90% of the P transported from surface irrigated crops is transported with eroded sediment (Berg and Carter, 1980). In contrast to rainfall, irrigation is a managed event. Runoff and soil erosion should be minimal from properly managed sprinkler irrigation or drip irrigation. Water flowing over soil during surface irrigation will detach and transport sediment. Annual soil loss from furrow irrigated fields can range from less than 1 to greater than 100 tons per acre (Berg and Carter, 1980; Koluvek et al., 1993). Typically, greater than 90% of the P in surface irrigation runoff from clean-tilled row-crop fields is transported with eroded sediment. Conversely, when erosion is minimal from crops such as alfalfa and pasture, greater than 90% of the total P is dissolved in the runoff water (Berg and Carter, 1980). Total P concentration in surface irrigation runoff correlates directly with sediment concentration (Fitzsimmons et al., 1972, Westermann et al., 2001). Dissolved reactive P concentration in surface irrigation runoff, on the other hand, correlates with soil test P concentration, but not with sediment concentration (Westermann et al., 2001). During detachment and movement of sediment in runoff, the finer-sized fractions of source material are preferentially eroded. Thus, the P content and reactivity of eroded particulate material is usually greater than the source soil (Carter et al., 1974; Sharpley et al., 1985). Therefore, to minimize P loss in the landscape, it is essential to control soil erosion. Particulate P movement in the landscape is a complex function of rainfall, irrigation, soil properties affecting infiltration and runoff of irrigation/rainfall/snowmelt, and soil management factors affecting erosion. Numerous management practices that minimize P loss by erosion are available including filter strips, contour tillage, cover crops, use of polyacrylamide and impoundments or small reservoirs.

Soil erosion can be estimated from erosion prediction models such as the Universal Soil Loss Equation (USLE) or the Revised Universal Soil Loss Equation (RUSLE) for water erosion and Wind Erosion Equation (WEQ) for wind erosion. However, neither USLE nor RUSLE can accurately predict irrigation erosion. Therefore, the potential for soil erosion is based on the erodibility of the soil along with the predominant slope of the field. While this factor does not predict sediment transport and delivery to a water body, it does indicate the potential for sediment and attached P movement across the slope or unsheltered distance toward a water body.

For the *Phosphorous Site Index*, the potential for soil erosion loss is determined by the erodibility of the soil (K_w factor) along with the slope of the field Table 3.

Table 3. Soil erodibility factor

Kw factor - surface mineral layer Whole Soil	Slope Gradients				
	< 2%	2 – 5%	5 – 10%	10 – 15%	> 15%
<= 0.10 Very low erodibility	Very Low	Very Low	Very Low	Very Low	Low
0.11 – 0.20 Low erodibility	Very Low	Very Low	Very Low	Low	Medium
0.21 – 0.32 Moderate erodibility	Very Low	Low	Low	Medium	High
0.33 – 0.43 High erodibility	Low	Low	Medium	High	Very High
0.44 – 0.64 Very high erodibility	Low	Medium	High	Very High	Very High

All factors shall be determined by using the NRCS soil survey data (Web Soil Survey) with field verification of the predominant slope in the field. **The soil erodibility value will range from very low to very high and shall be assigned a value of 0 (very low) to 8 (very high) and used in the calculation of the *P Site Index* (Table 1).**

Runoff Index

Dissolved P (DP) is another important source of P that is transported in surface runoff. Dissolved P exists mainly in the form of orthophosphate, which is available immediately for uptake by algae and other aquatic plants. The first step in the movement of DP in runoff is the desorption, dissolution, and extraction of P from soils, crop residues, and surface applied fertilizer and manure (Sharpley et al., 1994). These processes occur as irrigation water, rainfall, or snowmelt water interacts with a thin layer of surface soil (0.04 to 0.12 in) before leaving the field as runoff or leaching downward in the soil profile (Sharpley, 1995). The soil test P content of surface soils has been found to be directly related to DP concentrations in runoff. Field studies have shown that P losses by surface runoff are greater when soil test P values are above the agronomic optimum range (Turner et al., 2004). Laboratory research has also shown that soils with high agronomic soil test P values are more likely to have high concentrations of soluble, desorbable, and bioavailable P (Paulter and sims, 2000; Sibbensen and Sharpley, 1997; Sims, 1998b). In furrow irrigation runoff, even soil with low soil test P can have high runoff DP concentrations (Westermann et al., 2001).

For the *P Site Index*, soil runoff index is determined differently for surface irrigated vs sprinkler irrigated or fields with no irrigation. For surface irrigated fields use Table 4, for sprinkler irrigated or non-irrigated fields use Table 5.

Table 4. Runoff index for surface irrigated fields:

Criteria	**Value**
Fields with no runoff	0
Fields with water running off less than 50% of the irrigation set time	4
Fields with water running off 50% or more of the irrigation set time	8

Table 5. Runoff index for sprinkler or non-irrigated fields.

Hydrologic Soil Group	Slope Gradients				
	< 2%	2 – 5%	5 – 10%	10 – 15%	> 15%
A: Low Runoff Potential	Very Low	Very Low	Low	Medium	High
B: Moderately Low Runoff Potential	Very Low	Low	Medium	High	High
C: Moderately High Runoff Potential	Very Low	Medium	Medium	High	Very High
D, A/D, B/D, C/D: High Runoff Potential	Low	Medium	High	Very High	Very High

All factors shall be determined by using the NRCS soil survey data (Web Soil Survey) with field verification of the predominant slope in the field.

Leaching Potential

While surface transport processes are the major contributing factors in P transport from soil to water in most cases, leaching of P can contribute significant amounts of P to surface waters in some situations, such as in areas where there is relatively flat topography, high water tables, shallow soils over basalt and any artificial drainage system (e.g. ditches, subsurface drains). While P leaching is typically considered to be small there is potential for significant movement of P through the soil profile when soil P values increase to very high or excessive values due to long-term over-fertilization or manuring (Sims et al., 1998). Whether this leached P will reach surface waters depends on the depth to which it has leached and the hydrology of the site in question. In flat areas with shallow groundwater levels, P loss by leaching through soils contributes significantly to the phosphorus loads of streams (Culley et al., 1983; Heathwaite & Dils, 2000). Soils that are poorly drained with high water tables have a higher possibility of P loss than soils that are well drained with deep water tables. Also soils that are shallow (<24") overlying basalt have a higher possibility of P loss than deeper soils. It is common in poorly drained soils to have water tables rise to the soil surface during the winter and spring months, during this time there is the potential for release of P into these drainage waters which can then be carried to nearby streams via subsurface flow. When soils are wet (during spring and late fall) or during time periods when irrigation exceeds ET, shallow soils can potentially leach P into the underlying basalt which can then be carried to surface waters (i.e. springs).

For the *P Site Index*, leaching potential shall be based on a USDA-NRCS categorization scheme based on the soil hydrologic group, predominant slope, saturated hydraulic conductivity, depth to high water table (HWT) and depth to bedrock Table 6. This information shall be determined through site inspection and the NRCS Web Soil Survey.

Table 6. Leaching potential.

Soil Leaching Potential	Hydrologic Group A	Hydrologic Group B	Hydrologic Group C	Hydrologic Group D
Low	NA	NA	NA	All **except**: • Apparent HWT • Depth to bedrock < 24"
Medium	• Slope > 6% • No apparent HWT and Depth to bedrock > 24"	• Slope > 6% or slope ≤ 6% with K_{sat} < 0.24 in/hr • No apparent HWT and Depth to bedrock > 24"	All **except**: • Apparent HWT • Depth to bedrock < 24"	NA
High	• Slope < 6% • Apparent HWT or Depth to bedrock < 24"	• Slope < 6% with K_{sat} > 0.24 in/hr • Apparent HWT or Depth to bedrock < 24"	• Apparent HWT • Depth to bedrock < 24"	• Apparent HWT • Depth to bedrock < 24"

High Water Table (HWT) is defined as a saturated layer < 24" from the surface anytime during the year.

Distance from Edge of Field to Surface Water

Another factor that affects the risk of P transport from soils to surface waters is the distance between the P source (i.e., the field) and the receiving waters. In some areas, the nearest water body may be a mile or more from the field being evaluated with no connectivity between the field and surface water; in these cases, even high levels of soil P may have low risk for nonpoint source pollution since the potential for transport to the water body is low. On the other hand, fields that are directly connected to surface water, such as surface irrigated fields with tailwater ditches, directly convey runoff water to surface water bodies through the return flow system. In these cases, even fields with low soil P can convey a large amount of both particulate and soluble P to surface waters.

The *P Site Index* shall take into account the distance from field edge to the nearest surface water body or other conveyance system connected to surface water (tailwater ditches, return flow ditches, laterals (Table 7).

Table 7. Distance from edge of field to surface water

Distance From Edge of Field to Surface Water	Value
> 2,640’ (0.5 mile)	0
200’ to 2,640’	2
< 200’	8

Best Management Practices for Reducing Transport Losses of P

There are several best management practices (BMPs) that can reduce the transport and loss of P from agricultural fields. In many situations, a combination of management practices is more effective than one BMP alone. To account for the effect of BMPs on the off-site transport of P from agricultural fields, a reduction in the overall transport factor is applied with varying BMPs that could be implemented on farm.

Contour farming, i.e. planting across the slope instead of up and down the hill can reduce soil erosion significantly. It is estimated that contour farming can reduce sediment loss by 20 to 50% depending on the slope of the field (Wischmeier and Smith, 1978). Keeping soil surfaces covered through cover or green manure crops can reduce losses of P by reducing erosion losses, however in some cases soluble P is either not affected or can increase. Sharpley and Smith (1991) reported reductions in total P losses of 54 to 66% with the use of cover crops while soluble P was reduced by 0 to 63%. The use of perennial crops such as alfalfa will also reduce the amount of sediment and therefore P leaving the field.

The installation of a dike or a berm that captures runoff from the field will prevent the loss of both soluble and total P. The effectiveness will depend on the holding capacity of the retention area. The use of drip irrigation vs. surface irrigation can significantly reduce the amount of runoff and therefore P that is transported off site. Mchugh et al. (2008) reported a 90% reduction in total P loss from fields with subsurface drip irrigation vs. furrow irrigation. Vegetative filter strips can trap sediment thereby reducing the offsite transport of P. Abu-Zreig et al. (2003) found that filter strips removed 31 to 89% of total P with filter length being the predominant factor affecting filter strip efficacy. The use of polyacrylamide (PAM) with irrigation has been shown to reduce losses of P from both furrow and sprinkler irrigated fields. Applying PAM with irrigation water or directly to furrow soil reduced soil erosion more than 90% on research plots (Lentz et al. 1992, Sojka and Lentz 1997, Trout et al. 1995). A conservative estimate for production fields is 50% to 80% reduction in soil loss. By reducing soil erosion, PAM treatment also reduced total P concentrations in runoff water (Lentz et al. 1998) but had little impact on dissolved P concentrations (Bjorneberg and Lentz, 2005). When used with sprinkler irrigation PAM has been shown to reduce P losses by 30%, but the effectiveness of PAM is minimal after three irrigations (Bjorneberg et al., 2000). Conservation tillage can also reduce soil erodibility and increase residue in furrows, both of which reduce soil loss to irrigation return flow (Carter and Berg 1991).

Sediment ponds remove suspended material from water by reducing flow velocity to allow particles to settle. Sediment ponds also remove nutrients associated with sediment particles. A large pond removed 65% to 75% of the sediment and 25% to 33% of the total P that entered the pond (Brown et al. 1981). A smaller percentage of total P was removed because only the P associated with sediment was removed and a large portion of the total P flowing into the pond was dissolved. Average total P concentrations significantly decreased by 13 to 42% in five ponds with 2 to 15 hour retention times, while dissolved P concentrations only decreased 7 to 16% in thee of the five ponds (Bjorneberg et al., 2015). Dissolved P concentration may actually be greater in pond outflow than pond inflow because P may continue to desorb from sediment as water flows through the pond. Implementing sediment control practices on an 800 ha (2,000 ac) irrigation tract in the Columbia Basin of Washington reduced P discharges by 50% (King et al. 1982). Tailwater recovery systems that capture runoff from furrow irrigated fields and pump it back for re-use as irrigation water should eliminate the loss of P from the system during the irrigation system, provided that no water leaves the field.

The reduction in transport factor due to the implementation of BMPs is listed in Table 8. For each BMP implemented, the transport factor shall be reduced by the amounts listed in the tables. Combinations of BMPs will reduce the transport factor sequentially, for example if you had a score of 36 and you implemented contour farming and a sediment basin your score would then be:

$$36 - (0.2 \times 36) = 28.8 - (0.6 \times 28.8) = \mathbf{11.5}$$

Table 8. Management practices to reduce the loss of P from fields.

Management Practice[1]	BMP Coefficient
Contour Farming	0.20
Cover & Green Manure Crop	0.30
Dike or Berm	0.40 or 0.80
Drip Irrigation	0.80
Filter Strip[3]	0.35
PAM - Furrow Irrigation	0.60
PAM – Sprinkler Irrigation	0.30
Residue Management/Conservation Tillage[4]	0.30
Sediment Basin	0.30
Tailwater Recovery & Pumpback Systems[2]	0.80
Established Perennial Crop[5]	0.50

[1]BMPs designed by NRCS can receive full credit; otherwise the BMPs must meet the requirements set out in the BMP definition section.

Phosphorus Site Index

Part A: Phosphorus Loss Potential Due to Site and Transport Characteristics

Sample Calculation

Part A: Phosphorus Loss Potential Due to Site and Transport Characteristics

Calculation of the Total Site and Transport Value for Part A of the P Site Index

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Once the values for soil erodibility, soil surface runoff, leaching potential and distance from edge of field to surface water have been obtained, these values shall be added together to obtain a total site and transport value (sum for Part A).

EXAMPLE:

A field located in the Magic Valley with a Portneuf silt loam soil, 1.5% slope, that is surface irrigated with water running off of the field >50% of the irrigation set time. Hydrologic soil group C, K_w factor for erosion is 0.43, K_{sat} 0.2 to 0.6 in/hr, depth to water table > 80". The surface irrigation runoff flows directly into the return flow system.

Soil Erodibility
Using Table 3, a K_w factor of 0.43 with a slope of < 2% puts this in the "Low" category, with a value of **1** (Table 1).

Soil Surface Runoff
This field is surface irrigated with runoff >50% of the set time, which is a value of **8** (Table 1).

Leaching Potential
This soil is in Hydrologic Group C without a high water table and is not a shallow soil, which is a medium risk (Table 6) with a value of **2** (Table 1).

Distance from edge of field to surface water
Since the runoff from this field flows directly into the return flow system the distance from edge of field to surface water is 0' which would be a value of **8** (Table 1).

All of the field values in Part A are then added together to obtain the Total Site Transport Value

1 + 8 + 2 + 8 = 19

**If this site had a tailwater recovery and pumpback system the transport value would be reduced by 80%*

19 – (19 x 0.8) = 3.8

Sum of Part A = 3.8

Phosphorus Site Index

Part B: Phosphorus Loss Potential Due to P Source and Management Practices

Soil Test Phosphorus

Phosphorus exists in many forms in the soil, both inorganic and organic. Major inorganic forms are soluble, adsorbed, precipitated and minerals containing Al, Ca, and Fe. Each "pool" of soil P has a characteristic reactivity and potential for movement in either soluble or particulate forms. Iron and aluminum oxides, prevalent in most soils, strongly adsorb P under acidic conditions; under alkaline conditions, adsorption and precipitation are fostered by the presence of free calcium ions and calcium carbonate (Leytem and Westermann, 2003). Microorganisms and plant uptake can immobilize inorganic P by incorporation into biomass. Conversely, as organic materials decompose, soluble P can be released and made available for transport. How much P exists in each of these pools is determined by soil type, mineralogy, microbial activity, cropping, and fertilization practices (with both inorganic and organic sources of P).

Past and present research has demonstrated that there is a positive relationship between soil test P and dissolved P in surface runoff; that is, as soil test P increases, dissolved P in runoff also increases (Westermann et al., 2001; Turner et al., 2004). However, this relationship varies with soil type, cropping system and nature of the runoff episode. In addition to impacting P levels in surface waters, soil test P has also been found to affect P loss in drainage waters (Heckrath et al., 1995; Sims et al, 1998). Thus, as soils are fertilized to levels exceeding the soil test P values considered optimum for plant growth, the potential for P to be released to soil solution and transported by surface runoff, leaching, subsurface movement and even groundwater increases. Therefore, it is important to include a measure of the current soil test P values in any risk assessment tool for P.

For the *P Site Index,* soil test P values are expressed in ppm of either Olsen or Bray P. Olsen P is the most common (and appropriate) soil test for Idaho's calcareous soils. However certain regions of the state with lower soil pH (<7.4) may also use the Bray method for determination of soil test P.

P Site Index Value For Table 1 = 0.05 x Olsen Soil Test P (ppm), or

P Site Index Value For Table 1 = 0.025 x Bray Soil Test P (ppm)

Phosphorus Application Rate

The addition of fertilizer P or organic P to a field will usually increase the amount of P available for transport to surface waters. The potential for P loss when fertilizers, manures, or other P sources are applied is influenced by the rate, timing, and method of application and by the form of the P source (e.g. organic vs. inorganic). These factors also interact with others, such as the timing and duration of subsequent irrigation, rainfall or snowmelt and the type of soil cover present (vegetation, crop residues, etc.; Sharpley et al., 1993). Past research has established a clear relationship between the rate of fertilizer P applied and the amount of P transported in runoff (Baker and Laflen, 1982; Romkens and Nelson, 1974). These studies showed a linear relationship between the amount of P added as superphosphate fertilizer and P loss in runoff. Using manure as the source of P, Westerman et al. (1983) also demonstrated a direct relationship between the quality of runoff water and the application of manure. Therefore, it is important that the amount of P added to a site is accounted for in any risk assessment for nonpoint source pollution by P.

The P application rate is the amount of P in pounds P_2O_5 per acre that is applied to the crop. The amount of P in manures shall be determined either by sample submission for testing by a certified laboratory or calculated using Table 10.

Table 9. Phosphorus application rate. Corresponding value to be included in the *P Site Index (Table 1).*

P Application Rate (lbs P_2O_5 applied per acre)	Value
No Application	0
< 60	1
60 - 150	2
151 - 300	4
> 300	8

Table 10. Phosphorus concentration of dairy manure

Dairy Manure Type	%P_2O_5 on a wet basis
Solid stacked	0.57
Composted	0.69
Lagoon liquid	0.03
Slurry	0.30

Phosphorus Application Method

Directly related to the amount of fertilizer and organic P sources applied to a field is the method and timing of the application. Baker and Laflen (1982) determined that the dissolved P concentrations of runoff from areas receiving broadcast fertilizer P average 100 times more than from areas where comparable rates were applied 5cm below the soil surface. Muller et al (1984) showed that incorporation of dairy manure reduced total P losses in runoff five-fold compared to areas with broadcast applications. Surface applications of fertilizers and manures decrease the potential interaction of P with the soil, and therefore increase the availability of P for runoff from the site. When fertilizers and manures are incorporated into the soil, the soil is better able to absorb the added P and thus decrease the likelihood of P loss. It is particularly important that fertilizers and manures are not surface applied during times when there is no plant growth, when the soil is frozen, during or shortly before periods of irrigation, intense storms or times of the year when fields are generally flooded due to snowmelt. The major portion of annual P loss in runoff generally results from one or two intense transport periods. If P applications are made during any of these high risk times, the percentage of applied P lost would be higher than if applications are made when runoff probabilities are lower (Edwards et al., 1992). Also, the time between application of P and the first runoff even is important. Westerman and Overcash (1980) applied manure to plots and simulated rainfall at intervals ranging from one to three days following manure application. Total P concentrations in the runoff were reduced by 90% by delaying the first runoff event for three days. In order to manage manure and fertilizers to decrease potential for P transport off-site, they must be either applied below the surface or incorporated into the soil within a short period of time and also be applied shortly before the growing season when available P can be utilized by the plant.

For the *P site Index*: To determine the field value for application methods of P sources, information about the time of year and method of application must be obtained from the nutrient user and assigned values using Table 11.

Table 11. Values of P application methods for inclusion in *P Site Index (Table 1)*.

P Application Method	Value
None applied	0
Incorporated within 2 day or injected/banded below surface at least 2”	1
Incorporated within 7 days of application	2
Incorporated >7 days or no incorporation when applied between February 16 and December 15	4
Application between December 16 and February 15	8

The Phosphorus Site Index
Part B: Phosphorus Loss Potential Due to P Source and Management Practices

Sample Calculation

Part B: Phosphorus Loss Potential Due to P Source and Management Practices

Calculation of the Total P Source and Management Value for Part B of the P Site Index

Once the values for soil test P, P application rate and P application method have been obtained, these values shall be added together to obtain a total P source and management practice value (sum for Part B).

EXAMPLE:
The field described for calculation of Part A has an Olsen soil test P value of 80 and solid manure is applied at 50 tons/acre in October and is not incorporated.

Soil Test P value
Olsen P of 80 x 0.05 = **4**

P Application Rate
50 tons/acre = (50 x 2,000 x (0.57/100)) = 570, this would be a value of **8**

P Application Method
Surface applied between Feb 16 and Dec 15 and not incorporated, this is a value of **4**

All of the field values in Part B are then added together to obtain the Total P Source and Management Value

4 + 8 + 4 = 16

Sum of Part B = 16

The Phosphorus Site Index

Calculation and Interpretation of the Overall P Loss Rating for a Site

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To find the overall *P Loss Rating* for a site (the final *P Site Index Value*), multiply the total site and transport value from Part A by the total management and source value from Part B as follows:

***P Site Index* = [Sum of Part A] x [Sum of Part B]**

Sum of Part A = 19

Sum of Part B = 16

***P Site Index* = 19 x 16 or 304**

A *P Site Index* value of **304** is classified as **Very High (See Tables 2 or 12)**

*If a tailwater recover with a pumpback system was used as a BMP then the P Site Index value would be

Sum of Part A = 3.8

Sum of Part B = 16

***P Site Index* = 3.8 x 16 or 61**

A *P Site Index* value of **61** is classified as **Low (See Tables 2 or 12)**

Interpretation of the *P Site Index* Value

Compare the *P Site Index* value calculated as show above with the ranges given in Table 12 for Low, Medium, High, or Very High risk of P loss. **It is important to remember that a P Site Index value is an indication of the degree of risk of P loss, not a quantitative prediction of the actual amount of P lost from a given field.** Fields in the "Low" category are expected to have a lower potential for P losses than fields in the "Medium P loss rating category, while fields in the "Medium P loss rating category are expected to have a relatively lower potential for P loss than fields in the "High" P loss rating category, and so on. The numeric values used in Table 12 to separate the various P loss categories are based on the best professional judgement of the individuals involved in the development of the *P Site Index* using data from fields and farms in Idaho where field evaluations were conducted in 2017.

Table 12. Interpretation of the *Phosphorus Site Index* Value

***P Site Index* Value**	**Generalized Interpretation of the *P Site Index* Value**
< 75	**LOW** potential for P movement from this site given current management practices and site characteristics. There is a low probability of an adverse impact to surface waters from P losses from this site. Nitrogen-based nutrient management planning is satisfactory for this site. Soil P levels and P loss potential may increase in the future due to N-based nutrient management planning.
75 - 150	**MEDIUM** potential for P movement from this site given current management practices and site characteristics. Phosphorus applications shall be limited to the amount expected to be removed from the field by crop harvest (crop uptake) or soil test-based P application recommendations. Testing of manure P prior to application is required.
151 – 225	**HIGH** potential for P movement from this site given the current management practices and site characteristics. Phosphorus applications shall be limited to 50% of crop P uptake. Testing of manure P prior to application is required.
> 225	**VERY HIGH** potential for P movement from this site given current management practices and site characteristics. No P shall be applied to this site.

Best Management Practice Definitions

Contour Farming. Farming sloping land in such a way that planting is done on the contour (perpendicular to the slope direction). This practice would apply to fields having a slope of 2% or greater. When converting from surface to sprinkler irrigation, this can be as simple as planting across the direction of the surface water flow. For other more complex settings, the maximum row grade shall not exceed half of the downslope grade up to a maximum of 4%. The minimum ridge height shall be 2 inches for row spacing greater than 10 inches and 1 inch for row spacing less than 10 inches.

Cover & Green Manure Crop. A cover and/or green manure crop is a close-growing crop primarily for seasonal protection and soil improvement. This practice reduces erosion by protecting the soil surface. Cover crops must be established (have vegetative cover over a minimum of 30% of the soil) by November 1 and must be maintained to within 30 days prior to planting the following crop. There shall be a minimum of 2 to 3 plants per square foot (about 100,000 plants/acre).

Dike or Berm. This practice applies to non-surface irrigated fields only and is comprised of an embankment to retain water on the field. The dike or berm must be engineered to retain runoff from a 25 year 24 hour storm event (0.8 BMP coefficient) or from 1 inch of runoff from the field (0.4 BMP coefficient).

Drip Irrigation. The credit for implementing this practice only applies when switching from surface irrigation to drip irrigation. A drip irrigation system shall be comprised of an irrigation system with orifices, emitters or perforated pipe that applies water directly to the root zone or soil surface. This practice efficiently applies water to the soil surface with low probability of runoff, as determined using the calculation in Table 5.

Filter Strip. A filter strip is a strip of permanent herbaceous dense vegetation in an area where runoff occurs. A filter strip can only be used on fields having < 10% slope. Ideally they are perpendicular to the flow of water and the runoff from the source area is such that flow through the strip is in the form of sheet runoff. Channeling of water through a filter strip will severely reduce its effectiveness. Filter strips must be a minimum of 20 feet in length. If the length of the field contributing runoff to the filter strip is greater than 1000 feet, then the minimum filter strip width shall be 50 feet. They must be irrigated and maintained so that there is a minimum of 75% vegetative cover. The seeding rate shall be sufficient to ensure that the plant spacing does not exceed 4 inches (about 16-18 plants per square foot).

Polyacrylamide (PAM). PAM is an organic polymer that stabilizes the soil surface when applied with irrigation water. This practice can increase infiltration and reduce soil erosion. The PAM must be a soluble anionic polyacrylamide. Standards for proper implementation of this BMP shall follow the NRCS Conservation Practice Standard "Anionic Polyacrylamide (PAM) Application" (450-CPS-1).

Residue Management/Conservation Tillage. is any method of soil cultivation that leaves the previous year crop residue cover on the soil surface (such as corn stock or wheat stubble).. Conservation tillage must result in crop residue remaining on at least 30% of the soil surface. This practice reduces soil erosion by protecting the soil surface.

Sediment Basin. A basin or pond constructed to collect and retain sediment. This practice slows the velocity of flowing water which allows sediment to settle in the basin. Sediment basin size must be at least 500 cubic feet per acre of drainage area (20,000 ft^3 for 40 acre field or 20 ft x 200 ft x 5 ft). The length-to-width ratio shall be 2 to 1 or greater with a minimum depth of 3 feet. Sediment basins must be cleaned on an annual basis or more frequently.

Tailwater Recovery & Pumpback Systems. This practice applies to surface irrigated fields only. Design standards and management must follow the ASABE Engineering Practice Standard 408.3 "Surface Irrigation Runoff Reuse Systems". Irrigation runoff reuse systems have four basic components: 1) runoff collection and conveyance channels (tailwater ditches, drains), 2) storage reservoir (tailwater pit, pond, sump), 3) pumping plant (reuse, return, pumpback pump), and 4) delivery pipe (return, pumpback pipe). Runoff from irrigated fields is intercepted by a system of open channels or pipelines and conveyed by gravity to a storage reservoir or pumping plant. Capacity of the channels and pipelines shall be sufficient to convey the maximum expected runoff rate from irrigation. Also, the collection system must be able to safely convey or bypass runoff from precipitation. Reuse systems designed to capture 50% of the application volume will usually capture a large percentage of the total irrigation runoff.

Established Perennial Crop. This is a crop that is grown for more than one year. Perennial crop is considered to be "established" the season after it was seeded.

References

Abu-Zreig, M., R. Rudra, H.R. Whiteley, M.N. Lalonde, and N.K. Kaushik. 2003. Phosphorus removal in vegetated filter strips. J. Environ. Qual. 32:613-619

Baker, J.L., and J.M. Laflen. 1982. Effect of crop residue and fertilizer management on soluble nutrient runoff losses. Trans. ASAE 25:344-348.

Berg, R.D., and D.L. Carter. 1980. Furrow erosion and sediment losses on irrigated cropland. Journal of Soil and Water Conservation 35:267-270.

Bjorneberg, D.L. and Aase, J.K. and Westermann, D.T. (2000) Controlling sprinkler irrigation runoff, erosion, and phosphorus loss with straw and polyacrylamide. Transactions of the ASAE. 43(6):1545-1551.

Bjorneberg, D.L., D.T. Westermann, and J.K. Aase.2002. Nutrient losses in surface irrigation runoff. J. Soil Water Cons. 57:524-529.

Brown, M.I, JA. Bondurant, and C.E. Brockway. 1981. Ponding surface drainage water for sediment and phosphorus removal. Transactions of the ASAF 24:1478- 1481.

Carter, D.L., and R .D. Berg. 1991. Crop sequences and conservation tillage to control irrigation furrow erosion and increase farmer income. Journal of Soil and Water Conservation 46:139-142.

Carter, D.L., M.J. Brown, C.W. Robbins, and JA. Bondurant. 1974. Phosphorus associated with sediments in irrigation and drainage waters for two large tracts in southern Idaho. Journal of Environmental Quality 3:287-291.

Culley, J.L.B., Bolton, E.F. & Bernyk, V. 1983. Suspended solids and phosphorus loads from a clay soil: I. Plot studies. Journal of Environmental Quality, 12, 493–498.

Edwards, D.R., T.C. Daniel, and O. Marbun. 1992. Determination of best timing for poultry waste disposal: A modeling approach. Wat Res. Bul. 28:487-494.

Fitzsimmons, D.W., G.C. Lewis, D.V. Naylor, and J.R. Busch. 1972.Nitrogen, phosphorous and other inorganic materials in waters in a gravity-irrigated area. Transactions of the ASAE 15:292-295.

Heckrath, G., P.C. Brooks, P.R. Poulton, and K.W. T. Gouliding. 1995. Phosphorus leaching from soils containing different phosphorus concentrations in the Broadbalk experiment. J. Environ. Qual. 24:904-910.

Heathwaite, A.L. & Dils, R.M. 2000. Characterising phosphorus loss in surface and subsurface hydrological pathways. Science of the Total Environment, 251–252, 523–538.

King, LG., B.L. McNeal, F.A. Ziari, S.C. Matulich, and JP Law. 1982. On-farm improvements to reduce sediment and nutrients in irrigation return flow. Washington State University completion report for Grant No. R-805527 from the R .S. Kerr Environmental Research Laboratory. U.S. Environmental Protection Agency, Ada, OK. 193 pp.

Koluvek, P.K., K.K. Tanji, and T.J. Trout. 1993. Overview of soil erosion from irrigation. Journal of Irrigation and Drainage Engineering 119:929-946.

Lentz, R .D., I. Shainberg, R .E. Sojka, and D.L. Carter. 1992. Preventing irrigation furrow erosion with snail applications of polymers Soil Science Society of America Journal 56:1926-1932.

Lentz, R.D., R.E. Sojka, and C.W. Robbins 1998. Reducing phosphorus losses from surface-irrigated fields Emerging polyacrylamide technology. Journal of Environmental Quality 27:305-312.

Leytem, A.B. and Westermann, D.T. (2003) Phosphate sorption by Pacific Northwest calcareous soils. Soil Sci. 168:368-375.

Mchugh, A.D., S. Bhattarai, G. Lotz, and D.J. Midmore. 2008. Effects of subsurface drip irrigation rates and furrow irrigation for cotton grown on a vertisol on off-site movement of sediments, nutrients and pesticides. Agron. Sustain. Dev. 28:507-519.

Mueller, D.H., R.C. Wendt, and T.C. Daniel. 1984. Phosphorus losses as affected by tillage and manure application. Soil Sci. Soc. Am. J. 48:901-905.

Pautler, M.C., and J.T. Sims. 2000. Relationships between soil test phosphorus, soluble phosphorus, and phosphorus saturation in Delaware soils. Soil Sci. Soc.Am. J. 64:765-773.

Romkens, J.M. and D.W. Nelson. 1974. Phosphorus relationships in runoff from fertilized soils. J. Environ. Qual. 3:10-13.

Sharpley, A.N. 1985. The selective erosion of plant nutrients in runoff. Soil Science Society of America Journal 49:1527-1534.

Sharpley, A.N. 1995. Identifying sites vulnerable to phosphorus loss in agricultural runoff. J. Environ. Qual. 24:947-951.

Sharpley, A.N., S.C. Chapra, R. Wedepohl, J.T. Sims, T.C. Daniel, and K.R. Reddy. 1994. Managing agricultural phosphours for the protection of surface waters: Issues and options. J. Environ. Qual. 23:437-451.

Sharpley, A.N. and S.J. Smith. 1991. Effect of cover crop on surface water quality. p. 41-49, *In* Cover Crop for Clean Water. W.L. Hargrov (Ed.) Soil and Water Conservation Society, Iowa, USA.

Sibbesen, E. and A.N. Sharpley. 1997. Setting and justifying upper critical limits of r phosphorus in soils. p. 151-176. *In* H. Tunney et al. (eds) Phosphorus loss from soil to water. CAB International, London.

Sims, J.T. 1998. Phosphorus and soil testing: Innovations for water quality protection. Comm. Soil Sci. Plant Anal. 29:1471-1489.

Sims, J.T., R.R. Simard, and B.C. Joern. 1998. Phosphorus losses in agricultural drainage: Historical perspectives and current research. J. Environ. Qual. 27:277-293.

Sojka, R .E., and R .D. Lentz. 1997. Reducing furrow irrigation erosion with polyacrylamide (PAM). Journal of Production Agriculture 10:47-52.

Trout, T.I, R .E. Sojka, and R .D. Lentz. 1995. Polyacrylamide effect on furrow erosion and infiltration. Transactions of the ASAF 38:761-765.

Turner, B.L., M.A. Kay, and D.T. Westermann. 2004. Phosphorous in surface runoff from calcareous arable soils of the semiarid Western United States. J. Environ. Qual. 33:1589-1946.

Westermann, D.T., D.L. Bjorneberg, J.K. Aase, and C.W. Robbins. 2001. Phosphorus losses in furrow irrigation runoff. Journal of Environmental Quality 30:1009-1015.

Westerman, P.W., T.L. Donnely, and M.R. Overcash. 1983. Erosion of soil and poultry manure – a laboratory study. Trans ASAE 26:1070-1078.

Westerman, P.W. and M.R. Overcash. 1980. Shor-term attenuation of runoff pollution potential for land-applied swine and poultry manure. P. 289-292. In R.J. Smith et al. (eds.) Livestock waste – A renewable resource. Prox. 4th Int. Symp on Livestock Wastes, Amarillo TX, 15-17 Apr. ASAE, St. Joseph, MI.

Wischmeier, W.H. and D.D. Smith. 1978. Predicting rainfall erosion losses – A guide to conservation planning. USDA

NITROGEN MANAGEMENT PLAN WORKSHEET

NAME ______________________________

Crop Year (Harvested) ____________________

Field ID ______________________________

Acres ______________________________

Crop Nitrogen Management Planning	
1. Crop	
2. Production Unit	
3. Projected Yield (units/acre)	
4. N Recommended (lbs/acre)	
Post Production Actuals	
5. Actual Yield (units/acre)	
6. Total N Applied (lbs/acre)	
7. N Removed (lbs/acre)	
Notes:	
PSNT Test:	

N Applications/Credits	Recommended/ Planned N	Actual N
Manure/Organic Material N		
8. Available N in Manure/Compost (lbs/acre)		
Nitrogen Fertilizers		
9. Dry/Liquid N (lbs/acre)		
10. Foliar N (lbs/acre)		
11. Total Available N Applied (lbs/acre)		
Nitrogen Credits		
12. Available N in soil (lbs/acre)		
13. N in Irrigation Water (lbs/acre)		
14. Total N Credits (lbs/acre)		
15. Total N Applied & Available		

Certified By:	
Date:	

Instructions

1. This is the crop that is planted in the year for which the information is recorded.
2. This is the crop yield units ie. bushels, tons, cwt, etc.
3. Projected yield (units/acre). This is the yield that you are anticipating for this crop in this year.
4. N Recommended (lbs/acre). This is the amount of N recommended based on the projected yield.
5. Actual Yield (units/acre). The actual harvested yield on this field for this crop.
6. Total N Applied (lbs/acre). The actual amount of total N that was applied to this crop during this season from line 11.
7. N Removed (lbs/acre). The amount of N that was removed with the crop (calculated by summing all of the biomass removed multiplied by the tissue N concentration of the different biomass pools)
8. Available N in Manure/Compost (lbs/acre). This is the total amount of plant available N applied for the growing season including previous fall applications. Use Table 1 to determine the % PAN of total N in manure/compost/liquid/slurry etc.
9. Dry/Liquid N (lbs/acre). This is the total amount of N applied as fertilizer including starter fertilizer, broadcast applications, in season side-dress applications and any N applied with irrigation.
10. Foliar N (lbs/acre). This is the total amount of N applied as a foliar spray during the growing season.
11. Total Available N Applied (lbs/acre). This is the sum of blocks 8, 9 and 10.
12. Available N in soil (lbs/acre). This is determined from soil samples collected within 8 months of planting. It is preferential to collect a pre-plant soil sample within 3 weeks of planting for the most accurate accounting of N in soil. This must include soils from 0 to 12". The lbs/acre is calculated by multiplying the average ppm N ($NH_4 + NO_3$) in the 0 to 12" sample by 4. It is preferential to account for the N in the top 2' of soil. If you have soil samples from 0 to 12" and 12 to 24" you would multiply each sample by 4 and then add them together (0 to 12" ppm N x 4) + (12 to 24" ppm N x 4). Alternatively, if you only have a 0 to 12" soil sample you could multiply the ppm N x 8 to represent the first 2', however this is not as accurate.
13. N in irrigation water (lbs/acre). If irrigation water contains N, the N applied with irrigation water must be included.
14. Total N Credits (lbs/acre). This is the sum of blocks 12 and 13.
15. Total N Applied and Available. This is the sum of blocks 11 and 14.

Table 1. Plant available N in manure

Manure Source	N available (%)
Lagoon Liquid	80
Lagoon Slurry/Sludge	60
Solid Stacked Manure (corral)	30
Composted Manure	10

Appendix 10D Design and Construction Guidelines for Impoundments Lined with Clay or Amendment-treated Soil

Introduction

Waste storage ponds and treatment lagoons are used in agricultural waste management systems to protect surface and ground water and as a component in a system for properly utilizing wastes. Seepage from these structures has the potential to pollute surface water and underground aquifers. The principal factors determining the potential for downward and/or lateral seepage of the stored wastes are the:

- permeability of the soil and bedrock horizons near the excavated limits of a constructed waste treatment lagoon or waste storage pond
- depth of liquid in the pond that furnishes a driving hydraulic force to cause seepage
- thickness and permeability of horizons between the boundary of the lagoon bottom and sides to the aquifer or water table

In some circumstances, where permitted by local and/or State regulations, designers may consider whether seepage may be reduced from the introduction of manure solids into the reservoir. Physical, chemical, and biological processes can occur that reduce the permeability of the soil-liquid interface. Suspended solids settle out and physically clog the pores of the soil mass. Anaerobic bacteria produce by-products that accumulate at the soil-liquid interface and reinforce the seal. The soil structure can also be altered in the process of metabolizing organic material.

Chemicals in waste, such as salts, can disperse soil, which may also be beneficial in reducing seepage. Researchers have reported that, under some conditions, the seepage rates from ponds can be decreased by up to an order of magnitude (reduced 1/10th) within a year following filling of the waste storage pond or treatment lagoon with manure. Manure with higher solids content is more effective in reducing seepage than manure with fewer solids content. Research has shown that manure sealing only occurs when soils have a minimal clay content or greater. A rule of thumb supported by research is that manure sealing is not effective unless soils have at least 15 percent clay content for monogastric animal generated waste and 5 percent clay content for ruminant animal generated waste (Barrington, Jutras, and Broughton 1987a, 1987b). Manure sealing is not considered effective on relatively clean sands and gravels, and these soils always require a liner as described in the following sections.

Animal waste storage ponds designed prior to about 1990 assumed that seepage from the pond would be minimized by the accumulation of manure solids and a biological seal at the foundation surface. Figure 10D–1 shows one of these early sites, where the soils at grade were somewhat permeable sands. Monitoring wells installed at some sites with very sandy soils showed that seepage containing constituents from the pond was still occurring even after enough time had passed that manure sealing should have occurred.

This evidence caused U.S. Department of Agriculture (USDA) Natural Resources Conservation Service (NRCS) engineers to reconsider guidance on suitable soils for siting an animal waste storage pond. In the late 1980s guidance was developed that designs should not rely solely on the seepage reduction that might occur from the accumulation of manure solids in the bottom and on the sides of the finished structure. That initial design document was entitled "South National Technical Center (SNTC) Technical Guide 716." It suggested that if any of four site conditions were present at a proposed structure location, a clay liner or other method of reducing seepage would be used in NRCS designs. A few revisions were made, and the document was re-issued in September 1993.

Figure 10D–1 Animal waste storage pond constructed before the implementation of modern design guidelines

NRCS was reorganized in 1994, and guidance in old SNTC documents was not part of the revised document system of the Agency. Consequently, the 716 document was revised considerably, and the revised material was incorporated into appendix 10D of the Agricultural Waste Field Management Handbook (AWMFH) in October 1998. This 2008 version of appendix 10D continues to update and clarify the process of designing an animal waste storage pond that will meet NRCS-specified engineering design criteria and stated specified permeability requirements.

General design considerations

Limiting seepage from an agricultural waste storage pond has two primary goals. The first is to prevent any virus or bacteria from migrating out of the storage facility to an aquifer or water source. The second is to prevent the conversion of ammonia to nitrate in the vadose zone. Nitrates are very mobile once they are formed by the nitrification process. They can then accumulate significantly in ground water. The National drinking water standard for nitrate is 10 parts per million, and excessive seepage from animal waste storage ponds could increase the level of nitrates in ground water above this threshold. Other constituents in the liquid manure stored in ponds may also be potential contaminants if the seepage from the pond is unacceptably high.

Defining an acceptable seepage rate is not a simple task. Appendix 10D recommends an allowable seepage quantity that is based on a historically accepted tenet of clay liner design, which is that a coefficient of permeability of 1×10^{-7} centimeters per second is reasonable and prudent for clay liners. This value, rightly or wrongly, has a long history of acceptability in design of impoundments of various types, including sanitary landfills.

Assuming that a typical NRCS waste impoundment has a maximum liquid depth of 9 feet, a compacted clay liner thickness of 1 foot, and a one order of magnitude reduction in seepage due to manure sealing effects, the resulting seepage associated with this historically accepted permeability rate is about 1×10^{-6} centimeters per second, or about 9,240 gallons per acre per day. However, the NRCS no longer recommends basing design decisions on the assumption that a full one order of magnitude reduction will be achieved. The following criteria should be used in assessing the adequacy of a compacted clay liner system:

- When credit for a reduction of seepage from manure sealing (described later in the document) is allowed, NRCS guidance considers an acceptable initial seepage rate to be 5,000 gallons per acre per day. This higher value used for design assumes that manure sealing will result in at least a half order of magnitude reduction in the initial seepage. If State or local regulations are more restrictive, those requirements should be followed.
- If State or local regulations prohibit designs from taking credit for future reductions in seepage from manure sealing, then NRCS recommends the initial design for the site be based on a seepage rate of 1,000 gallons per acre per day. Applying an additional safety factor to this value is not recommended because it conservatively ignores the potential benefits of manure sealing.

One problem with basing designs on a unit seepage value is that the approach considers only unit area seepage. The same criterion applies for small and large facilities. More involved three-dimensional type analyses would be required to evaluate the potential impact of seepage on ground water regimes on a whole-site basis. In addition to unit seepage, studies for large storage facilities should consider regional ground water flow, depth to the aquifer likely to be affected, and other factors.

The procedures in appendix 10D to the AWMFH provide a rational approach to selecting an optimal combination of liner thickness and permeability to achieve a relatively economical, but effective, liner design. It recognizes that manipulating the permeability of the soil liner is usually the most cost-effective approach to reduce seepage quantity. While clay liners obviously allow some seepage, the limited seepage from a properly designed site should have minimal impact on ground water quality. Numerous studies, such as those done by Kansas State University (2000), have shown that waste storage ponds located in low permeability soils of sufficient thickness have a limited impact on the quality of ground water.

If regulations or other considerations require that unit seepage be less than 500 gallons per acre per day (1/56 inch per day), synthetic liners such as high-density polyethylene (HDPE), linear low-density polyethylene (LLDPE), ethylene propylene diene monomer (EPDM), or geosynthetic clay liners (GCL), concrete liners, or aboveground storage tanks may be more feasible and economical and should be considered. Figure 10D–2 shows a pond lined with a synthetic liner, figure 10D–3 shows a concrete-lined excavated pond, and figure 10D–4 shows an aboveground concrete tank. Above-ground tanks may be also constructed of fiberglass-lined steel. NRCS has significant expertise in the selection, specification, and construction of sites using these products in addition to clay liners. Guidance on these other technologies is contained in other chapters of the AWMFH.

Figure 10D–2 Pond with synthetic liner *(Photo credit NRCS)*

Figure 10D–3 Excavated animal waste storage pond with concrete liner *(Photo credit NRCS)*

Figure 10D–4 Aboveground storage tank for animal waste *(Photo credit Mitch Cummings, Oregon NRCS)*

Progressive design

Waste storage ponds and waste treatment lagoons are usually designed with specific objectives that include cost, allowable seepage, aesthetics, and other considerations. Designs are usually evaluated in a progressive manner, with less costly and simple methods considered first, and more costly and complex methods considered next. These design concepts should generally be considered in the order listed to provide the most economical, yet effective, design of these structures. The following descriptions cover details on design and installation of these individual design measures.

- The least expensive and least complex design is to locate a waste impoundment in soils that have a naturally low permeability and where horizons are thick enough to reduce seepage to acceptable levels. The site should also be located where the distance to the water table conforms to requirements of any applicable regulations.
- Soils underlying the excavated boundaries of the pond may not be thick enough or slowly permeable enough to limit seepage to acceptably low values. In this case, the next type of design often considered is a liner constructed of compacted clay or other soils with appropriate amendments. This type of liner may be constructed with soils from the excavation itself or soil may be imported from nearby borrow sources. If the soils require amendments such as bentonite or soil dispersants, the unit cost of the compacted liner will be significantly higher than for a liner that only requires compaction to achieve a satisfactorily low permeability.
- A synthetic liner may be used to line the impoundment to reduce seepage to acceptable levels. Various types of synthetic materials are available.
- A liner may be constructed of concrete, or a concrete or fiberglass-lined steel tank can be constructed above ground to store the wastes.

A useful tool in comparing design alternatives is to evaluate unit costs. Benefits of alternatives may then be compared against unit costs to aid in selecting a design alternative. Benefits may include reduced seepage, aesthetics, or other considerations. Many geomembrane suppliers may be able to provide rough cost estimates based on the size and locale of the site. In estimating the cost of a compacted clay liner, one should evaluate the volume of compacted fill involved in a liner of given thickness. Table 10D–1 illustrates a cost comparison for different thicknesses of compacted clay liners. If methods other than compacted clay liners are used, higher unit costs may apply (table 10D–2).

Table 10D–1 Cost comparisons of design options for compacted clay liner

Thickness of compacted liner (ft)	Number of cubic yards of fill per square foot (yd^3)	Assumed cost of compacted fill, per cubic yard ($)	Unit cost of stated thickness liner ($\$/ft^2$)
1.0	0.037037	3.00–5.00	0.11–0.19
1.5	0.055555	3.00–5.00	0.17–0.28
2.0	0.074074	3.00–5.00	0.22–0.37
3.0	0.111111	3.00–5.00	0.33–0.56

Table 10D–2 Cost comparison for other design options

Liner type	Unit costs ($\$/ft^2$)
Geosynthethic	0.50–1.25
Concrete, reinforced 5 inches thick	7.50–8.00

Soil properties

The permeability of soils at the boundary of a waste storage pond depends on several factors. The most important factors are those used in soil classification systems such as the Unified Soil Classification System (USCS). The USCS groups soils into similar engineering behavioral groups. The two most important factors that determine a soil's permeability are:

- The percentage of the sample which is finer than the No. 200 sieve size, 0.075 millimeters. The USCS has the following important categories of percentage fines:
  - Soils with less than 5 percent fines are the most permeable soils.
  - Soils with between 5 and 12 percent fines are next in permeability.
  - Soils with more than 12 percent fines but less than 50 percent fines are next in order of permeability.
  - Soils with 50 percent or more fines are the least permeable.
- The plasticity index (PI) of soils is another parameter that strongly correlates with permeability.

When considered together with percent fines, a grouping of soils into four categories of permeability is possible. The following grouping of soils is based on the experience of NRCS engineers. It may be used to classify soils at grade as an initial screening tool. Estimating permeability is difficult because so many factors determine the value for a soil. For *in situ* soils, the following factors, in addition to percent fines and PI, affect the permeability of the natural soils:

- The dry density of the natural soil affects the permeability. Soils with lower dry densities have higher percentage of voids (porosity) than more dense soils.
- Structure strongly affects permeability. Many clay soils, particularly those with PI values above 20, develop a blocky structure from desiccation. The blocky structure creates preferential flow paths that can cause soils to have an unexpectedly high permeability. Albrecht and Benson (2001) and Daniel and Wu (1993) describe the effect of desiccation on the permeability of compacted clay liners.
- While not considered in the USCS, the chemical composition of soils with clay content strongly affects permeability. Soils with a preponderance of calcium or magnesium ions on the clay particles often have a flocculated structure that causes the soils to be more permeable than expected based simply on percent fines and PI. Soils with a preponderance of sodium or potassium ions on the clay particles often have a dispersive structure that causes the soils to be less permeable than soils with similar values of percent fines and PI. The NRCS publication TR–28, Clay Minerals, describes this as follows:

  > *In clay materials, permeability is also influenced to a large extent by the exchangeable ions present. If, for example, the Ca (calcium) ions in a montmorillonite are replaced by Na (sodium) ions, the permeability becomes many times less than its original value. The replacement with sodium ions reduces the permeability in several ways. For one thing, the sodium causes dispersion (disaggregation) reducing the effective particle size of the clay minerals. Another condition reducing permeability is the greater thickness of water adsorbed on the sodium-saturated montmorillonite surfaces which diminishes the effective pore diameter and retards the movement of fluid water.*

- Alluvial soils may have thin laminations of silt or sand that cause them to have a much higher horizontal permeability than vertical permeability. This property is termed anisotropy and should be considered in flow net analyses of seepage.
- Other types of deposits may have structure resulting from their mode of deposition. Loess soils often have a high vertical permeability resulting from their structure. Glacial tills may contain fissures and cracks that cause them to have a permeability higher than might be expected based only on their density, percent fines and PI of the fines.

The grouping of soils in table 10D–3 is based on the percent passing the No. 200 sieve and PI of the soils. Table 10D–4 is useful to correlate the USCS groups to one of the four permeability groups.

Table 10D–3 Grouping of soils according to their estimated permeability. Group I soils are the most permeable, and soils in groups III and IV are the least permeable soils

Group	Description
I	Soils that have less than 20 percent passing a No. 200 sieve and have a PI less than 5
II	Soils that have 20 percent or more passing a No. 200 sieve and have PI less than or equal to 15. Also included in this group are soils with less than 20 percent passing the No. 200 sieve with fines having a PI of 5 or greater
III	Soils that have 20 percent or more passing a No. 200 sieve and have a PI of 16 to 30
IV	Soils that have 20 percent or more passing a No. 200 sieve and have a PI of more than 30

Table 10D–4 Unified classification versus soil permeability groups [1/]

Unified Soil Classification System Group Name	Soil permeability group number and occurrence of USCS group in that soil			
	I	II	III	IV
CH	N	N	S	U
MH	N	S	U	S
CL	N	S	U	S
ML	N	U	S	N
CL–ML	N	A	N	N
GC	N	S	U	S
GM	S	U	S	S
GW	A	N	N	N
SM	S	U	S	S
SC	N	S	U	S
SW	A	N	N	N
SP	A	N	N	N
GP	A	N	N	N

1/ ASTM Method D–2488 has criteria for use of index test data to classify soils by the USCS.
A = Always in this permeability group
N = Never in this permeability group
S = Sometimes in this permeability group (less than 10 percent of samples fall in this group)
U = Usually in this permeability group (more than 90 percent of samples fall in this group)

Permeability of soils

Table 10D–5 shows an approximate range of estimated permeability values for each group of soils in table 10D–3. The ranges are wide because the classification system does not consider other factors that affect the permeability of soils, such as the electrochemical nature of the clay in the soils. Two soils may have similar percent finer than the No. 200 sieves and PI values but have very different permeability because of their different electrochemical makeup. The difference can easily be two orders of magnitude (a factor of 100). The most dramatic differences are between clays that have a predominance of sodium compared to those with a preponderance of calcium or magnesium. High calcium soils are more permeable than high sodium soils.

Table 10D–5 summarizes the experienced judgment of NRCS engineers and generally used empirical correlations of other engineers. The correlations are for *in situ* soils at medium density and without significant structure or chemical content. Information shown in figure 10D–5 is also valuable in gaining insight into the probable permeability characteristics of various soil and rock types.

Some soils in groups III and IV may have a higher permeability than indicated in table 10D–5 because they contain a high amount of calcium. High amounts of calcium result in a flocculated or aggregated structure in soils. These soils often result from the weathering

Table 10D–5 Grouping of soils according to their estimated permeability. Group I soils are the most permeable and soils in groups III and IV are the least permeable soils.

Group	Percent fines	PI	Estimated range of permeability, cm/s	
			Low	High
I	< 20	< 5	3×10^{-3}	2
II	≥ 20	≤ 15	5×10^{-6}	5×10^{-4}
	< 20	≥ 5		
III	≥ 20	16 ≤ PI ≤ 30	5×10^{-8}	1×10^{-6}
IV	≥ 20	> 30	1×10^{-9}	1×10^{-7}

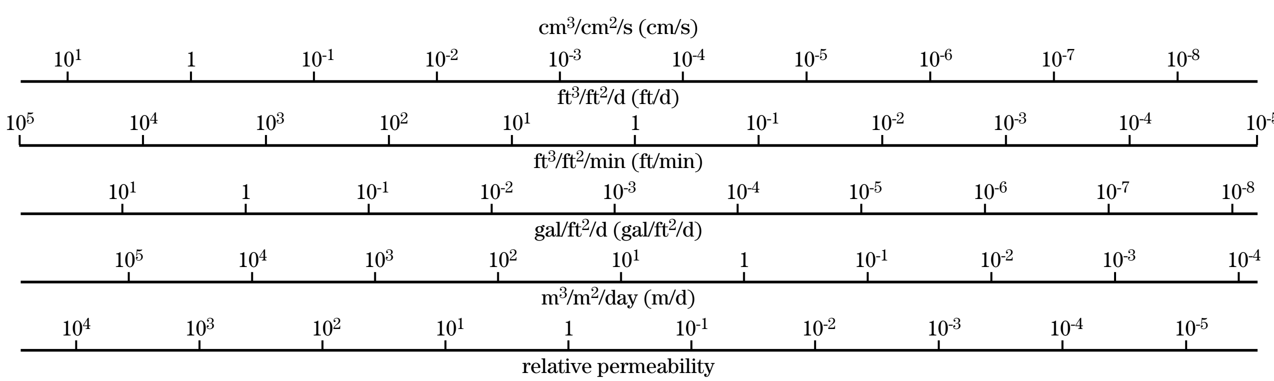
of high calcium parent rock, such as limestone. Soil scientists and published soil surveys are helpful in identifying these soil types.

High calcium clays should usually be modified with soil dispersants to achieve the target permeability goals. Dispersants, such as tetrasodium polyphosphate, can alter the flocculated structure of these soils by replacement of the calcium with sodium. Because manure contains salts, it can aid in dispersing the structure of these soils, but design should not rely on manure as the only additive for these soil types.

Soils in group IV usually have a very low permeability. However, because of their sometimes blocky structure, caused by desiccation, high seepage losses can occur through cracks that can develop when the soil is allowed to dry. These soils possess good attenuation properties if the seepage does not move through cracks in the soil mass. Soils with extensive desiccation cracks should be disked, watered, and recompacted to destroy the structure in the soils to provide an acceptable permeability. The depth of the treatment required should be based on design guidance given in the section **Construction considerations for compacted clay liners.**

High plasticity soils like those in group IV should be protected from desiccation in the interim period between construction and filling the pond. Ponds with intermittent storage should also consider protection for high PI liners in their design.

Figure 10D–5 Permeability of various geologic material (from Freeze and Cherry 1979)



	Very high	High	Moderate	Low	Very low
			Representative materials		
Soil types	Clean gravel (GP)	Clean sand, clean sand and gravel mixes (GW, GP, SW, SP, SM)	Fine sand, silty sand and gravel mixes (SP, SM, GM, GW–GM, GP–GM, SW–SM, SP–SM)	Silt, clay, and sand-silt-clay mixes, organic silts, organic clays (GM, GC, SM, SC, MH, ML, ML–CL, OL, OH, GW–GC, GC–GM, SW-SC, SP–SC, SC–SM)	Massive clay, no soil joints or other macropores (CL, CH)
			Any soil mass with joints, cracks or other macroporosity		
Rock types		Cavernous and karst limestones and dolomites, permeable basalts	Limestones, dolomites, clean sandstones	Interbedded sandstones, siltstones, and shales	Most massive rocks, unfractured and unweathered
			Fractured igneous and metamorphic rocks		

In situ soils with acceptable permeability

For screening purposes, NRCS engineers have determined that if the boundaries of a planned pond are underlain on the sides and bottom both by a minimum thickness of natural soil in permeability groups III or IV, the seepage from those ponds is generally low enough to cause no degradation of ground water. This assumes that soils do not have a flocculated structure. Unless State regulations or other requirements dictate a more conservative method of limiting seepage, it is the position of NRCS that special design measures generally are not necessary where agricultural waste storage ponds or treatment lagoons are constructed in these soils, provided that:

- at least 2 feet of natural soil in groups III or IV occur below the bottom and sides of the lagoon
- the soils are not flocculated (high calcium)
- no highly unfavorable geologic conditions, such as karst formations, occur at the site
- the planned depth of storage is less than 15 feet

Ponds with more than 15 feet of liquid should be evaluated by more precise methods. If the permeability and thickness of horizons beneath a structure are known, the predicted seepage quantities may be estimated more precisely. In some cases, even though a site is underlain by 2 feet of naturally low permeability soil, an acceptably low seepage rate satisfactory for some State requirements cannot be documented. In those cases, more precise testing and analyses are suggested. The accumulation of manure can provide a further decrease in the seepage rate of ponds by up to 1 order of magnitude as noted previously. If regulations permit considering this reduction, a lower predicted seepage can be assumed by designers.

Definition of pond liner

Compacted clay liner—Compacted clay liners are relatively impervious layers of compacted soil used to reduce seepage losses to an acceptable level. A liner for a waste impoundment can be constructed in several ways. When soil alone is used as a liner, it is often called a clay blanket or impervious blanket. A simple method of providing a liner for a waste storage structure is to improve a layer of the soils at the excavated grade by disking, watering, and compacting the soil to a thickness indicated by guidelines in following sections. Compaction is often the most economical method for constructing liners if suitable soils are available nearby or if soils excavated during construction of the pond can be reused to make a compacted liner. Soils with suitable properties can make excellent liners, but the liners must be designed and installed correctly. Soil has an added benefit in that it provides an attenuation medium for many types of pollutants. NRCS Conservation Practice Standard (CPS) 521D, Pond Sealing or Lining Compacted Clay Treatment, addresses general design guidance for compacted clay liners for ponds.

If the available soils cannot be compacted to a density and water content that will produce an acceptably low permeability, several options are available, and described in the following section. The options involve soil additives to improve the permeability of the soils and adding liners constructed of materials other than natural soils.

Treat the soil at grade with bentonite or a soil dispersant—Designers must be aware of which amendment is appropriate for adding to specific soils at a site. In the past, bentonite has been inappropriately used to treat clay soils and soil dispersants have inappropriately been used to treat sands with a small clay content.

The following guidelines are helpful and should be closely followed.

- ***When to use bentonite***—Soils in groups I and II have unacceptably high permeability because they contain an insufficient quantity of clay or the clay in the soils is less active than required. A useful rule of thumb is that soils amenable for treatment with bentonite will have PI values less than 7, or they will have less than 30 percent finer than the No. 200 sieve, or both.

  Bentonite is essentially a highly concentrated clay product that can be added in small quantities to a sand or slightly plastic silt to make it relatively low in permeability. CPS 521C, Pond Sealing or Lining Bentonite Treatment, covers this practice. NRCS soil mechanics laboratories have found it important to use the same type and quality of bentonite planned for construction in the laboratory permeability tests used to design the soil-bentonite mixture. Both the quality of the bentonite and how finely ground the product is before mixing with the soil will strongly affect the final permeability rate of the mixture. It is important to work closely with both the bentonite supplier and the soil testing facility when designing treated soil liners.

- **When to use soil dispersants**—Soils in groups III and IV may have unacceptably high permeability because they contain a preponderance of calcium or magnesium on the clay particles. Unfortunately, field or lab tests to determine when soils are likely to have this problem are not available. High calcium soils often occur when parent materials have excessive calcium. Many soils developed from weathering of limestone and gypsum may have this problem. See the section Design and construction of clay liners treated with soil dispersants, for more detail. Some States require the routine use of soil dispersants in areas that are known to have high calcium clay soils.

Use of concrete or synthetic materials such as geomembranes and geosynthetic clay liners (GCLs)—Concrete has advantages and disadvantages for use as a liner. A disadvantage is that it will not flex to conform to settlement or shifting of the earth. In addition, some concrete aggregates may be susceptible to attack by continued exposure to chemicals contained in or generated by the waste. An advantage is that concrete serves as an excellent floor from which to scrape solids. It also provides a solid support for equipment such as tractors or loaders.

Figure 10D–6 Agricultural waste storage impoundment lined with a geomembrane *(Photo credit NRCS)*

Geomembranes and GCLs are the most impervious types of liners if designed and installed correctly. Care must be exercised both during construction and operation of the waste impoundment to prevent punctures and tears. The most common defects in these liners arise from problems during construction. Forming seams in the field for geomembranes can require special expertise. GCLs have the advantage of not requiring field seaming, but overlap is required to provide a seal at the seams. Geomembranes must contain ultraviolet inhibitors if exposed to sunlight. Designs should include provision for protection from damage during cleaning operations. Concrete pads, double liners, and soil covering are examples of protective measures. Figure 10D–6 shows an agricultural waste storage facility with a geomembrane liner with ultraviolet inhibitors.

When a liner should be considered

A constructed liner may be required if any of the conditions listed are present at a planned impoundment.

Proposed impoundment is located where any underlying aquifer is at a shallow depth and not confined and/or the underlying aquifer is a domestic or ecologically vital water supply—State or local regulations may prevent locating a waste storage impoundment within a specified distance from such features. Even if the pond bottom and sides are underlain by 2 feet of naturally low permeability soil, if the depth of liquid in the pond is high enough, computed seepage losses may be greater than acceptable. The highest level of investigation and design is required on sites like those described. This will ensure that seepage will not degrade aquifers at shallow depth or aquifers that are of vital importance as domestic water sources.

Excavation boundary of an impoundment is underlain by less than 2 feet of suitably low permeability soil, or an equivalent thickness of soil with commensurate permeability, over bedrock—Bedrock that is near the soil surface is often fractured or jointed because of weathering and stress relief.

Many rural domestic and stock water wells are developed in fractured rock at a depth of less than 300 feet. Some rock types, such as limestone and gypsum, may have wide, open solution channels caused by chemical action of the ground water. Soil liners may not be adequate to protect against excessive leakage in these bedrock types. Concrete or geomembrane liners may be appropriate for these sites. However, even hairline openings in rock can provide avenues for seepage to move downward and contaminate subsurface water supplies. Thus, a site that is shallow to bedrock can pose a potential problem and merits the consideration of a liner. Bedrock at a shallow depth may not pose a hazard if it has a very low permeability and has no unfavorable structural features. An example is massive siltstone.

Excavation boundary of an impoundment is underlain by soils in group I—Coarse grained soils with less than 20 percent low plasticity fines generally have higher permeability and have the potential to allow rapid movement of polluted water. The soils are also deficient in adsorptive properties because of their lack of clay. Relying solely on the sealing resulting from manure solids when group I soils are encountered is not advisable. While the reduction in permeability from manure sealing may be one order of magnitude, the final resultant seepage losses are still likely to be excessive, and a liner should be used if the boundaries of the excavated pond are in this soil group.

Excavation boundary of an impoundment is underlain by some soils in group II or problem soils in group III (flocculated clays) and group IV (highly plastic clays that have a blocky structure)—Soils in group II may or may not require a liner. Documentation through laboratory or field permeability testing and computations of specific discharge (unit seepage quantities) is advised. Higher than normal permeability can occur when soils in group III or IV are flocculated or have a blocky structure. These are special cases, and most soils in groups III and IV will not need a liner provided the natural formation is thick enough to result in acceptable predicted seepage quantities.

These conditions do not always dictate a need for a liner. Specific site conditions can reduce the potential risks otherwise indicated by the presence of one of these conditions. For example, a thin layer of soil over high quality rock, such as an intact shale, is less risky than if the thin layer occurs over fractured or fissured rock. If the site is underlain by many feet of intermediate permeability soil, that site could have equivalent seepage losses as one underlain by only 2 feet of low permeability soil.

Some bedrock may contain large openings caused by solutioning and dissolving of the bedrock by ground water. Common types of solutionized bedrock are limestone and gypsum. When sinks or openings are known or identified during the site investigation, these areas should be avoided and the proposed facility located elsewhere. However, when these conditions are discovered during construction or alternate sites are not available, concrete or geosynthetic liners may be required, but only after the openings have been properly cleaned out and backfilled with concrete.

Specific discharge

Introduction

One way to require a minimal design at a site is to require a minimum thickness of a given permeability soil for a natural or constructed liner. An example of this would be to require that a clay liner constructed at a waste storage pond should be at least 1 foot thick, and the soil should have a coefficient of permeability of 1×10^{-7} centimeters per second or less.

However, using only permeability and thickness of a boundary horizon as a criterion ignores the effect of the depth of liquid on the predicted quantity of seepage from an impoundment. Using this approach would mean that the same design would be used for a site with 30 feet of water as one with 8 feet of water, for instance. A more rational method for stating a limiting design requirement is to compute seepage using Darcy's law for a unit area of the pond bottom.

A rational method of comparing design alternatives at a given site is needed. Such a method allows designers to evaluate the effect of changing one or more of the design elements in a site on the predicted seepage quantities. This document presents methods for computing the term "specific discharge" to use in comparing alternatives and to document a given design goal for a site. Specific discharge is defined as unit seepage.

It does not reflect the total seepage from a site, but rather provides a value of seepage per square unit area of pond bottom.

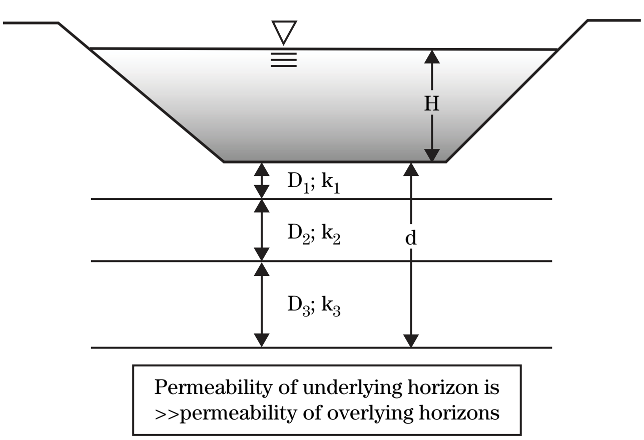
This document uses calculations of specific discharge to compare design alternatives and to determine if a given design meets regulatory requirements and guidelines. In some cases, the total seepage from a pond may be of interest, particularly for larger ponds in highly environmentally sensitive environments.

In those cases, more elaborate three-dimensional seepage computations using sophisticated finite-element computer programs may be warranted. It is outside the scope of this document to describe these types of analyses. Specialists who are experienced in using the complex software used for these computations should be consulted.

The parameters that affect the seepage from a pond with a natural or constructed clay liner are:

- The size of the pond—The total bottom area and area of the exposed sides of the pond holding the stored waste solids and liquids.
- The thickness of low permeability soil at the excavation limits of the pond—For design, the thickness of the soil at the bottom of the pond is often used because that is where seepage is likely to be highest. In some cases, however, seepage from the sides of the pond may also be an important factor. Seepage from the sides of ponds is best analyzed using finite element flow net programs. In some cases, rather than a single horizon, multiple horizons may be present.
- The depth of liquid in the pond—The depth of liquid at the top of the reservoir when pumping should commence is normally used.
- The coefficient of permeability of the soil forming the bottom and sides of the pond—In layered systems, an average or weighted permeability may be determined as shown in figure 10D–7.

Figure 10D–7 Conversion of permeability in layered profile to single value



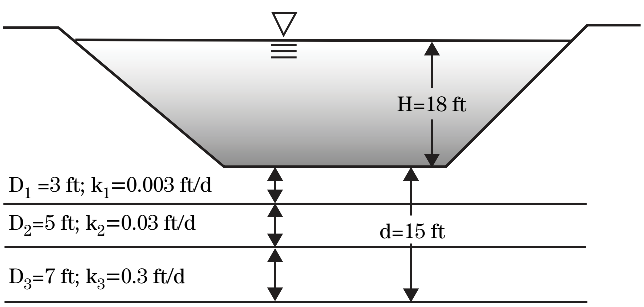
$$k_{average} = \frac{d}{\frac{D_1}{k_1} + \frac{D_2}{k_2} + \frac{D_3}{k_3}}$$

Example 10D–1 shows how to convert a multiple layer system into a single equivalent permeability. Using this method allows a designer to compute specific discharge when several horizons of constructed or natural soils occur below a site.

Example 10D–1

The excavated pond is underlain by 15 feet of soil consisting of three different horizons (fig. 10D–8). The thickness and permeability of each horizon is shown in the sketch. Compute the average vertical permeability of the 15 feet of soil.

Figure 10D–8 Idealized soil profile for example 10D–1



Solution

$$k_{average} = \frac{d}{\frac{D_1}{k_1} + \frac{D_2}{k_2} + \frac{D_3}{k_3}}$$

$$k_{average} = \frac{15}{\frac{3}{0.003} + \frac{5}{0.03} + \frac{7}{0.3}} = 0.0126 \text{ ft/d}$$

Definition of specific discharge

The term "specific discharge" has been coined to denote the unit seepage that will occur through the bottom of a pond with a finite layer of impervious soil. Specific discharge is the seepage rate for a unit cross-sectional area of a pond. It is derived from Darcy's law as follows. First, consider Darcy's law.

$$Q = k \times i \times A$$

For a pond with either a natural or constructed liner, the hydraulic gradient is the term i in the equation, and it is defined in figure 10D–9 as equal to (H+d)/d.

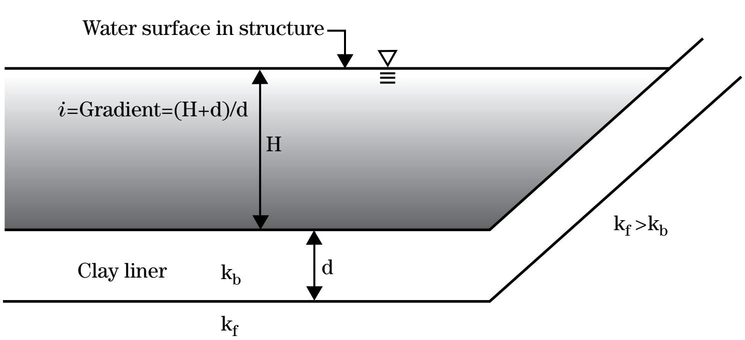
Given:
The Darcy's law for this situation becomes:

$$Q = k \times \frac{H+d}{d} \times A$$

where:

Q	= total seepage through area A	(L^3/T)
k	= coefficient of permeability (hydraulic conductivity)	($L^3/L^2/T$)
i	= hydraulic gradient	(L/L)
H	= vertical distance measured between the top of the liner and top of the liquid storage of the waste impoundment (fig. 10D–9)	(L)
d	= thickness of the soil liner (fig. 10D–9)	(L)
A	= cross-sectional area perpendicular to flow	(L^2)
L	= length	
T	= time	

Figure 10D–9 Definition of terms for clay liner and seepage calculations



Rearrange terms:

$$\frac{Q}{A} = \frac{k(H+d)}{d} \qquad (L/T)$$

By definition, unit seepage or specific discharge, is Q÷A. The symbol ν is used for specific discharge:

$$\nu = \frac{k(H+d)}{d} \qquad (L^3/L^2/T)$$

Specific discharge may be confused with permeability because the units are the same. In the metric system, specific discharge and permeability are often expressed in units of centimeters per second. The actual units are cubic centimeters of flow per square centimeter of cross section per second, but this reduces to centimeters per second. Specific discharge is different than permeability because specific discharge is an actual flow rate of liquid through a cross section of a soil mass, whereas permeability is a property of the soil mass itself. Permeability is independent of the hydraulic gradient in a particular site, whereas specific discharge accounts for both permeability of the soil and the gradient causing the flow, as illustrated in figure 10D–9. Because hydraulic gradient is dimensionless, the units of specific discharge and permeability are then the same.

Because specific discharge expressed as L/T has the same units as velocity, specific discharge is often misunderstood as representing the average rate or velocity of water moving through a soil body rather than a quantity rate flowing through the soil. Because the water flows only through the soil pores, the actual cross-sectional area of flow is computed by multiplying the soil cross section (A) by the porosity (n). The seepage velocity is then equal to the unit seepage or specific discharge, ν, divided by the porosity of the soil, n. Seepage velocity = (ν/n). In compacted liners, the porosity usually ranges from 0.3 to 0.5. The result is that the average linear velocity of seepage flow is two to three times the specific discharge value. The units of seepage velocity are L/T.

To avoid confusion between specific discharge and permeability, one possibility is to use different units for specific discharge than for the coefficient of permeability. Common units for permeability are recommended to be in feet per day or centimeters per second. Units for specific discharge should be in gallons per acre per day, acre-feet per acre per day, or acre-inches per acre per day.

To illustrate a typical computation for specific discharge, assume the following:

- A site has a liquid depth of 12 feet.
- The site is underlain by 2 feet of soil that has a coefficient of permeability of 1×10^{-6} centimeters per second (assume that a sample was obtained at the grade of the pond and sent to a laboratory where a flexible wall permeability test was performed on it).
- Compute the specific discharge, ν. First, the coefficient of permeability may be converted to units of feet per day by multiplying the given units of centimeters per second by 2,835.

$$k = \left(1\times10^{-6}\ \text{cm/s}\right)\times 2,835 = 0.002835\ \text{ft/d}$$

Then, the specific discharge ν is computed as follows:

$$\begin{aligned} \nu &= k \times \frac{H+d}{d} \\ &= 0.002835 \times \frac{12+2}{2} \\ &\cong 0.02\ \text{ft}^3/\text{ft}^2/\text{d} \\ &\cong 0.02\ \text{ft/d} \end{aligned}$$

Conversion factors for specific discharge are given in table 10D–6.

Table 10D–6 Conversion factors for specific discharge

To convert from	To units of	Multiply by
$ft^3/ft^2/d$	$in^3/in^2/d$	12
$ft^3/ft^2/d$	gal/acre/d	325,829
$in^3/in^2/d$	gal/acre/d	27,152.4
$in^3/in^2/d$	$cm^3/cm^2/s$	2.94×10^{-5}
$cm^3/cm^2/s$	gal/acre/d	9.24×10^{8}
$cm^3/cm^2/s$	$in^3/in^2/d$	34,015
$cm^3/cm^2/s$	$ft^3/ft^2/d$	2,835

To convert the computed specific discharge in the example into units of gallons per acre per day and cubic inches per square inch per day (in/d), use conversion factors given in table 10D–6.

- 0.02 foot per day×325,829 ≅ 6,500 gallons per acre per day
- 0.02 foot per day×12 = 0.24 cubic inch per square inch per day

A variety of guidelines have been used and regulatory requirements stated for specific discharge. Usually, guidelines require the specific discharge for a given waste storage structure to be no higher than a stated value. The following example demonstrates the unit seepage that will result from a typical size animal waste storage lagoon or storage pond with 2 feet of either very good natural soil or a very well constructed, 2-foot-thick clay liner in the bottom of the lagoon. A practical lower limit for the assumed permeability of a compacted clay or a very good natural liner is a coefficient of permeability equal to 5×10^{-8} centimeters per second. This is based on considerable literature on field and laboratory tests for compacted clay liners used in sanitary landfills.

The specific discharge for this ideal condition follows, assuming:

- The pond has a liquid depth of 15 feet.
- The site is underlain by 2 feet of soil (either a natural layer or a constructed clay liner) that has a coefficient of permeability of 5×10^{-8} centimeters per second
- Compute the specific discharge, ν. First, the coefficient of permeability is converted to units of feet per day by multiplying the given units of centimeters per second by 2,835. Then,

$$k = \left(1\times10^{-6}\ \text{cm/s}\right)\times 2{,}835 = 0.002835\ \text{ft/d}$$

Then, the specific discharge ν is computed as follows:

$$\begin{aligned}\nu &= k\times\frac{H+d}{d}\\ &= 1.42\times10^{-4}\ \text{ft/d}\times\frac{15\ \text{ft}+2\ \text{ft}}{2\ \text{ft}}\\ &\cong 0.0012\ \text{ft}^3/\text{ft}^2/\text{d}\\ &\cong 0.0012\ \text{ft/d}\end{aligned}$$

Converting this into units of gallons per acre per day:

$$0.0012\ \text{ft/d}\times 325{,}829 \cong 393\ \text{gal/acre/d}$$

Table 10D–7 lists typical specific discharge values used by State regulatory agencies. Requirements vary from State to State. Individual designers may regard minimum requirements as too permissive. Some States permit a designer to assume that the initial computed seepage rate will be reduced in the future by an order of magnitude by taking credit for a reduction in permeability resulting from manure sealing. Although the State or local regulations should be used in design for a specific site, the NRCS no longer recommends assuming that manure sealing will result in one order of magnitude reduction. A more conservative assumption described previously allows an initial seepage rate of 5,000 gallons per acre per day, which for the assumed typical site dimensions of 9 feet of liquid and 1 foot thickness of liner, assumes a one half order of magnitude reduction.

Table 10D–7 Typical requirement for specific discharge used by State regulatory agencies

Example specific discharge value	Equivalent value in gallons per acre per day
1/56 $in^3/in^2/d$	485
1/8 $in^3/in^2/d$	3,394
1/4 $in^3/in^2/d$	6,788
1×10^{-6} $cm^3/cm^2/s$	924

Design of compacted clay liners

If a site does not have a sufficient thickness of *in situ* low permeability soil horizons to limit seepage to an acceptably low value, a clay liner may be required. Some State regulations may also require a constructed clay liner regardless of the nature of the *in situ* soils at a site. Regulations sometimes require a specific thickness of a compacted soil with a documented permeability of a given value. An example of this is a State requirement that a waste storage pond must have in the bottom and sides of the pond at least 2 feet of compacted clay with a documented coefficient of permeability of 1×10^{-7} centimeters per second.

Clay liners may also be designed based on a stated allowable specific discharge value. Computations may be performed as detailed in following sections to determine a design that will meet a design specific discharge goal.

Detailed design steps for clay liners

The suggested steps for design of a compacted clay or amendment-treated liner are:

Step 1—Size the impoundment to achieve the desired storage requirements within the available construction limits and determine this depth or the height, H, of storage needed.

Step 2—Determine (from a geologic investigation) the thickness and permeability of horizons of natural clay underlying the bottom of the planned excavated pond. Investigate to a minimum of 2 feet below the planned grade of the pond or to depths required by State regulations, if greater. If natural low permeability horizons at least 2 feet thick or an equivalent thickness of soil with different permeability do not underlie the site, assume that a compacted clay liner (with or without amendments) will be constructed. The liner may be constructed of soils from the excavation if they are suitable for use, or soil may be imported from a nearby borrow source.

Step 3—Measure or estimate the permeability of the natural horizons or the compacted liner planned at the site. Use procedures shown in example 10D–1 to obtain a weighted permeability for the natural horizons.

Step 4—Compute the specific discharge using the values of head in the pond and thickness of natural horizons and their equivalent permeability in the specific discharge equation. If State or local regulations provide a required value for allowable specific discharge, design on the basis of those regulations. Currently, State regulations for specific discharge range from a low of about 500 gallons per acre per day (1/56 inch per day) to a high of about 6,800 gallons per acre per day (1/4 inch per day). If no regulations exist, a value of 5,000 gallons per acre per day may be used. If a designer feels that more conservative limiting seepage is advisable, that rate should be used in computations. It is seldom technically or economically feasible to meet a design specific discharge value of less than 500 gallons per acre per day using compacted clay liners or amendment-treated soil liners. To achieve lower values of unit seepage usually requires synthetic liners, concrete liners, or aboveground storage tanks.

Step 5—If the computed specific discharge meets design objectives, the site is satisfactory without additional design and may be designed and constructed.

Step 6—If the computed specific discharge at the site does not meet design objectives, use either method A or method B shown in following sections to design a compacted clay liner or a liner with soil amendment.

Notes to design steps:

- The calculated thickness of the soil liner required is sensitive to the relative values of soil permeability and the assumed allowable specific discharge value.
- The best and most economical way to reduce the required liner thickness is by reducing the soil's permeability. Liner permeability may be reduced by compacting soils to a higher degree, compacting them at a higher water content, and by using an appropriate additive such as bentonite or soil dispersants.
- By using higher compaction water contents and compacting soils to a high degree of saturation, permeability often can be reduced by a factor of 1/100.
- The liner soil must be filter compatible with the natural foundation upon which it is compacted. Filter compatibility is determined by criteria in NEH 633, chapter 26. As long as the liner soil will not pipe into the foundation, the magnitude of hydraulic gradient across the liner need not be limited.
- Filter compatibility is most likely to be a significant problem when a liner is constructed directly on top of very coarse soil, such as poorly graded gravels and gravelly sands.
- The minimum recommended thickness of a compacted clay liner is given in CPS 521D. The

minimum thickness varies with the depth of liquid in the pond.

- Clay liners constructed by mixing bentonite with the natural soils at a site should have a minimum thickness shown in CPS 521C. These minimum thicknesses are based on construction considerations rather than calculated values for liner thickness requirement from the specific discharge equations. In other words, if the specific discharge equations indicate a 7-inch thickness of compacted bentonite-treated liner is needed to meet suggested seepage criteria, the CPS 521C could dictate a thicker liner. That guidance should be considered in addition to the specific discharge computations.
- Natural and constructed liners must be protected against damage by mechanical agitators or other equipment used for cleaning accumulated solids from the bottom of the structure. Liners should also be protected from the erosive forces of waste liquid flowing from pipes during filling operations. CPSs provide guidance for protection.
- Soil liners may not provide adequate confidence against ground water contamination if foundation bedrock beneath the pond contains large, connected openings. Collapse of overlying soils into the openings could occur. Structural liners of reinforced concrete or geomembranes should be considered because the potential hazard of direct contamination of ground water is significant.
- Liners should be protected against puncture from animal traffic and roots from trees and large shrubs. The subgrade must be cleared of stumps and large angular rocks before construction of the liner.
- If a clay liner (or a bentonite-treated liner) is allowed to dry, it may develop drying cracks or a blocky structure. Desiccation can occur during the initial filling of the waste impoundment and later when the impoundment is emptied for cleaning or routine pumping. Disking, adding water, and compaction are required to destroy this structure created by desiccation. A protective insulating blanket of less plastic soil may be effective in protecting underlying more plastic soil from desiccation during these times the liner is exposed. CPSs address this important consideration.
- Federal and State regulations may be more stringent than the design guidelines given, and they must be considered in the design. Examples later in this section address consideration of alternative guidelines.

Two methods for designing constructed clay liner

Two methods for designing a clay liner are available. In method A, designers begin with an assumed or required value for allowable specific discharge. Using the depth of liquid storage in the pond and known or estimated values of the liner's coefficient of permeability, a required thickness of liner is computed. If the value obtained is unrealistic, different values for the liner permeability are evaluated to determine what values produce a desirable thickness of liner. CPSs also determine minimum liner thicknesses.

In method B, designers begin with a desired thickness of liner and an assumed or required value for specific discharge. Using the depth of liquid storage in the pond and the desired thickness of liner, a required coefficient of permeability for the liner is computed. If the value obtained is unrealistic, different values for the liner thickness are evaluated to determine what values produce an achievable permeability. Coordinating with soil testing laboratories is helpful in evaluating alternatives that can provide the required permeability for the liner.

Each of these methods is illustrated with detailed design examples as follows:

Method A—Using assumed values for the coefficient of permeability of a compacted clay based on laboratory tests of the proposed liner soil, compute the required thickness of a liner to meet the given specific discharge design goal. In the absence of more restrictive State regulations, assume an acceptable specific discharge of 5,000 gallons per acre per day.

The required thickness of a compacted liner can be determined by algebraically rearranging the specific discharge equation, as follows. Terms have been previously defined.

$$d = \frac{k \times H}{\nu - k}$$

Note: If the k value assumed for the liner is equal to or greater than the assumed allowable specific discharge, meaningless results are attained for d, the calculated thickness of the liner in the last equation. The reason is that the denominator would be zero, or a negative number. Another way of stating this is that the allowable specific discharge goal cannot be met if the liner soils have k values equal to or larger than the assumed allowable specific discharge, in consistent units. Note also that CPS 521D has requirements for minimum thickness of compacted clay liners. If the computed value for the required thickness is less than that given in CPS 521D, then the values in the CPS must be used.

Example 10D–2—Design a clay liner using method A

Given:
Site design has a required depth of waste liquid, H, in the constructed waste impoundment of 12 feet. A soil sample was obtained and submitted to a soil mechanics laboratory for testing. A permeability test on a sample of proposed clay liner soil resulted in a permeability value of 6.5×10^{-7} centimeters per second (0.00184 ft/d) for soils compacted to 95 percent of maximum Standard Proctor dry density at a water content 2 percent wet of optimum. The State requirement for the site requires a specific discharge no greater than an eighth of an inch per day. Compute the required thickness of liner to be constructed of soil having the stated permeability that will achieve this specific discharge.

Solution:
First, convert the required specific discharge into the same units as will be used for the coefficient of permeability. Using values for permeability of feet per day, convert the stated eighth of an inch per day specific discharge requirement into feet per day. To convert, divide an eighth by 12 to obtain a specific discharge requirement of 0.010417 foot per day. It is given that the k value at the design density and water content is 0.00184 foot per day. Calculate the required minimum thickness of compacted liner as follows:

The equation for required d is:

$$d = \frac{k \times H}{\nu - k}$$

Using English system units, substituting the given values for H and k, assuming an allowable specific discharge, ν, of 0.010417 foot per day, then

$$d = \frac{0.00184 \text{ ft/d} \times 12 \text{ ft}}{0.010417 \text{ ft/d} - .00184 \text{ ft/d}} = 2.6 \text{ ft}$$

CPS 521D requires a pond with a depth of water of 12 feet to have a minimum thickness liner of 1 foot, so the 2.6 foot requirement governs.

Method B—Using a given value for depth of liquid in the pond, assumed values for the thickness of a compacted clay based on construction considerations, CPS 521D requirements, State regulations, or the preference of the designer, compute the required permeability of a liner to meet the given specific discharge design goal. In the absence of more restrictive State regulations, assume an acceptable specific discharge of 5,000 gallons per acre per day. The required permeability of a compacted liner can be determined by algebraically rearranging the specific discharge equation as follows. Terms have been previously defined.

$$k = \frac{\nu \times d}{H + d}$$

If the computed value for the required permeability is less than 5×10^{-8} centimeters per second (1.4×10^{-4} ft/d), NRCS engineers' experience is that lower values are not practically obtainable and a thicker liner or synthetic liners should be used to achieve design goals.

Example 10D–3—Design a clay liner using method B

Given:
Site design has a required depth of waste liquid, H, in the constructed waste impoundment of 19 feet. CPS 521D requires a liner that is at least 18 inches (1.5 feet) thick. The site is in a State that allows NRCS design guidance of 5,000 gallons per acre per day to be used in the design. The NRCS guidance assumes that manure sealing will reduce this seepage value further and no additional credit should be taken.

Solution:
Step 1 First, convert the required specific discharge into the same units as will be used for the coefficient of permeability. Using values for permeability of feet per day, convert the stated 5,000

gallons per acre per day specific discharge requirement into feet per day. To convert using conversions shown in table 10D–6, divide 5,000 by 325,829 to obtain a specific discharge requirement of 0.0154 foot per day. The thickness of liner is given to be 1.5 feet. Calculate the required coefficient of permeability of the compacted liner as follows:

$$k = \frac{\nu \times d}{H + d}$$

Using English system units, substituting the given values for H of 19 feet and for d of 1.5 feet, assuming an allowable specific discharge, ν, of 0.0154 foot per day, then:

$$k = \frac{.0154 \text{ ft/d} \times 1.5 \text{ ft}}{19 \text{ ft} + 1.5 \text{ ft}}$$
$$= 1.1 \times 10^{-3} \text{ ft/d}$$

Convert to centimeters per second by dividing by 2,835.

$$k = \frac{1.1 \times 10^{-3} \text{ ft/d}}{2,835}$$
$$k = 4.0 \times 10^{-7} \text{ cm/s}$$

Step 2—The designer should coordinate testing with a laboratory to determine what combinations of degree of compaction and placement water content will result in this value of permeability or less. Design of the 1.5-foot-thick liner may proceed with those recommendations.

Construction considerations for compacted clay liners

Thickness of loose lifts

The permissible loose lift thickness of clay liners depends on the type of compaction roller used. If a tamping or sheepsfoot roller is used, the roller teeth should fully penetrate through the loose lift being compacted into the previously compacted lift to achieve bonding of the lifts. A loose lift thickness of 9 inches is commonly used by NRCS specifications. If the feet on rollers cannot penetrate the entire lift during compaction, longer feet or a thinner lift should be specified. A loose layer thickness of 6 inches may be needed for some tamping rollers that have larger pad type feet that do not penetrate as well.

Method of construction

Several methods are available for constructing a clay liner in an animal waste impoundment. Each has its advantages and disadvantages as described in following sections. A designer should consider the experience of local contractors and the relative costs of the methods in selecting the most appropriate design for a given site. The thickness of the planned soil liner, haul distance, planned side slopes for the pond, and other factors also guide a designer's decision on the best method to use.

Bathtub construction

This method of construction consists of a continuous thickness of soil compacted up and down or across the slopes. Figure 10D–10 shows the orientation of the lifts of a compacted liner constructed using this method, as contrasted to the stair step method, which is covered next. Figure 10D–11 shows two sites where the bathtub method of construction is being used.

This construction method has the following advantages over the stair-step method:

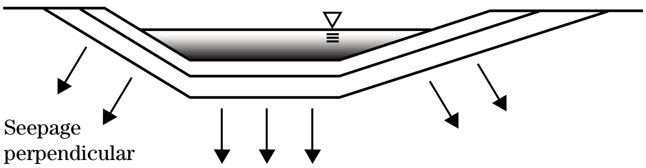
- The layers of compacted clay are oriented perpendicular to flow through the liner in this method. If the lifts making up the liner are not bonded well, the effect on seepage is minor, compared to the stair-step method.
- This method lends itself to constructing thinner lifts, which is more economical.

The bathtub construction method has the following disadvantages compared to the stair-step method:

- Side slopes must be considerably flatter than for the stair-step method, creating a pond with a larger surface area. A pond with a larger surface area has to store more precipitation falling on it, which could be considered an extra cost of the method.
- To permit equipment traversing up and down the slopes, slopes must be an absolute minimum of 3H:1V. Shearing of the soil by the equipment on steeper slopes is a concern. To prevent shearing of the compacted soil, the slopes of

Figure 10D–10 Methods of liner construction (after Boutwell 1990)

Bathtub construction



Stair-step construction

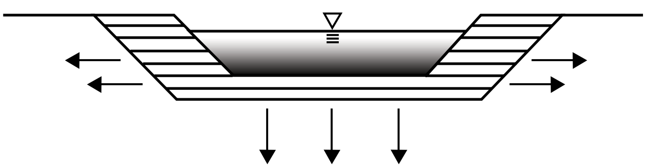


Figure 10D–11 Bathtub construction of clay liner *(photo courtesy of NRCS Virginia (top) and NRCS Nebraska (bottom))*

many compacted liners in ponds constructed using this method use 4H:1V slopes so that equipment will exert more normal pressure on the slope than downslope pressure.

Stair-step construction

The stair-step method of construction is illustrated in figure 10D–10. Construction of the liner consists of compacting lifts of soil around the perimeter of the liner in a stair-step fashion, finishing the job by shaving off some of the side liner and placing it in the bottom of the pond. This method of construction is required if the side slopes of the pond are any steeper than about 3H:1V. Advantages of this method of construction are:

- A thicker blanket, measured normal to the slope, will result compared to the bathtub method of construction (fig. 10D–10). This is a positive factor in seepage reduction.
- It allows steeper side slopes, and thus the surface area of the pond exposed to rainwater accumulation is smaller than a bathtub construction would permit.
- The thicker blanket reduces the impact of shrinkage cracks, erosive forces, and potential mechanical damage to the liner.
- Ponds constructed with this method are deeper for a given volume of waste than ponds constructed with the bathtub method, which favors anaerobic processes in the pond.

Disadvantages of the method are:

- This method may be more expensive than the bathtub method because the liner on the sides of the pond are thicker.
- Flow is parallel to the orientation of the layers forming the compacted liner on the pond sides. If care is not taken to obtain good bonding between lifts, seepage through the interface between lifts could be higher than expected.
- Contractors may be less familiar with this method of operation of equipment.

In the stair-step method of construction, the pond is first excavated. Borrow soil is then imported with a truck or scraper and spread in thin lifts (8 to 9 in thick) prior to compaction. Figure 10D–12a shows the first layer being constructed on the sides of the pond. This pond used a bentonite application. Each lift of soil is compacted with a sheepsfoot roller to obtain the desired dry density at the specified water content (fig. 10D–12b). The interior liner is constructed by bringing up lifts the full depth of the pond. Photo 10D–12c provides an overview of the stair-step process of constructing a clay liner in an animal waste storage pond. After the sides are constructed, some of the liner is shaved off and used to construct a liner in the bottom of the pond (fig. 10D–12c).

Soil type

Soils in groups III and IV are the most desirable for constructing a clay liner (table 10D–3). Some soils in group II may also be good materials for a clay liner, but definitely require laboratory testing to document their permeability characteristics. Soils in group I always require bentonite to form a liner with acceptably low permeability. Some soils in group II may also require bentonite to be an acceptable material for a liner. Some soils in groups III and IV require a soil dispersant to create an acceptably low permeability.

Classification

The most ideal soils for compacted liners are those in group III. The soils have adequate plasticity to provide a low permeability, but the permeability is not excessively high to cause poor workability. Group IV soils can be useful for a clay liner, but their higher plasticity index (PI greater than 30) means they are more susceptible to desiccation. If clay liners are exposed to hot dry periods before the pond can be filled, desiccation and cracking of the liner can result in an increase in permeability of the liner. A protective layer of lower PI soils is often specified for protection of higher PI clay liners to prevent this problem from developing.

Highly plastic clays like those in group IV are also difficult to compact properly. Special effort should be directed to processing the fill and degrading any clods in high plasticity clays to prevent this problem.

Size of clods

The size and dry strength of clay clods in soil prior to compaction have a significant effect on the final quality of a clay liner. Soil containing hard clayey clods is difficult to break down and moisten thoroughly. Adding water to the soil is difficult because water penetrates the clods slowly. High speed rotary pulverizers are sometimes needed if conditions are especially unfavorable. If soils containing large clay clods are

Figure 10D–12 Stair-step method *(Photo credit John Zaginaylo, PA, NRCS)*

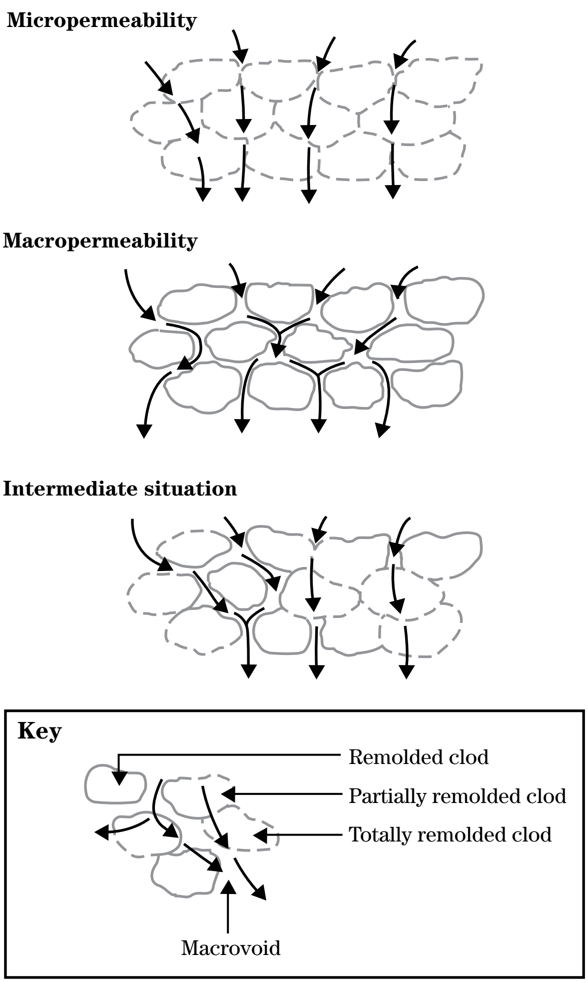
(a)

(b)

(c)

not treated properly, the resultant permeability will be much higher than might otherwise be true. Figure 10D–13 shows the structure that results from compacting soils containing clods that are not adequately broken down.

Figure 10D–13 Macrostructure in highly plastic clays with poor construction techniques (from Hermann and Elsbury 1987)



Natural water content of borrow

The water content of soils used to construct a clay liner is the most important factor in obtaining a low permeability liner for a given soil. If soils are too dry, they cannot effectively be compacted to a condition where their structure is acceptable and their permeability may be higher than desirable. Compacting a soil at the proper water content creates a structure that is most favorable to a low permeability. Adding water to compacted clay liners is an additional expense that must be considered. A good rule of thumb is that it requires about 3.2 gallons of water to increase the water content of a cubic yard of compacted soil by 1 percent.

Dry conditions in the borrow

If soils in the borrow area are dry, several problems may need to be addressed. If the soils are clays with relatively high plasticity (PI values greater than about 20), they are likely to be very cloddy when excavated. Water is slow to penetrate the clods and compaction is less likely to degrade clods if enough time has not elapsed between adding the water and compaction. More descriptions follow in subsequent sections, and figure 10D–13 illustrates how clods left in the compacted fill will likely cause the soil to have a higher than expected permeability.

If the water content of borrow soils is more than 3 or 4 percent drier than required for specified compaction conditions, consideration should be given to wetting the soils in the borrow prior to construction. Adding large amounts of water during processing on the fill is difficult and inefficient. Sprinklers can be set up in the borrow some time before construction is planned and then time will allow water to soak into the soils more thoroughly.

Wet conditions in the borrow

If the natural water content of the borrow soil is significantly higher than optimum water content, achieving the required degree of compaction may be difficult. A good rule of thumb is that a soil will be difficult to compact if its natural water content exceeds about 90 percent of the theoretical saturated water content at the dry density to be attained. The following procedure can help to determine if the soils in the borrow are too wet for effectively compacting them.

Step 1 Measure the natural water content of the soil to be used as a borrow source for the clay liner being compacted.

Step 2 Compute the highest dry density to which the soil can be compacted at this water content using the following equation, which assumes that the highest degree of saturation achievable is 90 percent:

$$\text{Achievable } \gamma_{dry} \text{ lb/ft}^3 = \frac{62.4}{\frac{w_n\%}{90} + \frac{1}{G_s}}$$

where:

$w_n(\%)$ = natural water content of borrow soils, %

G_s = specific gravity of the soil solids (dimensionless)

Specific gravity values are obtained by ASTM Standard Test Method D854. An average value for specific gravity is often assumed to be 2.68. However, soils with unusual mineralogy may have values significantly different. Soils with volcanic ash may have specific gravity values as low as 2.3, and soils with hematite in them may have values as high as 3.3, based on NRCS laboratory results.

Step 3 Perform a Standard Proctor (ASTM D698) compaction test on the same soil and determine the maximum dry density value. Compute the achievable degree of compaction by dividing the computed value of achievable dry density by the maximum Standard Proctor dry density.

Step 4 If the computed achievable degree of compaction is less than 95 percent, then drying of the sample will probably be required. In rare cases, compaction to a lower degree, such as 90 percent of Standard Proctor, at higher water contents will achieve an acceptably low permeability. Laboratory tests should be performed to evaluate whether a lower degree of compaction will result in an acceptable permeability value.

Note: The experience of NRCS engineers is that when the natural water content of a soil is more than 4 percent above optimum water content, it is not possible to achieve 95 percent compaction. Computations should always be performed, as this rule of thumb sometimes has exceptions. In most cases, drying clay soils by only disking is somewhat ineffective, and it is difficult to reduce their water content by more than 2 or 3 percent with normal effort. It may be more practical to delay construction to a drier part of the year when the borrow source is at a lower water content. In some cases, the borrow area can be drained several months before construction. This would allow gravity drainage to decrease the water content to an acceptable level.

Step 5 Another way of examining this problem is to assume that soils must be compacted to 95 percent of their Standard Proctor (ASTM D698) dry density and then compute the highest water content at which this density is achievable. Commonly, soils are difficult to compact to a point where they are more than 90 percent saturated. The following equation is used to determine the highest feasible placement water content at which the dry density goal is achievable:

$$\text{Highest placement w}(\%) = \frac{90(\%)}{100} \times \left[\frac{62.4}{\gamma_{dry} \text{ lb/ft}^3} - \frac{1}{G_s} \right]$$

Example 10D–4—Compute the achievable dry density of a potential borrow source

Given:

A borrow source is located and found to be in a desirable group III type soil. The soil has 65 percent finer than the No. 200 sieve and a PI of 18. The soil was sampled and placed in a water tight container and shipped to a soils laboratory. The natural water content of the soil was measured to be 21.8 percent. The lab also performed a specific gravity (G_s) test on the soil, and measured a value of 2.72. A Standard Proctor Test was performed on the sample and values for maximum dry density of 108.5 pounds per cubic foot and an optimum water content of 17.0 percent were measured.

Solution:

The maximum degree of compaction of this soil at the measured water content. If the soil is too wet to be compacted to 95 percent of maximum standard Proctor dry density, how much will it have to be dried to achieve compaction to 95 percent of maximum density?

$$\text{Achievable } \gamma_{dry} \text{ lb/ft}^3 = \frac{62.4}{\frac{w_n\%}{90} + \frac{1}{G_s}}$$

$$\text{Achievable } \gamma_{dry} \text{ lb/ft}^3 = \frac{62.4}{\frac{21.8\%}{90} + \frac{1}{2.72}} = 102.3 \text{ lb/ft}^3$$

Next, compute the achievable degree of compaction by dividing the achievable dry density by the maximum Standard Proctor dry density, expressed as a percentage. The achievable degree of compaction is then equal to 102.3 divided by 108.5×100=94.3 percent.

Now, determine how wet the sample could be and still achieve 95 percent compaction. Ninety-five percent of the maximum Standard Proctor dry density is 0.95×108.5=103.1 pounds per cubic foot. Substitute this value into the equation given:

$$\text{Highest placement w\%} = \frac{90}{100} \times \left[\frac{62.4}{\gamma_{dry} \text{ lb/ft}^3} - \frac{1}{G_S} \right]$$

$$\text{Highest placement w\%} = \frac{90}{100} \times \left[\frac{62.4}{103.1 \text{ lb/ft}^3} - \frac{1}{2.72} \right] = 21.4\%$$

This computation confirms the rule of thumb given that it is difficult to achieve 95 percent degree of compaction if the natural water content is greater than 4 percent above optimum. The stated value for optimum water content is 17.0 percent, so the rule of thumb says that if the natural water content exceeds 21.0 percent, achieving 95 percent degree of compaction will be difficult.

Methods of excavating and processing clay for liners

Clods in borrow soil

If borrow soils are plastic clays at a low water content, the soil will probably have large, durable clods. Disking may be effective for some soils at the proper water content, but pulverizer machines may also be required. To attain the highest quality liner, the transported fill should be processed by adding water and then turned with either a disk or a high-speed rotary mixer before using a tamping roller. Equipment requirements depend on the strength and size of clods and the water content of the soil.

Placement of lifts

Individual lifts of soil usually consist of an equipment width (often about 8 to 10 feet wide) layer of soil about 6 inches thick, after compaction. These lifts should be staggered to prevent preferential flow along the inter-lift boundaries. Figure 10D–14(a) shows the preferred way of offsetting the lifts. Figure 10D–14(b) shows a method that should be avoided. Bonding between the 6-inch lifts is also important so that if water does find its way down the boundary between two lanes of compacted soil that it cannot flow laterally and find the offset boundary.

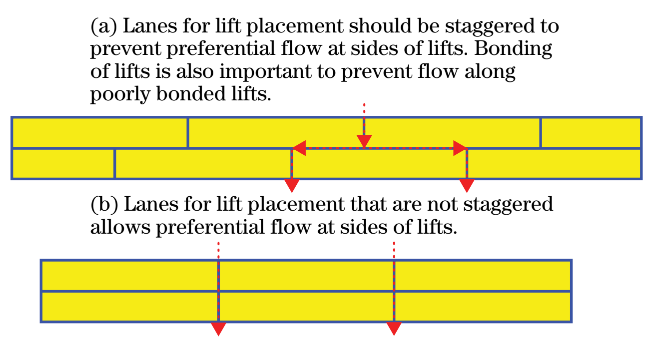
Macrostructure in plastic clay soils

Clods can create a macrostructure in a soil that results in higher than expected permeability because of preferential flow along the interfaces between clods. Figure 10D–13 illustrates the structure that can result from inadequate wetting and processing of plastic clay. The permeability of intact clay particles may be quite low, but the overall permeability of the mass is high because of flow between the intact particles.

Dry density and optimum water content

Compaction specifications for most earthfill projects normally require a minimum dry density (usually referenced to a specified compaction test procedure) and an accompanying range of acceptable water contents (referenced to the same compaction test procedure). This method of fill specification is usually based on en-

Figure 10D–14 Construction methods to limit interlift preferential flow paths



gineering property tests such as shear strength, bearing capacity, and permeability. When permeability is the primary engineering property of interest, as would be the case for a compacted clay liner, an alternative type of compaction specification should be considered. The reason for this is a given permeability value can be attained for many combinations of compacted density and water contents (Daniels and Benson 1990). Figure 10D–15 illustrates a window of compacted dry density and water content in which a given permeability could be obtained for an example soil. The principles involved can be illustrated as follows.

Assume that a given soil is being used to construct a clay liner for an animal waste impoundment. A moderately plastic silty clay classifying as CL in the USCS is used. In case 1, the soil being obtained from a nearby borrow area has a relatively high natural water content. The contractor elects to use lighter construction equipment that applies a relatively low energy in compacting the soil. The result is the soil is compacted to a condition where the compacted density is relatively low and the placement water content is relatively high. This is labeled as point 1 in the figure 10D–15. In case 2, the same soil is being used, but the site is being constructed in a drier time of year. The contractor elects to use a larger sheepsfoot roller and apply more passes of the equipment to achieve the desired product. This time the same soil is compacted to a significantly higher density at a significantly lower water content. This is labeled point 2 in the figure 10D–15.

Laboratory tests can be used to establish the boundary conditions and arrive at a window of acceptable densities and water contents for a clay liner. Figure 10D–16 shows how a different structure results between soils compacted wet of optimum and those compacted dry of optimum water content. It also illustrates that soils compacted with a higher compactive effort or energy have a different structure than those compacted with low energy.

Mitchell (1965) was instrumental in explaining how the permeability of clay soils is affected by the conditions under which they were compacted. Figure 10D–17 illustrates results of one series of experiments summarized in the study. Two samples of a soil were compacted using different energy at different water contents and their permeability was measured. Soil C was compacted using higher energy, like that used when a heavy sheepsfoot roller passed over each compacted lift multiple times. Soil B was compacted using a lower energy, equating to a smaller roller with a smaller number of passes used in the compaction process.

Figure 10D–15 Range at acceptable moisture/density for a typical clay liner

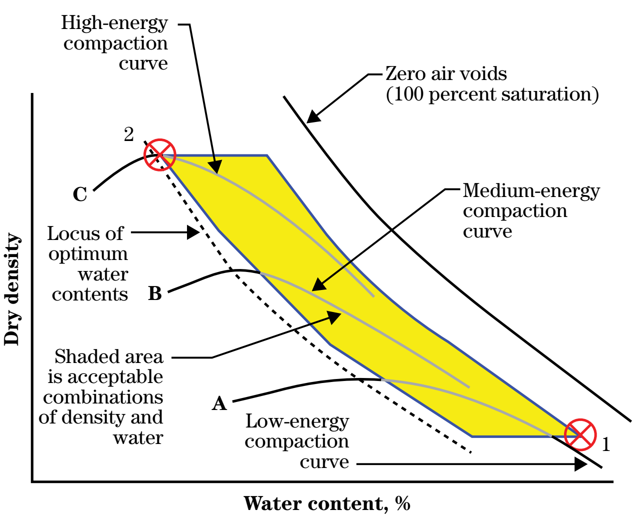
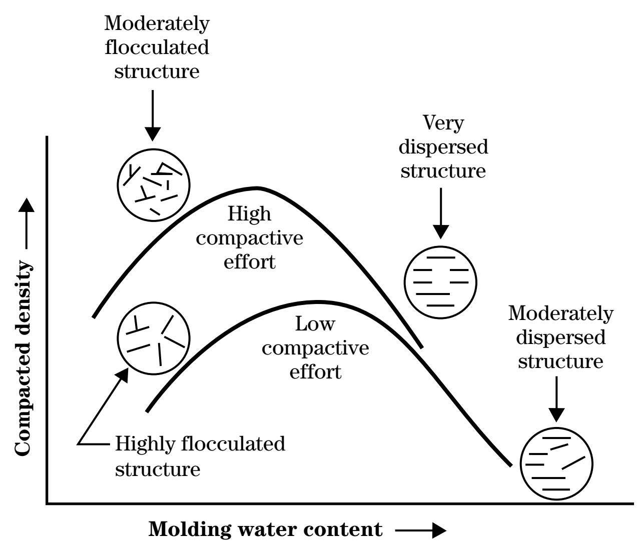


Figure 10D–16 Effect of water content and compactive effort on remolding of soil structure in clays (from Lambe 1958)

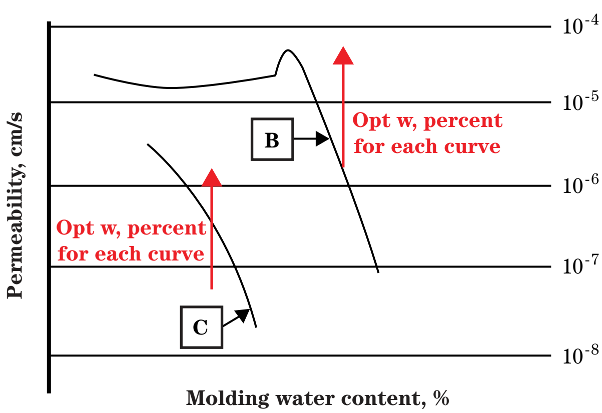


The curves show the relationship between the permeability of the compacted soil and the compaction water content, for the two energies used. The following general principles are seen:

- The permeability of the low energy soil (curve B) is high unless the compaction water content is significantly wet of optimum. Very high permeability results for compaction dry of optimum.
- The permeability of the higher energy soil (curve C) is relatively high for water contents less than optimum.

Lambe (1958) explains how the energy used and the water content of the soil at the time of compaction affect the permeability of the soil by creating structure in the soil. Figure 10D–16 summarizes his explanation of how different soil structures results from these two factors. Soils compacted with higher energy (heavier equipment and numerous passes of the equipment) at a higher water content have a dispersed structure. This structure creates very small plate-shaped voids that are resistant to water flow. Soils that are compacted with lower energy and/or lower water contents have a flocculated structure. This structure involves larger voids that are more conducive to water flow.

Figure 10D–17 Plot showing effect of molding water content on permeability (Mitchell 1965)



Percent saturation importance

Benson and Boutwell (2000) studied the correlation between field measured permeability values on compacted liners with laboratory measured values. The study found that when soils were compacted at drier water contents, even if a high density were obtained, that correlation between field and lab permeability test values was poor. The study found good correlation when soils were compacted at relatively higher water contents. Clods in clay soils are probably not broken down as well at lower compaction water contents which explains the higher permeability in the field. In lab tests, breaking down clods and obtaining test specimens without a structure is easier than done with field compaction procedures.

The conclusions of Benson and Boutwell's research were that if a designer is going to rely on laboratory permeability tests to predict the permeability of a compacted clay liner, the following rules of thumb apply.

- Soils should generally be compacted wet of the line of optimums. The line of optimums is illustrated in figure 10D–15. It is the locus of optimum water content values for a given soil for a range of compactive energy. A soil compacted with a low energy (like that resulting from a small sheepsfoot roller), curve A in figure 10D–15, will have a relatively low maximum density and high optimum water content. A soil compacted with a high energy (like that resulting from using a large heavy tamping roller), curve C in figure 10D–15, will have a high value for maximum density and a low value of optimum water content. The line of optimums is the locus of points connecting the values of optimum water content. Remember that optimum water content depends on the energy used and that Standard Proctor (ASTM D698) is only one standard type of compaction test. ASTM D1557, the modified energy test is also used for design of some clay liners.
- Eighty percent of field tests of dry density and water content should plot to the right of the line of optimums if the field permeability is expected to reflect the same values obtained in laboratory testing.
- The average water content of all quality control tests should be from 2 to 4 percent wetter than the line of optimums as defined.

Energy level of compaction

The relationship of maximum dry density and optimum water content varies with the compactive energy used to compact a soil. Higher compactive energy results in higher values of maximum dry unit weight and lower values of optimum water content. Lower compactive energy results in lower values of maximum dry unit weight and higher values of optimum water content. Because optimum water content varies with the energy used in compaction, its nomenclature can be misleading. The optimum water content of a soil varies with the particular energy used in the test to measure it.

Compactive energy is a function of the weight of the roller used, thickness of the lift, and number of passes of the roller over each lift. Rollers should be heavy enough to cause the projections (teeth or pads) on the roller to penetrate or almost penetrate the compacted lift. Enough passes must be used to attain coverage and break up any clods. Additional passes do not compensate for rollers that are too light.

Roller size is often specified in terms of contact pressure exerted by the feet on sheepsfoot or tamping rollers. Light rollers have contact pressures less than 200 pounds per square inch, while heavy rollers have contact pressures greater than 400 pounds per square inch.

Limited data are available for various sizes of equipment to correlate the number of passes required to attain different degrees of compaction. Typically, from 4 to 8 passes of a tamping roller with feet contact pressures of 200 to 400 pounds per square inch are required to attain degrees of compaction of from 90 to 100 percent of maximum Standard Proctor dry density. However, this may vary widely with the soil type and weight of roller used. Specific site testing should be used when possible.

Equipment considerations

Size and shape of teeth on roller

Older style sheepsfoot-type projections on rollers are best suited for compacting clay soils to achieve the lowest possible permeability. They are better suited than the modern style rollers called tamping rollers that have more square, larger area projections. The longer teeth on the older style sheepsfoot rollers are better at remolding plastic clay soils that are wet of optimum water content, and they are better at degrading clods in the soils (fig. 10D–18). The modern tamping-type rollers are effective in compacting soils at a drier water content when high bearing capacity is needed, like soils being compacted for highway subgrades (fig. 10D–19). The older style of sheepsfoot roller compactors are better suited for compaction to achieve low permeability.

Total weight of roller

To attain penetration of the specified loose lift, the roller weight must be appropriate to the specified thickness and the shape of the roller projections. Many modern rollers are too heavy to compact soils that are more than 1 or 2 percent wet of optimum water content. When the specified compaction water content is 2 percent or more wet of optimum water content, lighter rollers are essential. Permeability of clays is minimized by compaction at water contents wet of optimum.

Speed of operation

Heavy rollers operated at excessive speed can shear the soil lifts being compacted, which may result in higher permeability. Close inspection of construction operations should indicate if this problem is occurring, and adjustments to equipment or the mode of operation should then be made.

Vibratory versus nonvibratory sheepsfoot and tamping rollers

Some sheepsfoot and tamping rollers have an added feature, a vibratory action. This feature can usually be activated or deactivated while soils are being compacted. Vibratory energy adds little to the effectiveness of these rollers when the soils being compacted are clays. At the same time, the vibration of the equipment is not usually detrimental. One condition in which the vibratory energy of this type of equipment might be detrimental is when a clay liner is being constructed on a subgrade of low plasticity silts or sands that are saturated. The vibration of the equipment often causes these types of foundation soils to become dilatant as they densify, and the water expelled in this process can create a trafficability problem. For this reason, when subgrade soils are saturated low plasticity silts and sands, the vibratory action of the compaction equipment should be disabled.

Vibratory smooth-wheeled rollers

Vibratory smooth-wheeled rollers are well suited to compacting bentonite-treated liners. They should not be used for compacting clay liners, however. The smooth surface of the roller results in poor bonding between lifts and can cause problems like those shown in figure 10D–14. The load distribution of the rollers also causes the top of a lift to be compacted well but the bottom of the lift not as well, when fine-grained soils are being compacted. A vibratory smooth wheeled roller is shown in figure 10D–20.

Figure 10D–18 Longer style of teeth preferable for compacting soils for clay liner

Figure 10D–19 Modern type of tamping roller less well suited for compacting soils for clay liner

Freeze-thaw and desiccation

Freeze-thaw

Compacted clay liners may become damaged when the liner is exposed during freezing weather. Articles by Kim and Daniel (1992) and Benson and Othman (1993) describe the effects of freezing on clay liners and how the damage resulting from freezing may be permanent. Laboratory tests show that permeability rates may increase by 2 to 3 orders of magnitude (100–1,000 times). Freeze-thaw damage is more likely to affect the side slopes of a clay-lined pond than it will the bottom of the pond after it is filled. If freeze-thaw damage is regarded as likely to increase the permeability of the

Figure 10D–20 Smooth-wheeled steel roller compactor

soils on the side slopes of the pond, a thicker liner or protective cap of cover soil should be considered. The extra cost of freeze-thaw protection may cause a designer to consider a synthetic liner alternative for reasons of economy and confidence in the low permeability of the synthetic liner. For instance, Minnesota designs often include the use of GCL liners for this reason.

Desiccation

Compacted clay liners may also be damaged when the liner is exposed during hot, dry weather after construction and before the pond is filled. Desiccation may also occur during periods the pond is emptied. Articles by Daniel and Wu (1993) and Kleppe and Olson (1985) describe factors that affect desiccation. Using the sandiest soil available that will be adequately impermeable is helpful. Compacting the soil as dense and dry as practical while still achieving the design permeability goal is also helpful. Protective layers must be at least 12 inches thick to be effective, and even thicker layers may be needed for more plastic clay liners, those with PI values of 30 or higher.

Design and construction of bentonite amended liners

When soils at grade of an excavated pond are low plasticity sands and silts in groups I or II of table 10D–3, an unlined pond will result in unacceptably high seepage losses. Several design options are normally considered for this situation. The options are listed as follows in order of increasing cost:

- Clay soils suitable for a clay liner are located in a nearby borrow area and imported to the site to construct a compacted clay liner. CPS 521D applies to this practice.
- Soils from the excavation and at the excavated subgrade are treated with bentonite to create a compacted liner with the required permeability and thickness. CPS 521C applies to this practice.
- The pond may be lined with geosynthetic, a GCL, or lined with concrete. An aboveground storage tank is also an option.

Bentonite type and quality

Several types of bentonite are mined and marketed for use in treating soils to produce a low permeability liner. The most effective type of bentonite (less volume required per cubic foot of treated soil) is finely ground sodium bentonite that is mined in the area of northeast Wyoming, southeast Montana, and western South Dakota. This sodium bentonite is derived from weathered volcanic ash. Sodium bentonite is a smectite clay composed primarily of the mineral montmorillonite (Bentofix 2007). It has the ability to swell up to 10 to 15 times its dry natural volume when exposed to water. Other types of bentonite, usually calcium bentonite are also mined and marketed for treating soils. These types of bentonites are less active (less free swell potential) and more volume of bentonite per treated cubic yard of soil will be required to produce a target permeability than would be required if sodium bentonite were used.

Two methods of evaluating a bentonite source being considered for use as an additive for a liner has high swell properties exist. They are:

- Determine the level of activity based on its Atterberg limit values as determined in a soil testing laboratory. High-quality sodium bentonite has LL values greater than 600 and PI values greater than 550.
- High-quality sodium bentonite has a free swell value of 22 milliliter or higher, based on experience of NRCS engineers and generally accepted guidance. An ASTM Standard test method to evaluate the free swell potential of bentonite is used to verify the quality of bentonite used in GCL liners and is also suitable for evaluating bentonite proposed for a liner being constructed using CPS 521C. The ASTM method is D5890. A summary of the method follows.
  - — Prepare a sample for testing that consists of material from the total sample that is smaller than a No. 100 sieve.
  - — Partially fill a 100-milliliter graduated cylinder with 90 milliliters of distilled water.
  - — Add 2 grams of bentonite in small increments to the cylinder. The bentonite will sink to the bottom of the cylinder and

swell as it hydrates. Wash the sides of the cylinder and fill to the 100-milliliter level.

— After 2 hours, inspect the hydrating bentonite column for trapped air or water separation in the column. If present, gently tip the cylinder at a 45-degree angle and roll slowly to homogenize the settled bentonite mass.

— After 16 hours from the time the last of sample was added to the cylinder, record the volume level in milliliters at the top of the settled bentonite. Record the volume of free swell, for example, 22 milliliters free swell in 24 hours.

Figure 10D–21 shows an excellent quality bentonite reaction to the test. It has a free swell of about 27 milliliters.

Bentonite is furnished in a range of particle sizes for different uses. Fineness provided by the bentonite industry ranges from very finely ground, with most particles finer than a No. 200 sieve, to a granular form, with particles about the size of a No. 40 sieve. Laboratory permeability tests have shown that even though the same bentonite is applied at the same volumetric rate to a sample, a dramatic difference in the resulting permeability can occur between a fine and a coarse bentonite. It is important to use in construction the same quality and fineness as was used by the soils laboratory for the permeability tests to arrive at recommendations. Fineness for use in treating liners for waste impoundment can also be specified by an acceptable bentonite by supplier and designation, or equivalent. An example specification is Wyo Ben type Envirogel 200, CETCO type BS–1, or equivalent.

Figure 10D–21 Free swell test for bentonite ASTM D5890

Design details for bentonite liner

The criteria given in CPS 521C, Pond Sealing or Lining, Bentonite Treatment, provide minimum required liner thicknesses for various depth of liquids.

CPS 521C provides guidance on rates of application of bentonite for preliminary planning purposes or where the size and scope of the project does not warrant obtaining samples and having laboratory tests performed. These preliminary recommended rates of application are based on using high-quality sodium bentonite that is finely ground. The CPS 521C includes a table that shows a range of recommended application rates which vary with the type of soil being treated. Higher rates of application are needed for coarse, clean sands and lower rates for silts. The table shows a recommended application rate expressed in pounds of bentonite per square foot per inch of liner to be built. For example, a typical rate of application for a relatively clean sand would be about 0.625 pounds per square foot per inch of compacted bentonite-treated liner. The most up-to-date CPS 521C should always be consulted for recommended rates, in case they have changed since this document was written.

For planning purposes, using these recommended rates, the amount of bentonite needed for a job can be estimated. For example, assume that a pond is to be constructed with an area of the sides and bottom totaling one acre. Assume that considering the planned depth of water in the pond, a design has been formulated that calls for a 1-foot-thick bentonite-treated liner and that an application rate of 0.625 pounds per square foot per inch is needed. The total amount of bentonite required per square foot will be

$$0.625 \text{ lb/ft}^2 \times 12 \text{ in/ft} = 7.5 \text{ lb}$$

of bentonite per square foot. For an acre of pond area, the total amount needed will be

$$7.5 \text{ lb/ft}^2 \times 43{,}560 \text{ ft}^2\text{/acre} = 326{,}700 \text{ lb} = 163 \text{ tons}$$

The cost of bentonite is affected strongly by freight, and the further a site is from the area of the United States where bentonite is produced, the more costly it will be. Better unit prices are available for larger quantities.

Remember that the preliminary rates of application provided in CPS 521C assume that finely ground high-swell sodium bentonite is used. If plans anticipate that a lower quality bentonite with a free swell less than about 22 milliliters or a coarsely ground bentonite may be used, laboratory testing is required to establish a rate of application that will create a suitably low permeability. Design using the specific discharge approach will establish what the target permeability value should be.

The recommended procedure to arrive at a design for a bentonite-treated liner then is as follows:

Step 1 Obtain a sample of the soil to which the bentonite is to be added. Have the sample tested in a soils laboratory to determine its basic index properties, including percent fines and plasticity.

Step 2 Have a standard Proctor (ASTM D698) test performed to determine the maximum dry density and optimum water content.

Step 3 From the preliminary design of the site, determine the depth of water in the structure. Use CPS 521C to determine the minimum thickness of liner required.

Step 4 Using given or assumed values for allowable specific discharge, compute the required permeability of the bentonite-treated liner.

Step 5 Coordinate with a soils laboratory on testing to determine what degree of compaction, water content, and rate of application of the proposed additive is required to obtain this permeability. Consider whether high quality (free swell > 22 mL) is being used and whether finely ground or coarsely ground bentonite is proposed.

Step 6 Design the final liner based on the results of step 5.

Example 10D–5—Design of a bentonite-treated liner

Given:

A waste storage pond is planned with a depth of liquid of 21 feet. The State requirement for the location is a specific discharge no greater than one-fifty-sixth of an inch per day of seepage. Assume the soils at grade have been tested and found to be suitable for bentonite treatment. Find the minimum thickness liner required according to CPS 521C, and determine the required permeability to meet this specific discharge requirement.

First, consult CPS 521C to determine the minimum required thickness. Assume the current CPS requires a liner that is 18 inches thick (1.5 ft).

Convert the specified unit seepage rate (specific discharge) of one-fifty-sixth of an inch per day into the same units as will be used for permeability (centimeters per second). To convert, use conversion values shown in table 10D–6, multiply:

$$\nu = \frac{1}{56}\ \text{in/d} \times 2.94 \times 10^{-5} = 5.25 \times 10^{-7}\ \text{cm/s}$$

The thickness of the liner and depth of liquid in the pond must also be converted to metric units. To convert the liner thickness of 18 inches to centimeters, multiply by 2.54, which equals a liner thickness, d, of 45.72 centimeters. The liquid depth, H, of 21 feet is equal to

$$H = 21\ \text{ft} \times 12\ \text{in/ft} \times 2.54\ \text{cm/in} = 640.1\ \text{cm}$$

Using the equation described previously, solve for the required permeability:

$$k = \frac{\nu \times d}{H + d}$$

$$k = \frac{5.25 \times 10^{-7}\ \text{cm/s} \times 45.72\ \text{cm}}{640.1\ \text{cm} + 45.72\ \text{cm}} = 3.5 \times 10^{-8}\ \text{cm/s}$$

The designer should coordinate with a soils laboratory to determine how much bentonite of given quality is required to obtain this low a permeability. In the experience of NRCS engineers, relying on this low a permeability means that construction quality control must be excellent and all the procedures and materials used are of highest quality. Seldom should designs for clay liners rely on a design permeability much lower than 5×10^{-8} centimeters per second. A designer might want to proceed with this design but require a slightly thicker liner (24 in) to provide additional assurance of obtaining the design specific discharge.

Considerations for protective cover

CPS 521C recommends considering the addition of a protective soil cover over the bentonite-treated compacted liner in waste impoundments. There are several reasons why a soil cover should be provided:

- Desiccation cracking of the liner after construction and prior to filling is a significant problem because the bentonite used in treatment is highly plastic.
- Desiccation cracking of the liner on the side slopes may occur during periods when the impoundment is drawn down for waste utilization or sludge removal. Desiccation cracking would significantly change the permeability of the liner. Rewetting generally does not completely heal the cracks.
- Bentonite-treated liners are generally thinner than compacted clay liners. Because the liner is thin, it can be more easily damaged by erosion from rainfall and runoff while the pond is empty. Rills in a thin liner provide a direct pathway for seepage.
- Over excavation by mechanical equipment during sludge removal can damage the liner. A minimum thickness of 12 inches measured normal to the slope and bottom is recommended for a protective cover. The protective cover should be compacted to reduce its erodibility.

Construction specifications for bentonite liner

The best equipment for compacting bentonite-treated liners is smooth-wheeled steel rollers, as shown in figure 10D–20. Crawler tractor treads are also effective. Sheepsfoot rollers that are often used in constructing clay liners are not as effective. CPS 521C specifies that for mixed layers, the material shall be thoroughly mixed to the specified depth with disk, rototiller, or similar equipment. In addition, intimate mixing of the bentonite is essential to constructing an effective liner. If a standard disk is used, several passes should be specified. A high-speed rotary mixer is the best method of obtaining the desired mix (fig. 10D–22). A minimum of two passes of the equipment is recommended to assure good mixing. When multiple passes of equipment are used for applying and mixing the bentonite, the passes should be in directions perpendicular to each other. This encourages a more homogeneous mixture.

Another construction consideration is the moisture condition of the soil into which the bentonite is to be mixed. Unless the soil is somewhat dry, the bentonite will most likely ball up and be difficult to thoroughly mix. Ideally, bentonite should be spread on a relatively dry soil, mixed thoroughly, then watered and compacted.

Depending on the type of equipment used, tearing of the liner during compaction can occur on slopes of 3H:1V or steeper. Compacting along, rather than up and down slopes, could be unsafe on 3H:1V or steeper side slopes. For most sites, slopes of 3.5H:1V or 4H:1V should be considered.

Bentonite-treated liners are often constructed in lifts that are 4-inch compacted thickness. Liners should be designed in multiples of 4 inches for this reason. Often, the first layer of bentonite-treated soil is the soil exposed in the bottom of the excavation. By applying bentonite to the exposed grade, disking it in to a depth of about 6 inches, and compacting it, the first layer is formed. Subsequent lifts are formed by importing loose fill adequate to form additional 4-inch-thick lifts.

Figure 10D–22 Pulvermixer (high-speed rotary mixer) (*Photo credit Stacy Modelski, NRCS*)

Design and construction of clay liners treated with soil dispersants

Previous sections of this appendix caution that soils in groups III and IV containing high amounts of calcium may be more permeable than indicated by the percent fines and PI values. Groups III and IV soils predominated by calcium usually require some type of treatment to serve as an acceptable liner. The most common method of treatment to reduce the permeability of these soils is use of a soil dispersant additive containing sodium.

Types of dispersants

The dispersants most commonly used to treat high calcium clays are soda ash (Na_2CO_3) and polyphosphates. The two most common polyphosphates are tetrasodium pyrophosphate (TSPP), and sodium tripolyphosphate (STPP). Common salt (NaCl) has been used in the past, but it is considered less permanent than other chemicals and is not permitted in the current CPS 521B. NRCS experience has shown that usually about twice as much soda ash is required to effectively treat a given clay when compared to the other two dispersants. However, because soda ash is often less expensive, it may be the most economical choice in many applications.

Design details for dispersant-treated clay liner

CPS 521B, Pond Sealing or Lining, Soil Dispersant, provides minimum thicknesses of liners using the dispersant-treated layer method, based on the depth of liquid in the pond. CPS 521B provides guidance on approximate rates of application of soil dispersants based on testing performed by the NRCS laboratories. Rates provided in the CPS are in terms of pounds of dispersant required per 100 square feet for each 6-inch layer of liner. The total amount of dispersant per 100 square feet is then equal to the number of 6-inch lifts in the completed liner multiplied by the rate per lift.

Example 10D–6—Steps in design of a dispersant-treated liner

Assume for the purposes of this example that a soil has been tested at a site and found to be a flocculated clay with an unacceptably high permeability. The designer chooses to evaluate a soda ash-treated liner. Consult the current CPS 521B for guidance on application rates for soda ash. Assume that the current CPS suggests an application rate of 15 pounds of soda ash per 100 square feet of liner for each 6-inch-thick lift of finished liner. Next, assume that based on the depth of water in the pond that the CPS 521B requires a total liner thickness of 12 inches. Then, because each 6-inch-thick lift requires 15 pounds of soda ash per 100 square feet, the total amount of soda ash required for this example would be 30 pounds of soda ash per 100 square feet. The most up-to-date CPS 521B should always be consulted for recommended rates, in case they have changed since this document was written.

The recommended rates of application of dispersants in CPS 521B are based on the most up-to-date information from the NRCS soils testing laboratories. The rates are in general conservative, and if a designer wanted to evaluate lower rates of application, samples should be obtained and sent to a laboratory for documenting the efficacy of lower rates. If this procedure is followed, the following steps are usually implemented.

Step 1 Obtain a sample of the soil to which the dispersant is to be added. Have the sample tested in a soils laboratory to determine its basic index properties, including percent fines and plasticity.

Step 2 A standard Proctor (ASTM D698) test is performed to determine the maximum dry density and optimum water content.

Step 3 From the preliminary design of the site, determine the depth of water in the structure and use CPS 521B to determine the minimum thickness of liner required.

Step 4 Using given or assumed values for allowable specific discharge, compute the required permeability of the dispersant-treated liner.

Step 5 Coordinate with a soils laboratory on testing to determine what degree of compaction, water content, and rate of application of the proposed additive is required to obtain this permeability. Consider local practice and consult suppliers to determine the relative costs of soda ash versus polyphosphates.

Step 6 Design the final liner based on the results from previous steps.

Example 10D–7—Comprehensive example for a dispersant-treated liner

Given:
A waste storage pond is planned with a depth of liquid of 18 feet. The State requirement for the location is a specific discharge no greater than 2,000 gallons per acre per day of seepage. Assume the soils at grade have been tested and found to require dispersant treatment. Assume that the current CPS 521B requires a minimum liner thickness of 1.5 feet. The example problem is to determine what permeability is required to meet the stated specific discharge requirement.

Solution:
First, the required specific discharge value, which is given in units of gallons per acre per day has to be converted the same units that will be used for required permeability. Assume that permeability will be expressed in centimeters per second, so use table 10D–6 to convert the value of 2,000 gallons per acre per day to centimeters per second as follows:

$$\nu = \frac{2{,}000 \text{ gal/acre/d}}{9.24 \times 10^{8}} = 2.2 \times 10^{-6} \text{ cm/s}$$

Next, convert the liner thickness and depth of liquid from units of feet to centimeters:

$$d = 18 \text{ in} \times 2.54 \text{ cm/in} = 45.72 \text{ cm}$$

$$H = 18 \text{ ft} \times 12 \times 2.54 \text{ cm/ft} = 548.64 \text{ cm}$$

Using the equation described previously, solve for the required permeability:

$$\begin{aligned} k &= \frac{\nu \times d}{H + d} \\ &= \frac{2.2 \times 10^{-6} \text{ cm/s} \times 45.72 \text{ cm}}{548.64 \text{ cm} + 45.72 \text{ cm}} \\ &= 1.7 \times 10^{-7} \text{ cm/s} \end{aligned}$$

The designer should coordinate with a soils laboratory to determine how much soil dispersant of the desired type is required to obtain this low a permeability. In the experience of NRCS engineers, obtaining this value of permeability using a soil dispersant should not require special effort or unusual amounts of additive. At the same time, seldom should designs for dispersant-treated clay liners rely on a design permeability much lower than 5×10^{-8} centimeters per second. A designer should proceed with this design specifying the application rate recommended by the soils lab and a 1.5-foot-thick liner to obtain the design specific discharge.

Construction specifications for a dispersant-treated clay liner

The best equipment for compacting clays treated with dispersants is a sheepsfoot or tamping type of roller. CPS 521B specifies that the material shall be thoroughly mixed to the specified depth with a disk, high speed rotary mixer, or similar equipment. Because small quantities of soil dispersants are commonly used, uniform mixing of the dispersants is essential to constructing an effective liner. If a standard disk plow is used, several passes should be specified. A high-speed rotary mixer is also essential to obtain a thorough mixture of the dispersant with the clay being amended. Figure 10D–23 shows this type of equipment. At least two passes of the equipment is recommended to assure good mixing.

Other construction considerations are also important. Using the bathtub method of construction on slopes of 3H:1V or steeper can cause tearing of the liner during compaction and reduce the effectiveness of compac-

Figure 10D–23 High-speed rotary mixer used to mix dispersants into clays (*Photo credit Jody Kraenzel, NRCS*)

tion equipment. Slopes as flat as 3.5H:1V or 4H:1V should be considered for this factor alone, for bathtub type construction.

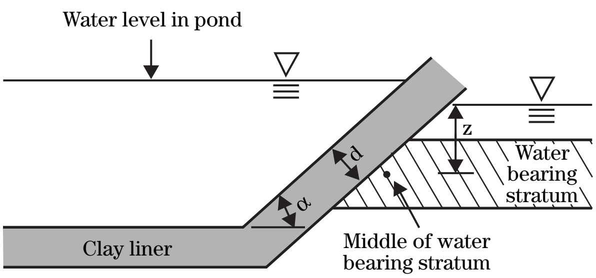
Current CPSs usually require a liner thicker than 6 inches. A liner generally can be satisfactorily constructed in a series of lifts by mixing in the required amount of soil dispersant to a 9-inch-thick loose depth and then compacting it to the 6 inches. Thicker liners should be constructed in multiple lifts, with the final compacted thickness of each lift being no greater than 6 inches.

Uplift pressures beneath clay blankets

A clay blanket may be subject to uplift pressure from a seasonal high water table in the foundation soil underneath the clay liner. The uplift pressure in these cases can exceed the weight of the clay liner, and failure in the clay blanket can occur (fig. 10D–24). This problem is most likely to occur during the period before the waste impoundment is filled and during periods when the impoundment may be emptied for maintenance and cleaning. Figure 10D–25 illustrates the parameters involved in calculating uplift pressures for a clay blanket. The most critical condition for analysis typically occurs when the pond is emptied. Thicker blankets to attain a satisfactory safety factor should be used if they are required.

Figure 10D–24 Failure of compacted liner from uplift forces below clay blanket (*Photo credits NRCS, TX*)

Figure 10D–25 Uplift calculations for high water table and clay blanket (from Oakley 1987)



The factor of safety against uplift is the ratio of the pressure exerted by a column of soil to the pressure of the ground water under the liner. It is given by the equation:

$$FS = \frac{\gamma_{sat} \times d \times \cos(\alpha)}{z \times \gamma_{water}}$$

where:

d = thickness of liner, measured normal to the slope

α = slope angle

γ_{water} = unit weight or density of water

γ_{sat} = saturated unit weight of clay liner

z = vertical distance from middle of clay liner to the seasonal high water table

A factor of safety of at least 1.1 should be attained. The safety factor can be increased by using a thicker blanket or providing some means of intercepting the ground water gradient and lowering the potential head behind the blanket. Often, sites where seasonal high water tables are anticipated designs include a perimeter drain to collect the water and prevent this type of damage. Another option is a concrete structure above ground.

Another situation where a clay liner may be damaged from hydrostatic pressure is one where a site is located in a flood plain of a stream or river. The site may have to be built above ground level in this location to avoid a seasonal high water table. Figure 10D–26 illustrates the problem that may occur that must be considered by designers. A temporary flood condition in the flood plain can subject the agricultural waste impoundment to a differential head when the pond is empty. The pond could be empty shortly following construction or it could be empty to apply waste to crops. Uplift pressure may cause piping of sandy horizons underlying the site and boils, and sloughing of side slopes can occur as shown in figure 10D–26. The photo shows a clay-lined animal waste impoundment where the clay liner was damaged from excessive hydrostatic uplift forces caused by temporary storage of flood waters outside the embankment. The liner must be thick enough to resist predicted buoyant forces if it is possible for the pond to be empty or near empty during a flood. Drains will be ineffective because in a flood, outlets will be submerged.

Figure 10D–26 Uplift conditions caused by temporary flood stage outside lagoon (*Photo credit NRCS, WA*)

Perimeter drains for animal waste storage ponds

When a high water table is anticipated and uplift pressures are anticipated, one approach to solving the problem is to install a drain around the pond. The drain may completely encircle the pond if a designer anticipates a general elevated water table in the site vicinity. At other sites with a more sloping ground surface, the perimeter drain may only be installed on the side(s) of the impoundment where the elevated water table is anticipated. Drains may be used both for clay liners and geosynthetic liners.

Drains usually are constructed by
- digging a trench to the depth needed to draw down the water table
- placing a perforated or slotted drainage pipe
- surrounding the drain with granular material that is compatible with both the slot size in the pipe and the gradation of the surrounding foundation soils

Pipes with small slots that are compatible with a filter sand like ASTM C–33 are preferred to avoid having to use two filter gradations. If pipes with larger perforations are used, they should be surrounded with gravel to prevent particles from moving into the pipe. Figure 10D–27 (a, b, and c) show typical installations where a single filter and perforated pipe is used. Another approach to installing a drain is to dig a trench, line it with geotextile, and after putting a slotted collector pipe in the trench, filling it with gravel. Figure 10D–28 shows this type of installation.

Several types of drain pipe may be used. One type is a low strength corrugated pipe with slots or perforations surrounded by a filter envelope of granular material. Figure 10D–29 is an example of this type of collector pipe. If a higher strength pipe is required, figure 10D–30 shows another type of pipe that is sometimes used for these types of installations.

Figure 10D–27 Typical drain installations using single filter with well-screened collector pipe

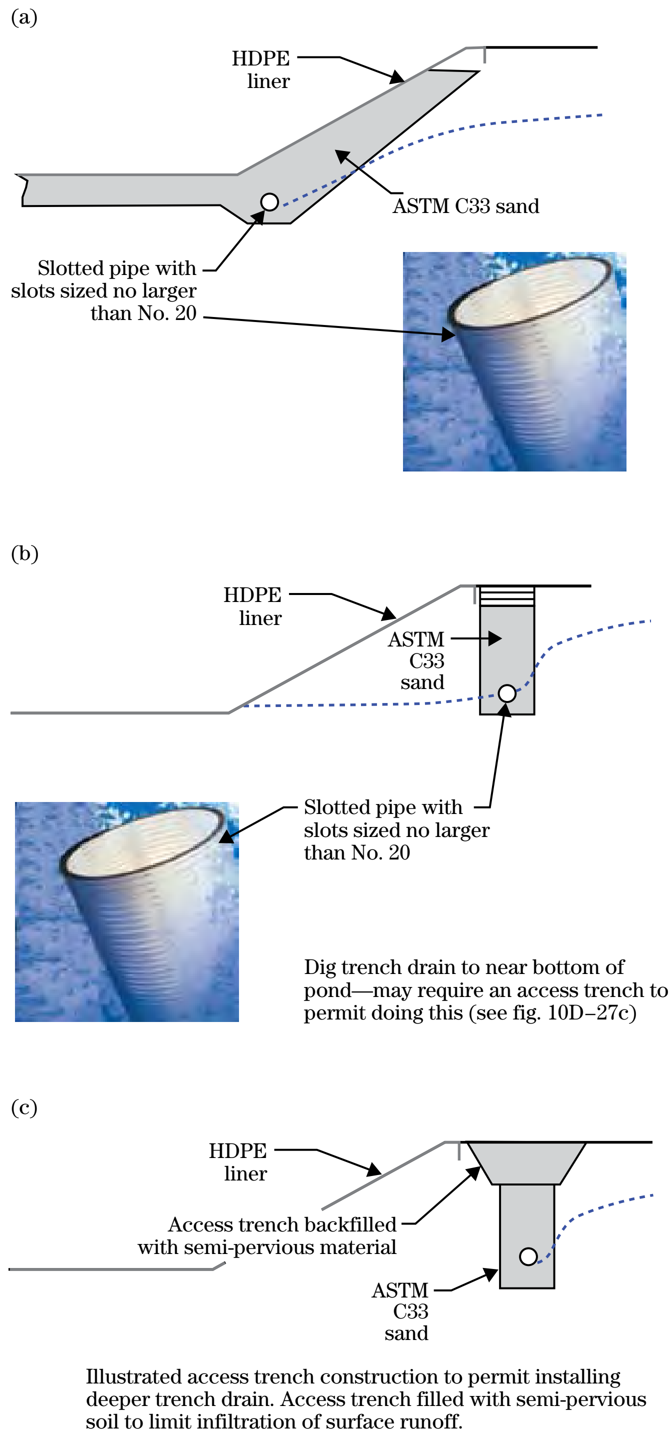


Figure 10D–28 Perforated collector pipe installed the gravel envelope with trench lined with geotextile

Figure 10D–29 Low-strength perforated drainage tubes

Figure 10D–30 Corrugated drainage pipe with slots, doubled walled pipes may be specified if higher strengths are needed

Soil mechanics testing for documentation

Laboratory soil testing may be required by regulations for design, or a designer may not choose to rely on correlated permeability test values. The NRCS National Soil Mechanics Center Laboratories have the capability to perform the necessary tests. Similar testing is also available at many commercial labs. The accepted method of permeability testing is by ASTM Standard Test Method D5084, Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter. Figure 10D–31 shows the equipment used for performing the test.

Contact the labs for more detailed information on documentation needed and for procedures for submitting samples.

Figure 10D–31 Equipment used for performing ASTM D5084

Molding a sample for a flexible wall permeability test

Disassembled mold with compacted specimen

Preparing sample in cell for flexible wall permeability test

Molded sample after dissembling mold

If the only tests requested are gradation and Atterberg limit tests, smaller samples are needed. The size of sample that should be submitted depends on the gravel content. The following recommendations should be adhered to:

Estimated gravel content of the sample 1/ (%)	Sample moist weight (lb)
0–10	5
10–50	20
>50	40

1/ The sample includes the gravel plus the soil material that passes the No. 4 sieve (approx. 1/4-inch mesh).

If gradation analysis, Atterberg limits, compaction, and permeability testing are requested, considerably larger samples are required. When all these tests are needed, the sample size should be as follows:

Estimated gravel content of the sample 1/ (%)	Sample moist weight (lb)
0–10	50
10–50	75
>50	100

1/ The sample includes the gravel plus the soil material that passes the No. 4 sieve (approx. 1/4-inch mesh).

Submitting samples at their natural water content is important so designers can compare the natural water content to reference compaction test values. Samples should always be shipped in moisture proof containers for this reason. The best container for this purpose is a 5-gallon plastic pail commonly obtained in hardware stores. These pails have tight fitting lids with a rubber gasket that ensures maintenance of the water content in the samples during shipping. These 5-gallon pail containers are much more robust and less likely to be damaged during shipment than cardboard containers.

If designs rely on a minimum degree of compaction and water content to achieve stated permeability goals in a clay liner, testing of the clay liner during construction may be advisable to verify that design goals have been achieved. Field density and water content measurements are routinely made using procedures shown in NEH, Section 19, Construction Inspection.

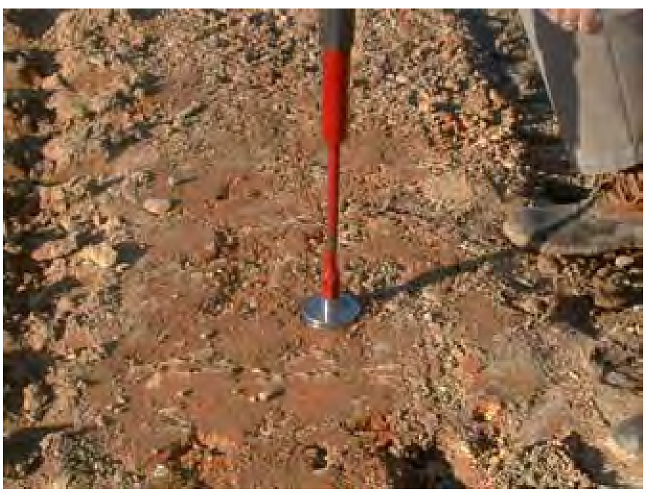
Other methods for documenting liner seepage

Performing density/water content tests during construction is a generally accepted method of documenting that a clay liner has been constructed according to specifications. If the liner is found to meet the requirements of the compaction specifications, the assumption is that the permeability values documented from laboratory testing on samples that were compacted at the specified density and water content will be achieved. In some cases, no additional documentation is required. In other cases, regulations require obtaining samples of the completed liner and performing permeability tests on them. Figure 10D–32 shows one way that a Shelby tube type of sample may be obtained without mobilizing a drilling rig. The Shelby tube used is typically a standard tube with a 3-inch outside diameter and 2 7/8-inch inside diameter. This size sample can be placed directly in a flexible wall permeameter for testing, after extrusion in the laboratory.

Another method for obtaining a sample of a compacted clay liner is with a drive sampler like that shown in figure 10D–33.

Figure 10D–32 Shelby tube sample being obtained with backhoe bucket used to force tube into clay liner *(Photo credit Jody Kraenzel, NRCS, NE)*

Figure 10D–33 Obtaining undisturbed sample of compacted clay liner using thin-walled drive cylinder



In the situation where a storage pond was constructed several years before documentation on quality of construction and permeability was required, studies are sometimes made in an attempt to measure seepage losses directly. One approach that has been used was developed by researchers at Kansas State University. This approach involves installing precise water level monitoring devices and evaporation stations. Seepage losses can be estimated by carefully monitoring the levels in the pond during periods when no waste is introduced into the pond and no rainfall occurs. After estimating the amount of evaporation, and subtracting that from the total decline in the level of the pond during that period, seepage loss can be estimated. Figure 10D–34 shows equipment for measuring evaporation in a pond.

Figure 10D–34 Equipment used to monitor evaporation at an agriculture waste storage lagoon. Measurements are used in total lagoon seepage evaluations.

Summary

- The reduction in the quantity of seepage that occurs as manure solids accumulate in the bottom and on the sides of storage ponds and treatment lagoons is well documented. However, manure sealing is not effective for soils with a low clay content. Its effectiveness is not accepted by all designers and cannot be used in the designs of storage ponds by some State and local regulations.
- Soils can be divided into four permeability groups based on their percent fines (percent finer than the No. 200 sieve) and plasticity index (PI). Soils in groups III and IV may be assumed to have a coefficient of permeability of 1×10^{-6} centimeters per second or lower unless they have an unusual clay chemistry (high calcium), or they have a very blocky structure.
- Group I soils will generally require a liner. Soils in group II will need permeability tests or other documentation to determine whether a desirable permeability rate can be achieved for a particular soil.
- If natural clay blankets are present at a site below planned grade of an excavated pond, the seepage rate should be estimated based on measured or estimated permeability values of the low permeability horizons beneath the liner and above an aquifer. If the estimated seepage rate is less than that given in NRCS guidance or State regulations, no special compacted liner may be required. If the soils at grade are not of sufficient thickness and permeability to produce a desirably low seepage rate, a liner should be designed to achieve the seepage rate that is the design goal.
- Guidance is given on factors to consider whether a constructed liner may be required. Four conditions are listed in which a liner should definitely be considered.
- Allowable specific discharge values are discussed and guidance is provided on reasonable values to use for design when other regulatory requirements are not specified.
- Flexibility is built into the design process. The depth of the liquid, the permeability, and thickness of the soil liner can be varied to provide an acceptable specific discharge.
- The guidelines provided for design of clay liners in this appendix provide designers with the tools to evaluate the probable unit seepage or specific discharge through a clay liner. The methods presented allow a designer to determine what treatment is required to achieve specific discharge or permeability goals.
- Methods provide designers with the ability to evaluate the effect of changes in a proposed design on the estimated unit seepage rate.
- As additional research becomes available, practice standards and guidance in this document may warrant revision.

References

Albrecht, B.A., and C.H. Benson. 2001. Effect of desiccation on compacted natural clays. *In* J. of Geotechnical and Geoenvironmental Engineering. pp. 67–75.

Barrington, S.F., P.J. Jutras, and R.S. Broughton. 1987a. The sealing of soils by manure: I. Preliminary investigations. Canadian Agric. Eng. 29(2):99–103.

Barrington, S.F., P.J. Jutras, and R.S. Broughton. 1987b. The sealing of soils by manure: II. Sealing mechanisms. Canadian Agric. Eng. 29(2):105–108.

Benson, C.H., and G.P. Boutwell. 2000. Compaction conditions and scale-dependent hydraulic conductivity of compacted clay liners. *In* Constructing and Controlling Compaction of Earth Fills. ASTM STP 1384, D.W. Shanklin, K.R. Rademacher and J.R. Talbot, eds. American Society for Testing and Materials, West Conshohocken, PA.

Benson, C.H., and M. Othman. 1993. Hydraulic conductivity of compacted clay frozen and thawed *in situ*. *In* J. of Geotechnical Engineering, Amer. Soc. of Civil Eng. Vol 119, No. 2. pp. 276–294.

Boutwell, G., and C.L. Rauser. 1990. Clay liner construction. Amer. Soc. of Civil Eng./Penn DOT Geotechechnical Seminar. Hershey, PA.

Daniel, D.E. 1993. Compacted clay liners and covers for arid sites. *In* J. of Geotechnical Engineering, Amer. Soc. of Civil Eng., Vol. 119, No. 2. pp. 223–237.

Daniel, D.E., and C.H. Benson. 1990. Water content-density criteria for compacted soil liners. *In* Journal of Geotechnical Engineering, Amer. Soc. of Civil Eng., Vol. 116, No. 12. pp. 1811–1830.

Daniel, D.E., and Yung-Kwang Wu. 1993. Compacted clay liners and covers for arid sites. *In* J. of Geotechnical Engineering, Amer. Soc. of Civil Eng., Vol. 119, No. 2, pp. 223–237.

Ham, J.M., and T.M. Desutter. 1998. Seepage losses from swine-waste lagoons: a water balance of study. Evaluation of Lagoons Containment of animal waste. Kansas State University. Manhattan, KS. 3.2–3.19

Hermann, J.G., and B.R. Elsbury. 1987. Influential factors in soil liner construction for waste disposal facilities. Proc. Geotechnical Practice for Waste Disposal. Amer. Soc. of Civil Eng., Ann Arbor, MI. pp. 522–536.

Kansas State University. 2000. Animal waste lagoon water quality study. Ham, J.M., L.N. Redd, and C.W. Rice. Manhattan, KS.

Kim, W., and D. Daniel. 1992. Effects of freezing on hydraulic conductivity of compacted clay. *In* J. Geotechnical Engineering, Amer. Soc. of Civil Eng., Vol. 118, No. 7.

Kleppe, J.H., and R.E. Olson. 1985. Desiccation cracking of soil barriers. ASTM Special Technical Publication 874, Hydraulic Barriers in Soil. Philadelphia, PA. pp. 263–275.

Lambe, T.W. 1958. The structure of compacted clay. *In* J. of the Soil Mechanics and Foundation Division, Amer. Soc. of Civil Eng., Vol. 84, No. Soil Mechanics 5, pp. 1654–1 to 1654–34.

Mitchell, J.K., D.R. Hooper, and R.G. Campanella. 1965. Permeability of compacted clay. J. Soil Mechanics and Foundation Div., Amer. Soc. of Civil Eng.. Vol. 91, No. 4. pp. 41–65.

Oakley, R. 1987. Design and performance of earth-lined containment systems. Amer. Soc. of Civil Eng. Conf. Geotech. Prac. Waste Disposal, p. 117–136.

U.S. Department of Agriculture, Natural Resources Conservation Service. 1994. Guide for determining the gradation of sand and gravel filters. National Engineering Handbook, Part 633, Chapter 26.

U.S. Department of Agriculture, Soil Conservation Service. 1970. TR–28 Clay Minerals.

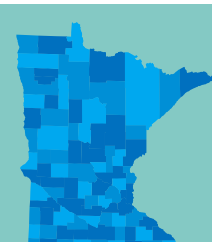
Groundwater

April 2019

Best Management Practices and Data Needs for Groundwater Protection

The MPCA promotes the development of best management practices that prevent, minimize, reduce and eliminate sources of groundwater degradation.

MINNESOTA POLLUTION CONTROL AGENCY



Legislative charge

The Groundwater Protection Act of 1989 (GWPA) requires the Minnesota Pollution Control Agency (MPCA) to develop, promote and monitor the effectiveness of best management practices (BMPs) that prevent, minimize, reduce, and eliminate sources of groundwater degradation. These requirements apply to MPCA programs with activities that may cause or contribute to groundwater pollution for non-agricultural pollutants (https://www.revisor.mn.gov/statutes/cite/103H.001).

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Contents

Executive summary

The Groundwater Protection Act of 1989 (GWPA) requires the Minnesota Pollution Control Agency (MPCA) to develop, promote, and monitor the effectiveness of best management practices (BMPs) that prevent, minimize, reduce, and eliminate sources of groundwater degradation. These requirements apply to MPCA programs with activities that may cause or contribute to groundwater pollution for non-agricultural pollutants.

To address the requirements of the GWPA, the MPCA has set goals in its groundwater program and work plans to identify and evaluate groundwater BMP effectiveness. The goals direct the MPCA to: 1) identify groundwater BMPs, 2) highlight BMPs where more data are needed to evaluate their effectiveness, and 3) develop a plan to address data needs that will enhance program groundwater BMPs.

This report provides a review of MPCA programs that identifies 1) groundwater BMPs, and 2) highlights areas where additional data is needed to evaluate the effectiveness of BMPs in preventing groundwater contamination. The report focuses on MPCA programs that typically conduct less groundwater monitoring or have limited information about their program's impacts to groundwater quality. These include the following programs:

- Subsurface Sewage Treatment Systems (SSTS)
- Animal Feedlots
- Biosolids
- Land and Water Quality Permits for land applied industrial wastewaters and by–products
- Stormwater
- Solid Waste Demolition Landfills
- Municipal Inflow and Infiltration (I&I)

A review of the MPCA remediation programs was not included in this effort because these programs routinely collect and analyze an extensive amount of groundwater data to verify that their program practices are effectively protecting groundwater resources with the objective of meeting health-risk based drinking water standards.

Individualized program reviews were conducted by gathering information about groundwater BMPs from program documents that included: fact sheets, permits, policy and rule; and through interviews with program staff to identify program data needs. The interviews with program staff highlighted program data needs that can be used to prioritize data collection efforts to evaluate the effectiveness of program BMPs. The data needs analysis will also serve as a framework to develop plans to evaluate MPCA program groundwater BMPs to address the third goal of the MPCA's strategic plan.

Minnesota Pollution Control Agency groundwater best management practices

The MPCA programs use numerous BMPs to prevent groundwater contamination that are incorporated into their programs' rules, permits, policies, and guidelines. These program BMPs are specifically designed to address the contaminants of concern managed by each of the programs and contain additional requirements that address sensitive groundwater settings, a key requirement of the GWPA.

Examples of BMPs that apply to sensitive groundwater settings include: setback distances for land applied manure, biosolids and industrial by-products (Industrial by-products); locational restrictions for manure storage and demolition landfills based on groundwater sensitivity; design guidelines for stormwater infiltration in the Minnesota Stormwater Manual; more stringent nitrogen application rates on highly permeable soils for biosolids, and more rigorous design guidelines for SSTS that are based on aquifer sensitivity.

Summaries of program groundwater BMPs are presented within individual program write-ups under the heading “Program practices used to protect groundwater” under the “Program Best Management Practices and Data Needs” section of the report.

Data needs

Several programs have recommended the collection of groundwater quality data to evaluate the impacts of their program BMPs. More specifically, BMP effectiveness could be evaluated from additional groundwater data collection at: mid to large-sized SSTS sites, select animal feedlot drain-tile discharge and manure storage basins, stormwater infiltration sites in sensitive groundwater settings, and at industrial wastewater sprayfield land application sites.

Programs that manage land-applied solid waste do not require the collection of groundwater quality data because their BMPs have been specifically designed to prevent groundwater contamination (biosolids, land-applied manure from feedlots, and industrial by-products). These programs have not recommended groundwater monitoring, as a priority data need. Research suggests that when these program BMPs are properly applied, impacts to groundwater quality are minimal, though there is recognition that more study needs to be done on the possible presence of pharmaceuticals, steroids, and hormones.

Analysis of water quality data was also identified as a need, to assess the impacts and effectiveness of ongoing program BMPs. The Demolition Landfill Program has a need to conduct a statistical analysis of groundwater monitoring data collected over the last eight to ten years at demolition landfills to assess the impacts of program BMPs contained in their Demolition Landfill Guidelines. The Animal Feedlot Program would also benefit from a follow-up sampling and analysis of water quality data collected from larger permitted facilities from a limited number of monitoring wells and tile drainage stations.

An important change noted in this update in 2018 is that most of the programs discussed here have stopped storing basic data in a centralized system at the Agency. Where they once used the now-retired Delta database, they no longer store these data in its replacement, Tempo. Staff are uniform in their hope that data storage will begin within the next few years to rectify this lack, to be available for review and analysis, but no mention is made of specific Agency plans.

An abbreviated list of the program data needs is included in the table below and repeated in Appendix A. More detailed descriptions are provided at the end of each individual program write-up and in the report summary.

Information on the Groundwater Protection Act of 1989 and Minn. Stat. ch. 103H is available at: https://www.revisor.mn.gov/statutes/cite/103H.001. The Degradation Prevention Goal of the law states:

> It is the goal of the state that groundwater be maintained in its natural condition, free from any degradation caused by human activities. It is recognized that for some human activities this degradation prevention goal cannot be practicably achieved. However, where prevention is practicable, it is intended that it be achieved. Where it is not currently practicable, the development of methods and technology that will make prevention practicable is encouraged.

Table 1. Program data needs and recommendations

MPCA Programs	Program data needs and recommendations
Solid Waste Demolition Landfill	• Encourage reuse of demolition materials to reduce reliance on unlined facilities • Provide incentives to owners of unlined landfills to move to facilities that are more protective of degradation through using liners and leachate collection systems • Seek funding for these changes in the State of Minnesota 2018-19 Biennial Budget
Subsurface Sewage Treatment Systems (SSTS)	• Groundwater monitoring at MSTS sites • Assess impacts of smaller ISTS to groundwater monitoring for CECs • Reduce the intentional flushing of unused pharmaceuticals from home and farm
Animal Feedlot	• Follow-up testing and analysis of the drain tile discharge water sampling performed at feedlots, whose permits require testing • Evaluate older manure storage basins lacking double liners in SE Minnesota karst region • Investigate groundwater quality at larger manure storage basins
Land Application of Industrial Wastewaters and IBPs	• Unusual wastes and their environmental fate for land application scenarios are currently (2018) being investigated by the USGS Toxic Substances program • Loading rates at high BOD irrigation sites in Minnesota are much less than similar sites in other states such as MI, which may lead to further study • Site information related to application that used to be entered in the now-retired Delta database is not currently entered in its replacement, Tempo, as of 2018. There will be an attempt to once again capture this information in the future.
Stormwater	• Promote creation of statewide GIS layers to evaluate options to infiltrate stormwater in new development & redevelopment areas in context of vulnerable aquifers • Develop case studies to assess groundwater impacts for stormwater infiltration BMPs (e.g. the Minnesota Stormwater Manual; consider Cl, pathogens, infiltration at brownfields, etc.) • Data collection for stormwater infiltration projects
Biosolids	• No specific recommendations for groundwater monitoring • Biosolids annual reports have been scanned into Tempo, but the data is not in a readily accessible format. New biosolids site approvals and cumulative metals loading data have not been stored electronically since the switch to Tempo. There is a recognized program need to store this data within Tempo. • There is a recognition that the fate of persistent organic compounds (i.e. pharmaceuticals, personal care products, steroids, PFAS, and hormones) in biosolids is important; however, the financial and staff resources necessary to conduct this type of work are beyond the scope of the program’s current resources.
Inflow and Infiltration (I&I)	• Limited groundwater impact concerns. Concerns relate to groundwater leaking into wastewater infrastructure. • Investigating leakage to groundwater would be difficult and has not been done in the Municipal Program.

A. Solid Waste Demolition Landfill Program

This program review includes an overview of the best management practices (BMPs) used by the MPCA's Solid Waste Demolition Landfill Program (SWDLP) to prevent groundwater contamination from construction and demolition landfills (C&D landfills). It also presents the nature of groundwater quality impacts, which occur at unlined demolition landfills across the state. Finally, it identifies the steps needed to evaluate groundwater quality data from demolition landfills to better evaluate the effectiveness of program practices in the protection of groundwater resources.

Program BMPs used to protect groundwater

The SWDLP uses a combination of regulatory tools to protect groundwater resources at C&D landfills, including the Demolition Landfill Guidance (DLG), permit requirements, and policies that emulate the mixed municipal solid waste landfill rules. Other regulatory tools used by the SWDLP that indirectly protect groundwater resources include: environmental and technical reviews, facility inspections, operator training, technical assistance, compliance and enforcement, fact sheets, and guidance documents. The DLG and the Landfill Report describe many of the program practices that protect groundwater resources, as described below.

Locational requirements and site evaluations

The DLG states, "The single most effective action that owners/operators of demolition Landfills can take is to locate the demolition Landfills in areas that will inherently protect ground water and surface water from the risks of contamination. Prohibited locations which must be avoided include active karst topography, flood plains and other areas likely to result in groundwater contamination."

- The Solid Waste Rules prohibit the placement of demolition landfills in areas that would result in groundwater contamination. An existing permitted Landfill that does not meet the location standards above will not be re-permitted.
- Permitting or re-permitting a C&D landfill requires that a site evaluation be conducted to identify potential risks and the need for groundwater monitoring. The site evaluation must verify whether a site meets location standards, has an adequate separation distance between the fill and water table, and provides sufficient information on groundwater flow directions.

Facility classification

The MPCA has developed a three-class system to better manage the potential risks to groundwater from C&D landfills. The three-class system sets different groundwater monitoring and design requirements, and waste acceptance criteria for C&D landfills that are based on waste characteristics and hydrogeologic setting.

- In general, larger C&D landfills have more significant safeguards, such as liners, leachate collection systems, and groundwater monitoring. These landfills are primarily located within the Twin Cities Metropolitan Area. Many smaller C&D landfills are located in rural areas and serve fewer businesses and people and are less likely to have liners or groundwater monitoring; however, operators use more rigorous waste screening practices to control unacceptable wastes that could contaminate the groundwater.
- The DLG sets BMPs for waste screening for the different classes of C&D landfills and defines acceptable waste streams and the requirements for waste stream screening procedures, and Industrial Solid Waste Plans.

Groundwater monitoring

The SWDLP policy states that "all Class II and III Landfills should conduct groundwater monitoring."

- The DLG provides a groundwater monitoring decision matrix to determine whether monitoring is necessary, based on the depth to the water table and the soil type beneath the C&D landfill.
- Decisions to require groundwater monitoring are made upon initial permit issuance or during permit reissuance, which occurs on a 10-year cycle. As noted previously, roughly 65% of all C&D landfills now have some type of groundwater monitoring in place.
- Groundwater monitoring information is reviewed annually and is used to determine if a facility is impacting groundwater quality. Exceedances of groundwater performance standards can lead to permit-required actions to reduce and prevent contaminant impacts. Actions may include: additional monitoring, addition of a less permeable cover atop landfill wastes, or possibly installation of liners beneath the waste to prevent and reduce leaching of contaminants to groundwater.
- In addition to groundwater monitoring requirements, some C&D landfill facilities must also conduct groundwater receptor surveys to identify groundwater users in the vicinity of their facility that may potentially be impacted.

Nature of concern related to groundwater quality

C&D landfills are located in a number of different hydrogeologic settings across the state and vary in size, design and in their contents of construction and demolition debris. C&D landfills may impact groundwater quality through leaching of contaminants from landfill wastes through the soil to groundwater. The degree to which this occurs is greatly affected by the characteristics of the wastes, hydrogeologic setting, and engineering controls at the landfill. These concerns are presented in greater detail in the report to the Minnesota Legislature on "Management of Industrial Solid Waste and Construction and Demolition Debris in Land Disposal Facilities", January 15, 2009 (Landfill Report), pages 15-17, at the web link http://www.pca.state.mn.us/index.php/view-document.html?gid=41.

To protect groundwater as a source of drinking water the SWDLP applies health-based drinking water limits at C&D landfills and may also apply surface water quality standards for groundwater that may discharge to surface waters of the state. Exceeding these limits triggers permit required actions at the compliance boundary of a C&D landfill, as set forth in Minnesota Solid Waste Rules 7035, subp. 4.

Groundwater quality concerns

Rationale/Background - when the state's 88 unlined C&D landfills were created, it was believed that disposal of standard construction materials such as brick, mortar, wood, metal, etc. would not pose a groundwater threat (Figure 1). As a result, these landfills were not required to be lined or to have leachate collection systems. Over time, construction materials have changed to include more chemicals, adhesives, and plastics – all of which behave differently than wood, metal and brick when subjected to conditions found in landfills. Today, as precipitation percolates through C&D debris and continues to flow out of landfills, the result is frequently contaminated groundwater.

Groundwater monitoring shows that these unlined demolition landfills are contaminating groundwater. Of the state's 88 unlined C&D landfills, 67 have groundwater monitoring on site, and 42 (63%) of those show groundwater contamination that exceeds Minnesota Department of Health (MDH) and U.S. Environmental Protection Agency (EPA) standards. Only four of the monitored sites have shown no contamination at all. Clearly, C&D landfills can generate releases to groundwater, with potential consequences to the environment and public health.

Table 2. Unlined demolition activities

Open permitted unlined demolition activities

MPCA Solid Waste Demolition Landfill Program	No Groundwater Monitoring	Confirmed No Exceedance	Confirmed Intervention Limit Exceedance	Confirmed EPA/MDH Limit Exceedance	Evaluating Groundwater Compliance	Total
Demolition - Class 1	20	3	1	33	16	73
Demolition - Class 2	-	1	1	9	3	14
Demolition - Class 3	-	-	-	-	-	-
Demo - Pre-Guidance	1	-	-	-	-	1
Total	21	4	2	42	19	88

The problem happens by two processes. The first process occurs when the water and organic materials from the landfills enter the ground. This serves to mobilize and concentrate low levels of metals naturally occurring in the soils (i.e. arsenic and manganese), allowing these metals to "flow" into and contaminate the groundwater. The second process occurs when water contaminated by materials in the landfill (i.e. boron and vinyl chloride) seeps through the ground and contaminates groundwater. One or both of these processes may be happening over time in a landfill.

Boron is a major contaminant of concern and is believed to be from flame retardants used to treat sheetrock, lumber and insulation. Nitrates have also been detected in C&D landfill groundwater monitoring systems, but are more likely a result of regional anthropogenic sources and less likely due to wastes contained in the C&D landfills. Testing for volatile organic compounds (VOCs) has shown a limited number of detections at relatively low concentrations at most facilities that include: tetrahydrofuran, vinyl chloride and infrequent detections of Freon and hydrocarbon compounds. More recent testing of groundwater has also identified the presence of per and poly-fluoroalkyl substances (PFAS) at concentrations significantly below groundwater intervention limits for most sites.

MPCA staff have also reviewed C&D landfill leachate data, which provides an indication of what contaminants could potentially enter groundwater systems. Results from this review show that several metal and VOC contaminants are present; however, few of these contaminants have been detected in the groundwater systems at these facilities. This indicates that where facilities have liners they appear to be providing a high degree of protection to groundwater resources.

It is important to note that all significant detections of groundwater contamination are from unlined landfills that pre-date the MPCA's current regulatory regime. Current landfill practices, including more rigorous waste screening procedures, increased use of liners and landfill cover, and groundwater monitoring, all help to reduce and prevent impacts to groundwater resources at C&D landfills. Overall, groundwater-monitoring data from C&D landfills indicates limited impacts to groundwater resources and currently there are no known impacts to private or municipal wells from these facilities.

Program data needs and BMP recommendations

The SWDLP is currently working on a proposal that would address current threats to groundwater posed by construction and demolition (C&D) debris in unlined landfills and expand the reuse of demolition materials to reduce the need for these landfills in the future. The proposal would offer grants and loans to private and public owners of unlined C&D landfills to help divert waste from these landfills and enable a transition to facilities that are more protective of human health and the environment. If funded the following would be allowable uses of the grants or loans:

- To establish or expand programs to recycle/reuse demolition materials, thus reducing the flow of waste into landfills and reducing the threat to groundwater.
- To enhance monitoring for the purpose of better understanding the nature and extent of existing groundwater contamination.
- To incentivize protective actions while the new regulatory system is being created:
  - Cap and close C&D landfills as appropriate to prevent contamination of groundwater.
  - Install liners and leachate collection systems as appropriate at new/expanding facilities.
  - Convert C&D landfills to become C&D transfer stations.

In addition to the above proposal, the MPCA SWDLP must prepare a report that evaluates groundwater quality data from demolition debris land disposal facilities. In evaluating groundwater quality data, comparisons must include at least the following:

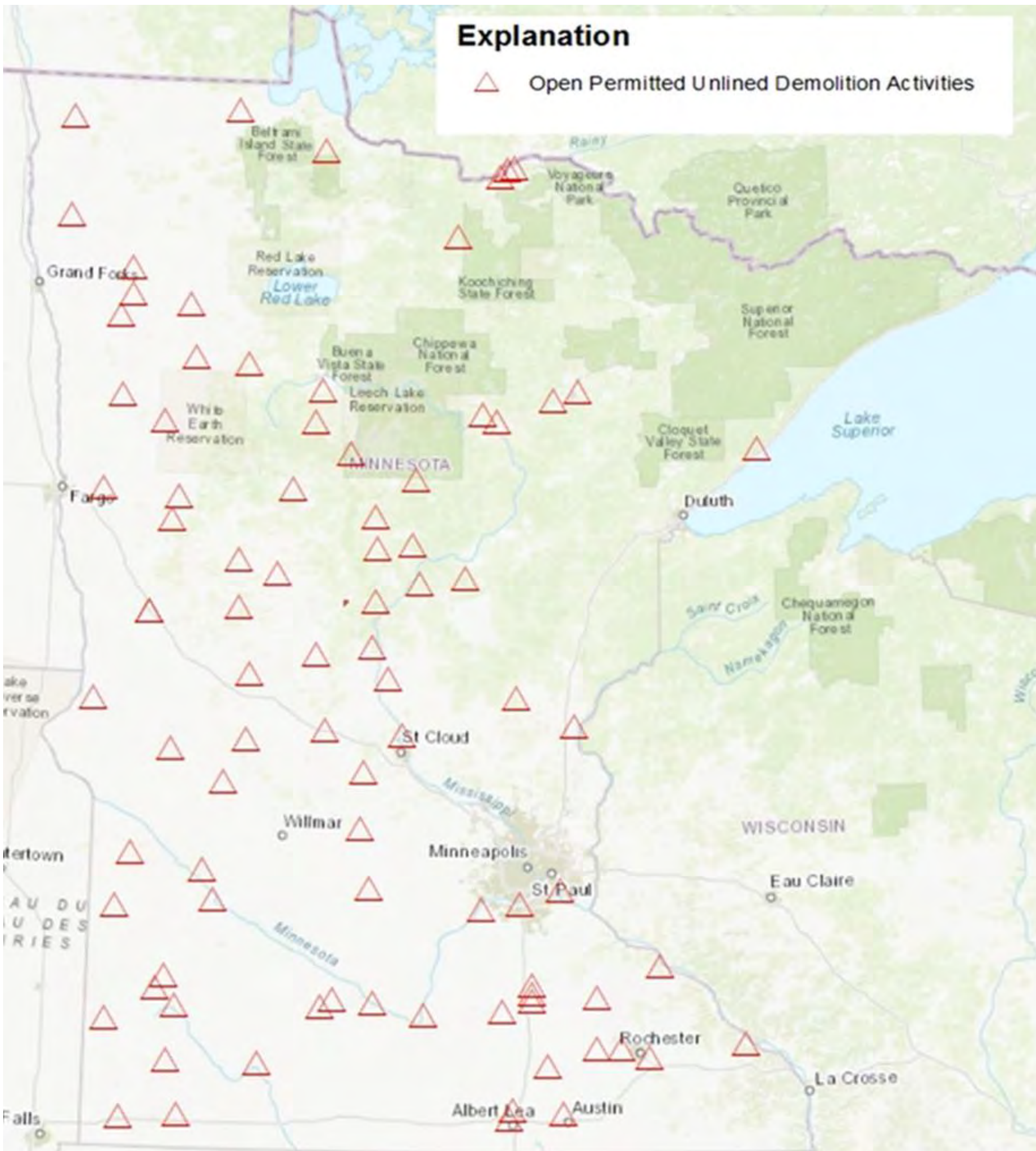
- Adopted health risk limits established in Minn. R. 4717.7500 and Minn. R. 4717.7860.
- Adopted standards, and health advisories & values from both federal and state governments.
- State solid waste intervention limits.

The report must also examine at least:

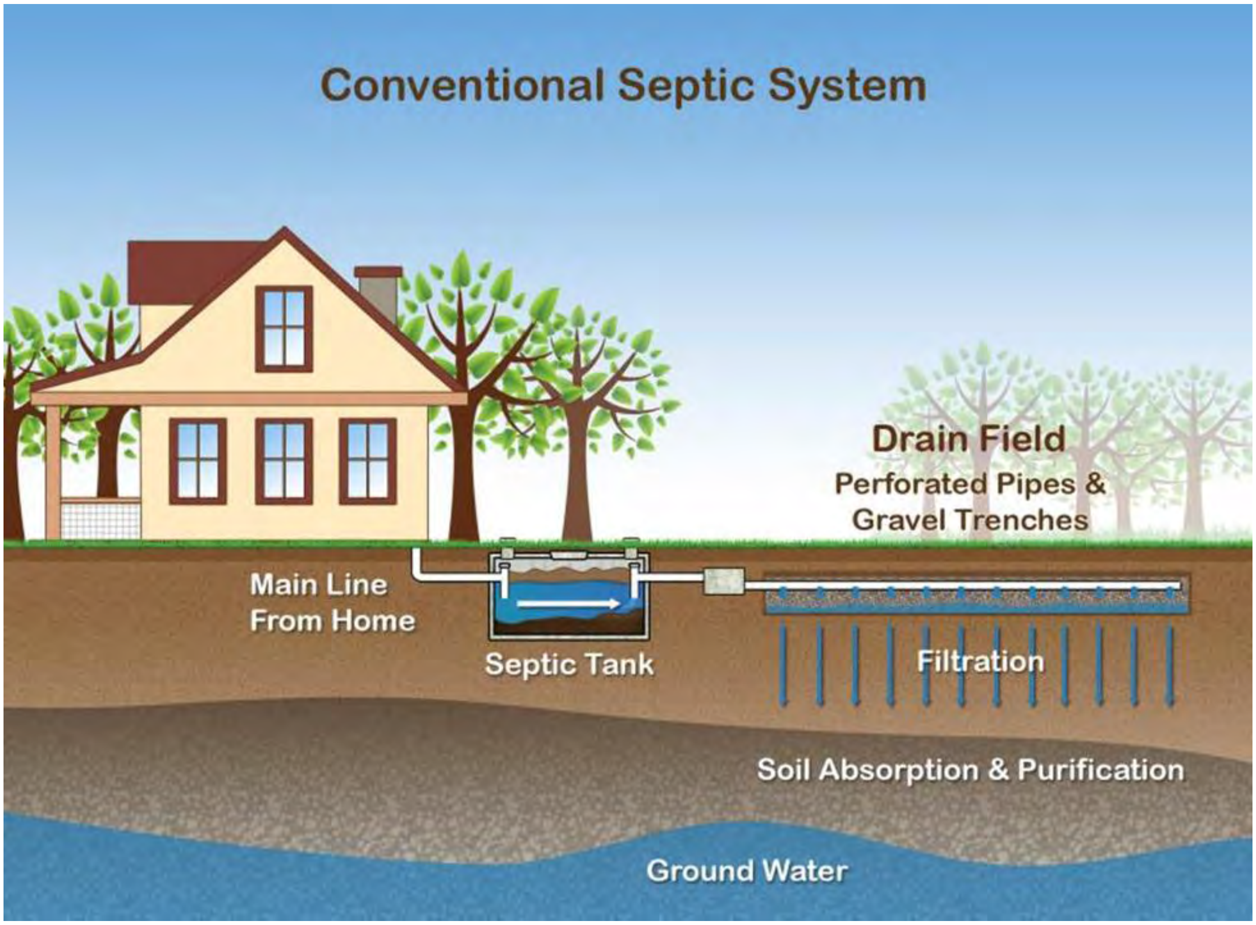
- The role oxidation-reduction reactions have in groundwater chemistry at permitted demolition debris land disposal facilities and compare the role oxidation-reduction reactions have in general to other regulated facilities such as septic systems, surface impoundments, and lined land disposal facilities.
- Compare concentrations to groundwater quality data from other local, regional, and statewide wells, including domestic wells, not associated with landfills.

The findings from this report will be used by the MPCA SWDLP to further evaluate the effectiveness of program BMPs that prevent, minimize, reduce and eliminate sources of groundwater degradation from unlined demolition landfills.

Figure 1. Open permitted unlined demolition activities



B. Subsurface Sewage Treatment Systems

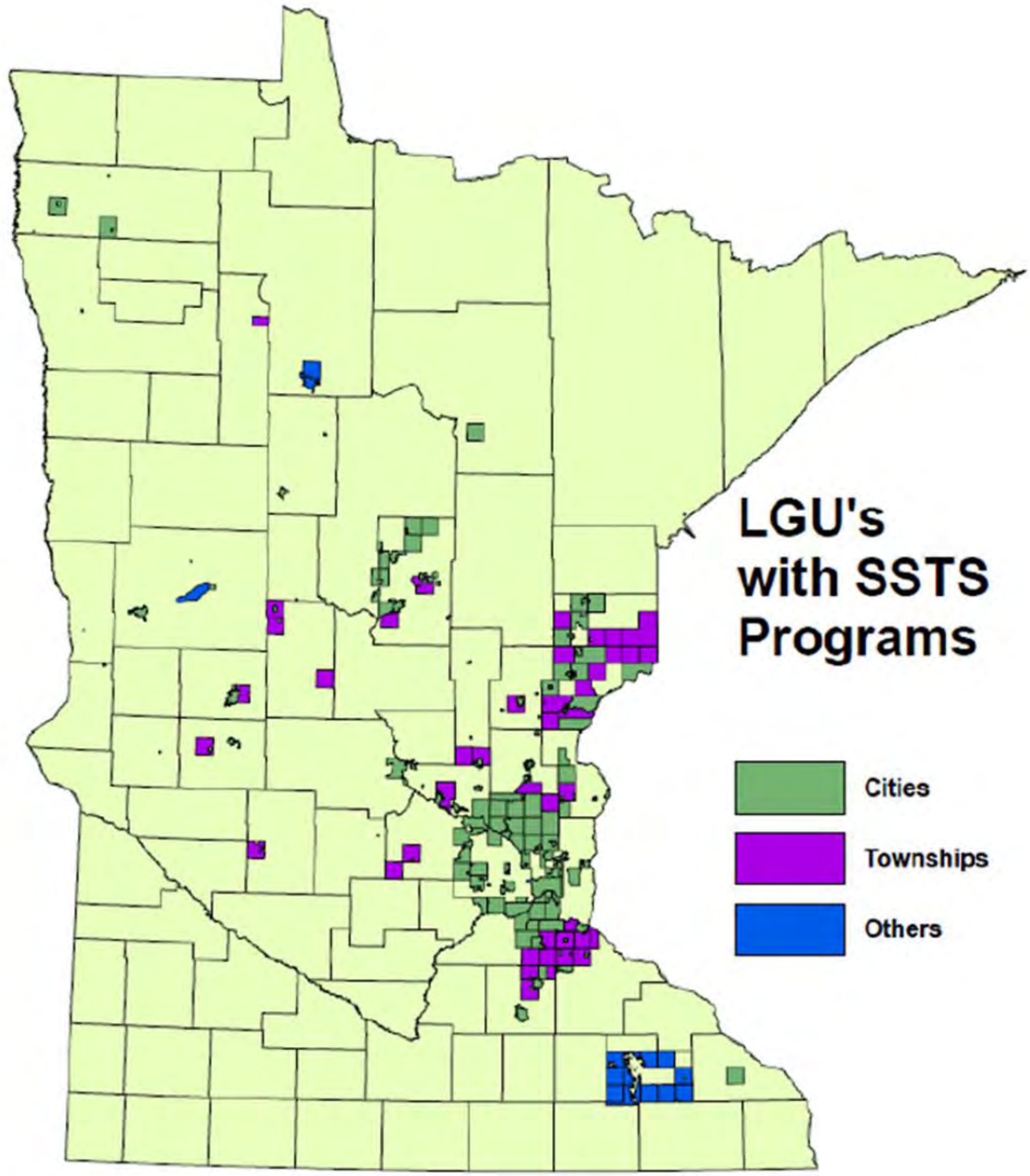


This program review identifies program practices implemented by the MPCA's Subsurface Sewage Treatment Systems (SSTS) program to prevent the contamination of groundwater. It also identifies program areas where additional data are needed to better evaluate the effectiveness of SSTS program practices to protect groundwater resources and makes recommendations to address some of these data gaps.

Overview

The SSTS program oversees the treatment of sewage discharge to SSTS in accordance with state statute (Minn. Stat. 115.55) and rules (Minn. R. ch. 7080-7083). Subsurface or soil-based treatment systems treat approximately one quarter of Minnesota's domestic wastewater (sewage). In 2017, 211 Local Government Units (LGU) reported 537,354 SSTSs in Minnesota. There were 10,906 construction permits issued for both new or replacement systems and 770 SSTS repairs for a grand total of 11,676 SSTS related permits. Over a period of 16 years, from 2002 to 2017, LGUs reported that over 187,766 construction permits were issued. A map showing locations of known SSTS programs is shown in Figure 2. Roughly 98% of these systems are smaller individual sewage treatment systems (ISTS) serving flows of 2,500 gallons per day (gpd) or less. The remaining 2% include mid-sized sewage treatment systems (MSTS) serving flows between 2,501 and 10,000 gpd, and large sewage treatment systems (LSTS) serving flows of 10,000 gpd or greater. Individual sewage treatment systems and MSTS are regulated by local units of government (i.e. city, township, or county). All counties except Ramsey oversee SSTS programs. Minnesota rules require the MPCA to regulate LSTS due to the greater volume of wastewater treated and their associated potential for environmental and health risks. Overall,

Figure 2. Location of county, city, township and other known SSTS programs in 2017



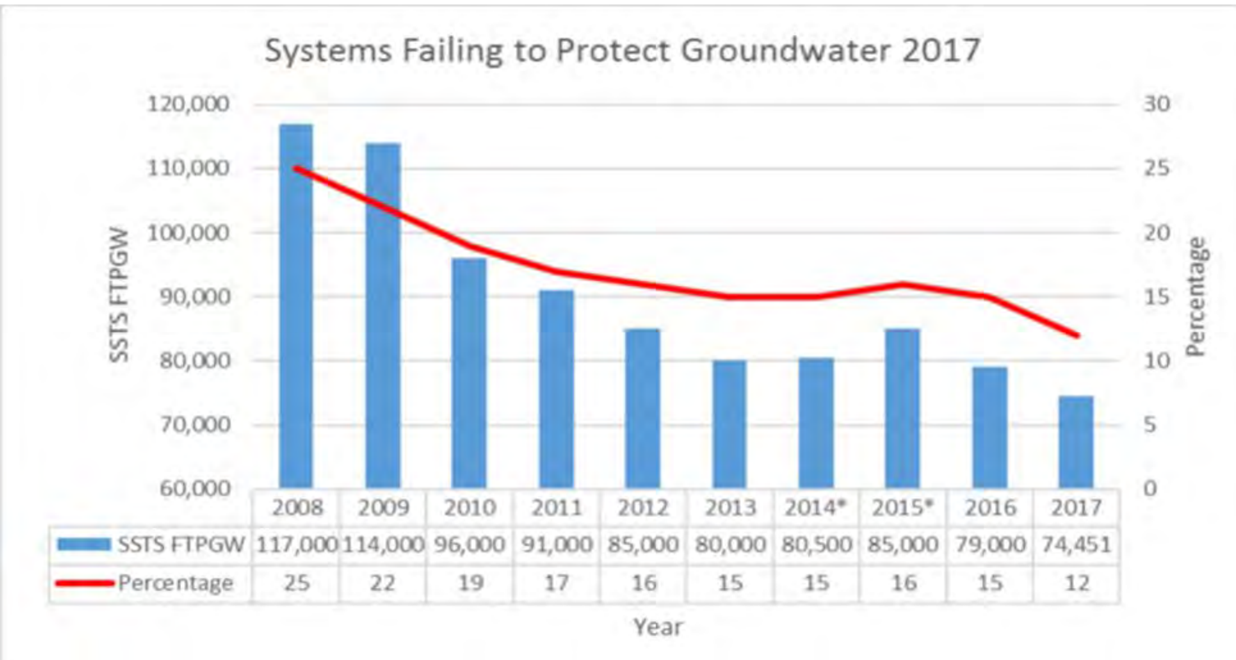
groundwater protection increases based on SSTS size and proximity to vulnerable aquifers. Larger systems have additional monitoring requirements, permit conditions, and BMPs applied to their location, design, installation, use and maintenance.

Nature of concern related to groundwater

Subsurface Sewage Treatment Systems discharge sewage into the ground, where it is treated before mixing with groundwater and surface waters. The wastewater in SSTS contains organic matter and solids, pathogenic organisms (bacteria, viruses, and parasites), nutrients, and some chemicals. A properly operating SSTS will convert a large percentage of the total nitrogen in the sewage to nitrate. Once the nitrate-laden effluent reaches the groundwater, concerns arise about use of that groundwater as a drinking water supply.

LGUs were asked to provide their best estimates of SSTS compliance information as part of the MPCA 2017 SSTS Annual Report, including total number of SSTS in their jurisdiction, the number estimated in compliance, the number estimated to be an imminent threat to public health and safety, and the number estimated to be failing to protect groundwater. The percent of compliant SSTS has increased from 75% in 2008 to 82% in 2017, and the estimated number of systems failing to protect groundwater decreased over the same time period from 117,000 (25%) to 74,451 (12%) systems in 2017; a decrease of 42,549 systems (Figure 3).

Figure 3. The estimated number of systems failing to protect groundwater (FTPGW).



Existing SSTS compliance inspections

Groundwater quality depends not just on the regulations controlling SSTS systems, but also on compliance inspections, to ensure that the SSTS systems are functioning as planned. Out of the total 537,354 SSTS reported in Minnesota in 2017, approximately 2.8% of the existing septic systems were reported to have been inspected in the prior year. Inspections are an important part of addressing existing systems that pose an environmental or human health risk. Local governments include inspection triggers, such as at the time of property transfer or when a building permit is sought, in their ordinances to create a mechanism for verifying system conformance and correcting nonconforming systems within the timeframes specified through state statute or local ordinance.

There were 15,250 compliance inspections of existing systems reported by local SSTS programs representing a 2.7% increase from 2016 (14,847).

Contaminants of concern

Nitrate/nitrogen is the main concern for septic system impacts to groundwater. Nitrates, once formed, will move with groundwater and will likely not denitrify, except in some favorable soil and groundwater conditions. Pathogens and phosphorus generally adsorb to the soil and are treated adequately by these systems. Pathogens are usually attenuated in soil treatment systems; there are a few cases of bacterial and viral transport in groundwater. Phosphorus typically precipitates in the unsaturated zone or is adsorbed in the aquifer close to drain fields; this is less so in older systems where phosphorus saturation can occur.

In addition to pathogen and nutrient concerns noted above, contaminants of emerging concern, such as pharmaceuticals, personal care products, and endocrine active compounds are present in septic effluents. Though the SSTS program has limited capacity to assess the presence of many of these compounds, and has typically made their focus the control and prevention of nitrate/nitrogen and pathogens from entering the groundwater, progress has been recently made on pharmaceuticals and groundwater.

Pharmaceuticals

Pharmaceuticals wind up in STSS via excretion from normal use by people (i.e. because not all of the drug is fully metabolized in the body) and through improper disposal of unused medications by flushing, both at homes and at care facilities.

Pharmaceuticals are commonly detected in Minnesota surface water, groundwater and sediment. The concentrations detected are low relative to other contaminants, but they can have potential negative impacts on the environment, aquatic species, and human health. It is extremely difficult and costly to remove these compounds from wastewater and drinking water once they are present. Preventing entry to the environment is the best way to address potential impacts of pharmaceuticals. Two approaches to doing this are: 1) minimizing input to SSTS and 2) promoting education and support for care providers, pharmacists, and prescribing practitioners about the pharmaceutical “footprint”.

The MPCA, the U.S. Drug Enforcement Agency (DEA) and the Minnesota Board of Pharmacy worked together to develop the regulatory framework that has allowed over 300 pharmacies and law enforcement agencies to begin voluntary collection of unused medications. There are several independent and chain operated pharmacies that began collection within the past two years after the DEA and state regulations were revised. Sites continue to come online with very few discontinuing collection.

Through this system, over 600,000 pounds of unused drugs were collected in Minnesota between 2007 and 2017. The amount of unused drugs collected annually grew tremendously between 2013 and 2017, with the total for 2017 at over 175,000 pounds.

Voluntary collection of unused pharmaceuticals will increase with further with expansion of the collection network and outreach and education to the general public, doctors, and pharmacies. As of 2018, there were only two counties in Minnesota without a local collection option, but the MPCA is working on a grant to help bring collection to those counties as well as other currently underserved areas.

Manufacturers, health care facilities of all types (including long-term care facilities), and animal health facilities may flush waste medications if allowed by their local treatment plants. Because flushing involves no cost, it is still used by many of these operations.

Pollution prevention efforts for medications at this point in time mainly means reducing the overuse of medications, which will reduce what is directly excreted and released into the environment. The changes in prescribing recommendations for antibiotics, and for opioids and other controlled substances, should reduce the amount of medications released into the environment from excretion.

This is especially true looking at the "preventive" use of antibiotics in livestock. This is being studied at the federal level, as well as in Minnesota chiefly through the Department of Health's One Health Antibiotic Stewardship Collaborative. The European Union has banned "off label" use of antibiotics and hormones in livestock, which presumably reduced the use of the drugs and the resulting discharge into the environment. Livestock in the US consume roughly 70% of the antibiotics produced for use. You can view the work efforts and components of the collaborative here: http://www.health.state.mn.us/onehealthabx/.

Manufacturers are putting some effort into more effective drug delivery systems, which may reduce the amount of medication released through excretion, but those efforts will take years to produce measurable results.

Other program practices used to protect groundwater

As noted previously, the SSTS program applies Minn. R. ch.7080 through 7083 to oversee the treatment and dispersal of sewage discharge to subsurface treatment systems. These rules include a large number of requirements for the proper location, design, installation, use and maintenance of SSTS systems to protect our state's water resources from the discharge of treated sewage to the groundwater, that include the following:

- Nitrogen BMPs for MSTS and LSTS based on system size and the sensitivity of the aquifer.
- Registration of treatment products for nitrogen and phosphorus reduction.
- Identifying imminent threats to public health and safety from uncontrolled surface discharges.
- A plan to strengthen local county programs to continue to reduce the percentage of failing SSTS, which have fallen in nine years from 39% to 12%, with a goal to eventually get the percentage of failing systems below five.
- Design guidelines for larger ISTS and MSTS that require the assessment of soil and groundwater conditions so that systems are protective of groundwater resources. Guidelines include:
  - Groundwater sensitivity and mounding assessments.
  - Nitrogen modeling and nitrogen BMPs to reduce total nitrogen, and nitrogen limits.
  - Determining whether a site is located in a Drinking Water Supply Management Area.
  - Vertical separation distances to groundwater.
  - System design criteria based on the above factors.
- A groundwater nitrate nitrogen policy that provides a technical basis for permitting decisions as well as a means to ensure the best, reasonable protection of groundwater resources.
- Well testing (nitrates), point of sale requirement (not a state requirement).
- Education, certification, and training.
- Compliance and enforcement.

Program data needs and recommendations

- Mid-sized sewage treatment systems – The SSTS program would greatly benefit from groundwater monitoring data collected at MSTS sites to verify whether these systems are meeting groundwater nitrogen limits set in design guidance. In addition, monitoring of groundwater mounding is needed to evaluate system performance and to compare these results to predictions from numerical (MODFLOW) and analytical (Kahn & Hantush) groundwater models. This type of research is needed in both sand, gravel, and finer textured glacial till soils that occur across the state. Assessment of the predictive ability of groundwater mounding models in different geologic settings will help support program decisions regarding system performance and ultimately lead to reduced review times and site assessment work.
- Individual sewage treatment systems – The assessment of impacts to groundwater from smaller ISTS is also needed because of their large numbers. There is little to no groundwater monitoring conducted for these types of systems, and many were installed prior to the enactment of minimum statewide standards for ISTS in 1996.
- Monitoring for contaminants of emerging concern – As noted previously, the SSTS program does not have the capacity to test for contaminants of emerging concern (CECs) including endocrine active compounds. It is known that sewage effluent contains CECs; however, their occurrence has not been investigated for SSTS in Minnesota.
- Pharmaceuticals - work needs to continue to cut down on the flushing of unused drugs into treatment systems of all types, by including more collection facilities in the effort, both for human and livestock use (and overuse).
- Land application of solids removed from SSTS systems – monitoring could be added to track the possible migration of contaminants into groundwater.

Based on discussions with program staff, the most immediate data needs, with respect to groundwater protection concerns, are for MSTS as described in the first bullet above. Next would most likely be groundwater data from ISTS sites; however, a number of homes and businesses have straight pipe discharges of sewage effluent to surface waters, which represents an even greater immediate concern to surface water resources. Currently, the SSTS program has limited capacity to investigate the above listed data gaps and any work in these areas would need to be conducted with local partners and stakeholders outside of the program.

C. Animal Feedlot Program

This program review identifies some of the program practices and BMPs used by the MPCA's Animal Feedlot Program (Feedlot Program) to prevent the contamination of groundwater resources. It also identifies program areas where additional data is needed to better evaluate the effectiveness of feedlot program practices to protect groundwater resources and makes recommendations to address some of these data gaps.

Overview

The Feedlot Program regulates the land application and storage of animal manure for over 25,000 registered feedlots in Minnesota in accordance with Minn. R. ch.7020. In addition, there are approximately 5,000 to 10,000 smaller, unregistered feedlots across the state. Overall, there are more feedlot sites than can be evaluated on an individual basis, and therefore, there is limited monitoring of their impacts on groundwater quality, with the exception of a few of the larger facilities.

Feedlots are located in agricultural areas across Minnesota with the greatest number occurring in the southern and central portions of the state. Feedlots vary in size, as measured by the number of animals they manage (animal units), and in the quantity of manure they land apply or store in manure storage basins. In general, larger feedlots have more rules and regulations they must follow to protect groundwater resources.

Nature of concern related to groundwater

Groundwater can be contaminated by nutrients (primarily nitrate-nitrogen) and microbial pathogens from animal manure. Animal manure contains significant quantities of nitrogen and if not properly managed, can lead to nitrate contamination of groundwater. The main concern regarding feedlot contaminant impacts to groundwater systems is through the application of manure to the land and its storage in manure storage basins. The land application of manure, if not conducted properly, can overload the soil/crop system and lead to leaching of contaminants to the groundwater. In addition, the design, construction, and maintenance of manure storage basins and their location relative to vulnerable groundwater settings play big roles in whether manure storage systems are likely to affect groundwater quality.

Many feedlots are located in areas of the state with vulnerable aquifers where groundwater quality is highly susceptible to contamination from land surface activities. Nitrate contamination of groundwater has been shown to be a problem in areas having coarse-textured soils with shallow groundwater and solution weathered bedrock. Pathogens can also move directly to groundwater through cracks in the soil, especially near old wells, sinkholes, quarries, and areas having shallow soils over fractured bedrock.

Contaminants of concern

As stated above, nitrate-nitrogen and pathogens have been identified as the contaminants of greatest concern from feedlots that may impact groundwater quality. Groundwater studies of manure storage systems by the MPCA have also identified high concentrations of ammonia, organic nitrogen, phosphorus, organic carbon, potassium, chloride, manganese, and iron in groundwater plumes downgradient of manure storage areas. In these same studies, high nitrate concentrations were measured where sites were underlain with a thick unsaturated zone, indicating the conversion of organic nitrogen and ammonia most likely resulted in the higher nitrate concentrations. In general, MPCA studies showed the greatest impacts to groundwater quality occurred at sites lacking a constructed liner for their manure storage basins.

Moreover, as was mentioned in the previous section on Surface Sewage Treatment Systems, the use (and overuse) of antibiotics as a preventive measure in the treatment of livestock must be considered a likely source of the contamination of groundwater. This possible misuse of antibiotics is being studied at the federal level, as well as in Minnesota chiefly through the Department of Health’s One Health Antibiotic Stewardship Collaborative. The European Union has banned “off label” use of antibiotics and hormones in livestock. Off label use is the practice of proscribing drugs for an unapproved purpose, a practice that boosts antibiotic use in livestock. Livestock in the US consume roughly 70% of the antibiotics produced for use. More information available at: http://www.health.state.mn.us/onehealthabx/.

Program practices used to protect groundwater

The Feedlot Program protects groundwater quality primarily through the application of Minn. R. ch. 7020, in addition to a mix of BMPs, program policies, fact sheets, and guidelines that contain specific requirements and recommendations for water quality protection. Some examples of Feedlot Program practices that protect groundwater quality, and how they do so, are listed below.

- Manure management plans are considered one of the primary program practices that protect groundwater quality. Manure management plans regulate the rate and timing of the land application of manure to prevent overloading the soil/crop system with excess nitrogen and phosphorus, reducing the potential for nitrogen leaching to groundwater.

- Feedlot general permit conditions place additional constraints on manure applications in areas with vulnerable aquifers (sand and gravel aquifers) and restrict applications in the winter for concentrated animal feedlot operations.
- Rules for liquid manure storage basins (7020.2100) set the liner design standards and location restrictions for feedlots to prevent leakage of liquid manure to underlying soils and groundwater.
- Feedlot water quality discharge standards (7020.2003) require that manure, its runoff and process wastewaters are prohibited from flowing into a sinkhole, fractured bedrock, well, surface tile intake, mine or quarry. Feedlots and manure storage areas must comply with Minn. R. ch. 7050 effluent limit standards.
- Location restrictions and expansion limitations (7020.2005) apply to new animal feedlots or manure storage areas within a shoreland, a floodplain, 300 feet of a sinkhole, 100 feet of a private well, or 1,000 feet of a community water supply well, or other wells serving schools or day care centers.
- Groundwater monitoring is required as laid out in a program policy memorandum from June 2008 - “MPCA Feedlot Program Ground Water Monitoring at New Liquid Manure Storage Areas”.
- Guidelines for the land application of manure, “Applying Manure in Sensitive Areas” developed by the MPCA and Natural Resources Conservation Service (NRCS), provides feedlot operators with a user-friendly overview of state requirements and recommended program practices to protect water quality.

Program data needs and recommendations

Feedlot Program staff identified several areas where additional data would be helpful in determining the effects of feedlot impacts on groundwater quality, as follows:

- **Obtain Water quality data from perimeter drain tile discharge at manure storage basins** - Provide professional evaluation follow-up on testing results of drain tile discharge water for drain systems that MPCA has required of permittees around manure storage basins. There are a large number, perhaps thousands, of perimeter tile drainage systems around concrete or earthen manure storage basins. However, there are only around a dozen feedlot sites statewide that have permit conditions outlining the sampling of drain tile discharge on a routine basis. One challenge to obtain regular samples comes from the seasonal fluctuations in perimeter drain tile flow. At many times the groundwater is not saturated enough to allow the drain tile to flow readily enough to obtain a sample. The drain systems are set around the base of the storage basins to lower the water table beneath the basin and maintain a separation distance of four feet between the bottom of the basin and the underlying water table. The drain tiles typically discharge to county ditches, which flow to surface waters of the state. The quality of water from the drain tiles is representative of the groundwater beneath the manure storage basins and would indicate if there is contaminant leakage from the basins to the groundwater.
- **Evaluate manure storage basins in southeast Minnesota karst region** – In southeastern Minnesota, a number of manure storage basins were built in the mid-1990s, prior to when manure storage basins were required to have double liners. Basins or lagoons built without double liners have a greater potential for catastrophic failure in karst settings. Feedlot staff have conducted some visual inspections of these facilities; however, it would be good to evaluate the condition of the older storage basins (>15 years old) more rigorously. This evaluation could

determine the locations of older basins, depth to bedrock, proximity to springs, sinkholes, streams, and include any soil data or construction information available on these structures from the NRCS, Soil and Water Conservation District, Joint Powers Boards, etc. A pilot study could be conducted for a county where good geologic information is available from county geologic atlases, along with groundwater data and hydrogeologic studies, and where cooperation from local government units is likely. Such counties could include Wabasha, Fillmore, or Olmsted Counties. MPCA groundwater studies from 2001 for these types of structures could supplement this type of analysis, and MPCA could review old-field log books from sample collection efforts.

- **Investigate groundwater quality at larger manure storage basins** – Conduct focused investigations at manure storage basins that pose a greater risk to groundwater quality. Newly constructed basin capacities continue to grow in size each year, with some basin volumes in the 20-30 million-gallon range, per cell. Use information from MPCA Groundwater Monitoring and Assessment Program studies, a comprehensive literature review, and experiences from other states to prioritize site investigations. Collect samples of soil and groundwater with a geoprobe at basins with the following characteristics: unlined basins and or earthen basins; liquid storage greater than 5 million gallons; locations in hydrogeologically sensitive areas of the state with either sand/gravel or fractured bedrock beneath the basin; locations in areas that supply drinking water to wells or springs; and where the uppermost water bearing unit is an aquifer, located in a vulnerable drinking water supply management area, and with liner design seepage rates of 1/56”/day vs. 1/560”/day).

Preventive antibiotics and hormones – The use of antibiotics as a preventive measure in the treatment of livestock must be considered a likely source of the contamination of groundwater.

D. Land Application Sites for Industrial Wastewater and Industrial by-products

This program review identifies program practices implemented by the MPCA Water Quality Permits Program to prevent the contamination of groundwater from the land application of industrial wastewaters and industrial by-products (IBP). It also identifies whether additional data is needed to better evaluate the effectiveness of program practices to protect groundwater resources and discusses other areas of potential concern.

Overview

The Water Quality Permits Program oversees the permitting and regulation of the land application of industrial wastewaters and industrial by-products, primarily generated by the food, beverage and agricultural processing industry. The land application of industrial wastewaters is regulated primarily through National Pollutant Discharge Elimination System (NPDES) and State Disposal System (SDS) permits. These permits set limits on the land application of nutrient-rich process wastewaters for its beneficial use as a fertilizer on agricultural fields. There are currently 25 facilities with NPDES/SDS permits that land apply industrial wastewaters, located mainly in southern and central Minnesota. At most, of these facilities industrial wastewaters are applied by spray irrigation to fields planted to a forage crop during the growing season. These facilities have annual application rates that range between several million gallons up to 100 million gallons for larger facilities. The regulations in the

NPDES/SDS permits emphasize groundwater protection through good crop and irrigation management and set requirements for land application activities with the goal to protect both groundwater and surface water.

The land application of industrial by-products is most often regulated by the MPCA SDS general permit (MNG960000) for wastes generated from the food and beverage processing industry. Under the general permit, industrial byproducts may be land applied for their beneficial use as a fertilizer and soil amendment to agricultural lands. Industrial by-products include materials such as: liquid or dewatered wastewater treatment sludges, wash water from small food preparation, whey from cheese processing, sweet corn silage, ethanol by-products, and materials with similar characteristics. Approximately 80 industrial facilities are covered under this general permit. A gross estimate of land applied industrial by-products in 2012 indicates 65 million gallons and an additional 77 wet tons of industrial by-products were land applied, which is typical of most years.

A majority of industrial by-product management requirements were adopted from the biosolids rules (Minn. R. ch. 7041) into the general industrial by-product permit. The permit requirements for both industrial wastewater and industrial by-products have stated goals to protect water quality in accordance with Minn. Stat. chs. 115 and 116, and Minn. R. chs. 7001, 7050, 7060, and the U.S. Clean Water Act.

Nature of concern related to groundwater quality

Industrial wastewaters and industrial by-products are considered to be high strength organic wastes that may contain nutrients, salts, organic matter, and, to a lesser degree, pathogens. Potential impacts to groundwater quality can occur from their over-application or improperly timed applications, which can exceed the capacity of the soil/crop treatment zone to assimilate the nitrogen they contain, leading to nitrate contamination of the groundwater. In addition, salts in these materials can build up in soils and shallow groundwater leading to contamination of groundwater with chlorides.

Industrial wastewaters are applied through spray irrigation to the same fields continuously for many years. These types of applications have shown impacts to shallow groundwater in the form of nitrate-nitrogen and chlorides at some application sites. Most land application sites receiving high strength industrial wastewaters are required to monitor the condition of the wastewater received, along with the groundwater, tile line discharge, and soils and crops as a part of their permit requirements.

A number of industrial spray sites show elevated nitrate and chloride concentrations in the shallow water table adjacent to the application fields. Concentrations of nitrates or chlorides in excess of permit limits requires actions on the part of the facility to remedy these conditions that include increased monitoring, reductions in applications, or entirely eliminating applications to a field. In general, groundwater contamination at most facilities has shown decreasing trends in recent years and continues to be monitored. There are currently no known cases of groundwater contamination, in excess of drinking water standards, in private or public water supply wells that are directly linked to industrial spray activities in Minnesota.

In contrast to industrial wastewaters, most industrial by-products are surface applied or injected into soils and are routinely applied to different fields or different areas of a field from year to year. Conducting groundwater monitoring at industrial by-product application sites was considered in the development of the industrial byproduct general permit; however, because of the characteristics of food, beverage, and agricultural industrial by-products and the numerous conservative management practices required in the general permit, they are considered to pose a limited environment risk to groundwater if managed properly. For these reasons, industrial by-product land application sites are not required to have groundwater monitoring systems in place.

Contaminants of concern

As noted above, the contaminants of concern in industrial wastewaters and industrial by-products include: nutrients (nitrogen and phosphorus primarily), salts, organic matter, and may contain pathogens. The risk from pathogen contamination in these materials is considered minimal because these materials are generated from food grade by-products. Overall, nutrients, organic matter, and pathogens are considered to be adequately treated where land application is conducted properly and should not create groundwater contaminant problems.

However, the Water Quality Permits Program is routinely faced with permitting decisions regarding the land application of "unusual industrial by-products" that do not fit the definition or characteristics of food and beverage industrial by-products. The industrial by-product general permit is designed to address by-products from the food and beverage industry and may not have appropriate requirements that are protective of human health and the environment for "unusual industrial by-products". Individual permits are required when the by-product falls outside the agriculture and food and beverage universe and monitoring and management requirements need more specificity than provided in the general permit. The program currently has a need to better understand the fate and transport of constituents contained in "unusual industrial by-products" to avoid contamination of groundwater resources and determine levels where these contaminant pose a risk to human health and the environment. Examples of unusual industrial by-products include petroleum compounds in wash waters, constituents of personal care products discharged by beauty shops, and wastes generated from various manufacturing facilities located outside of sewer service areas.

Program practices used to protect groundwater

As noted above, the Water Quality Permits Program regulates the land application of both industrial wastewaters and industrial by-products through NPDES and SDS permits. The permits set limits and conditions on the locations, quantities and characteristics of land applied industrial wastewaters and industrial by-products that are designed to prevent groundwater contamination.

Historically, program policy has required that land applied industrial wastewaters and industrial by-products must provide a beneficial use as a fertilizer or soil amendment and not be land applied solely for the purpose of waste disposal. However, if land application of some of the unusual wastes is approved, the policy on beneficial use may need to be changed. A number of the permit requirements provide specific protection of groundwater and several provide indirect protection of groundwater resources through management practices that prevent releases of pollutants to the environment, as follows:

- Industrial wastewater facilities that spray irrigate high strength effluent, which receives limited treatment, are required to conduct groundwater monitoring around their spray fields. In addition, these facilities are required to conduct rigorous environmental monitoring throughout the irrigation season that includes monitoring of: tile line discharges, the received wastewater effluent, cooling water, county ditches, soils, crops, and occasionally offsite private wells.
- The permits for industrial wastewater application sites include intervention limits in groundwater for nitrate-nitrogen that are one-quarter of the drinking water standard for nitrate of 10 mg/l. In addition, the industrial wastewater permit sets a total chloride intervention limit

at the secondary drinking water standard of 250 mg/l. An exceedance of either of these limits requires actions by the permittee to prevent these exceedances.

- Industrial wastewater facilities must have a Type V certified operator responsible for the day-to-day operations of the wastewater treatment disposal system.
- Industrial wastewater facilities must prepare a Sprayfield Management Plan that includes details of monitoring, irrigation scheduling, loading rates, soil moisture monitoring, runoff collection, drain tile discharge or collection, and crop management practices.
- Tile drainage systems beneath land application sites are also monitored and have limits set for ammonia-nitrogen and biological oxygen demand. Monitoring data from the tile line discharge is representative of the water quality that may be infiltrating to groundwater.
- Industrial by-products must be completely characterized before a permit can be issued for industrial by-product land application. Industrial by-products must not exceed specific concentration limits for metals, dioxin, and PCBs, and cannot be a hazardous waste.
- The industrial by-product general permit requires that a Type IV certified operator oversee the land application of industrial by-products and ensure they are properly applied. Industrial by-product application sites must also be reviewed by the Type IV operator and their soils tested.
- Land-applied industrial by-products are subject to a number of limitations and restrictions that protect groundwater resources that include:
  - Hydraulic loading limits based on soil texture.
  - Separation distances from drinking water wells, and sinkholes.
  - No industrial by-product applications on fallow ground for the cropping year.
  - Limits on nitrogen applications.
  - Additional restrictions on Industrial by-products that contain pathogens.

The industrial by-product program has implemented an Unusual Waste Review that includes a multi-program task group to determine the proper management of unusual wastes, such as vehicle carwash wastewaters. These wastes may contain constituents such as PFAS that are not typically found in industrial by-products that could impact groundwater quality and must be addressed accordingly. The State of New Jersey is currently investigating the threat posed by PFAS compounds used in carwashes due to the connection of many of the facilities to large septic systems, and the resulting discharge of this contamination to groundwater.

Program data needs

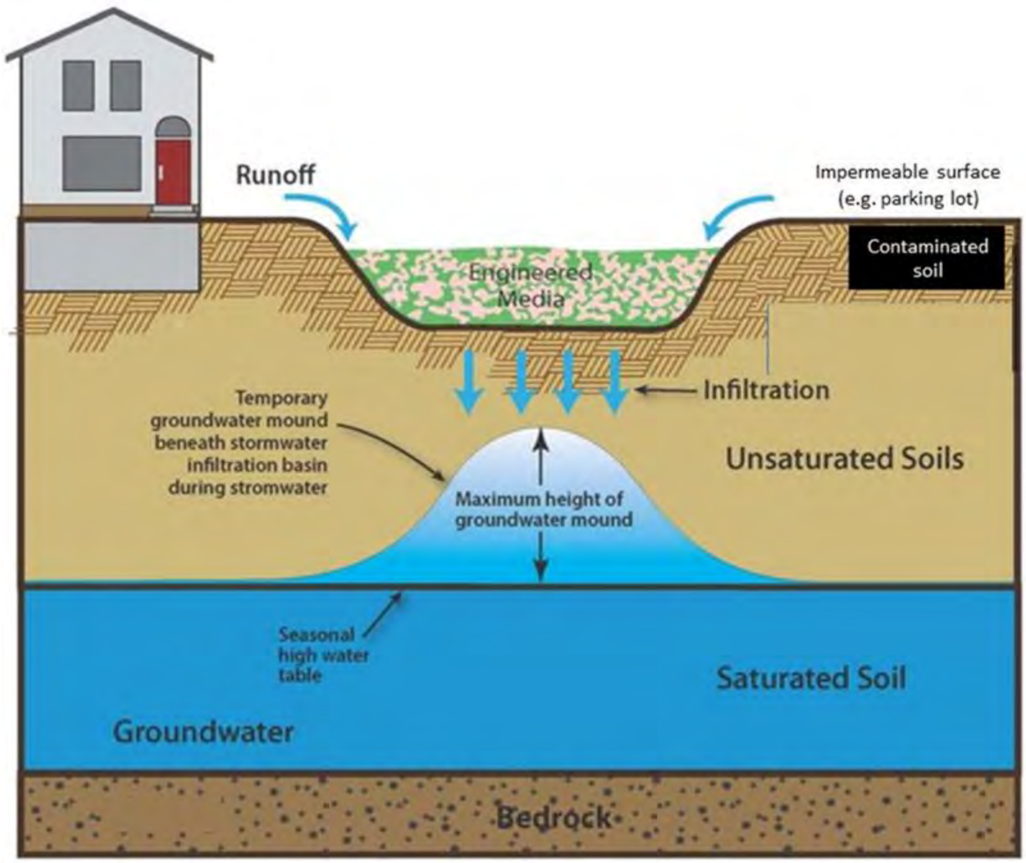
- **Groundwater evaluations -** As risk data becomes available on emerging chemicals of concern, MPCA staff may need to review chemical additives used in land application activities and it may be necessary to review the decision to land apply certain waste types. The Agency is still determining how to proceed with possible groundwater contamination with arsenic, iron, and manganese at high biological chemical demand (BOD) irrigation sites. Preliminary review shows that loading rates are much less in Minnesota than problem sites in other states such as Michigan. If the Agency does decide to review the application of waste for arsenic, iron, and manganese at industrial wastewaters and industrial by-products sites, then it should also consider expanding the review to the animal feedlot and biosolids programs, as similar contamination opportunities apply to all three programs.
- **Unusual wastes** - the Water Quality Permits Program is routinely faced with permitting decisions regarding the land application of unusual wastes that do not fit the definition or characteristics of typical food and beverage industrial by-products or fit neatly into any other land application program at the MPCA. Program staff from water quality, solid waste, and

hazardous waste meet when these types of waste management issues require new approaches. Both carwash wastewater and wastewaters and solids from holding tanks and trap wastes have been addressed in guidance documents. The program requires information on the fate and transport and toxic effects of contaminant compounds contained in unusual wastes in order to develop scientifically based application requirements.

Examples of unusual wastes include constituents of personal care products discharged by beauty shops (personal care products), and wash water wastes generated from various manufacturing facilities located outside sewer service areas. The issue of unusual wastes and their environmental fate for land application scenarios is currently (2018) being investigated by the US Geological Survey's Toxic Substances Hydrology Program. The group has a current study looking at wastewater discharges from food, beverage, and feedstock processing plants. The project team has sampled wastewater discharges from the plants to characterize the chemical signatures. They will likely look at effects from land application in a future, as yet unfunded study.

- **Data review and reporting** - data related to industrial by-product land application activities were once entered into the MPCA's now-retired Delta permit database; however, with the implementation of Tempo, that no longer occurs. The goal is to have facilities enter data, currently required to be reported in the Annual Report, directly into e-Services similar to what facilities are doing for wastewater Discharge Monitoring Reports (DMRs). It is anticipated that this will not occur for a few years. Data for spray irrigation facilities are entered into Tempo through DMRs.

E. Stormwater Program



Stormwater Program

This program review identifies program practices implemented by the MPCA's Stormwater Program (SWP) that reduce and prevent the degradation of groundwater from stormwater runoff. This review identifies data needs for better evaluating the effectiveness of SWP practices to protect groundwater resources and provides recommendations for addressing these data needs.

Overview

The MPCA's SWP regulates the discharge of stormwater and snowmelt runoff from municipal separate storm sewer systems (MS4), construction activities, and industrial facilities, mainly through the administration of NPDES/SDS permits. The SWP program oversees the permitting of approximately 250 municipal systems, 2,000 construction stormwater sites, and 2,500 industrial facilities, in any given year. The SWP administers general permits (and in some cases, individual permits) that incorporate state (Minn. R. ch. 7090) and federal Clean Water Act requirements to reduce the amount of sediment and pollution in stormwater runoff that enters surface and groundwater.

Management of urban stormwater runoff utilizes volume control practices (e.g., infiltrate, evaporate or reuse), filtration practices (e.g., rain gardens, sand filters), rate control and sedimentation practices (e.g., stormwater ponds), and new pollutant removal technologies (e.g., chemically enhanced treatments such as iron enriched sand filters). On a national scale, the EPA has strongly encouraged federal facilities and states to adopt low impact development (LID) practices, primarily for infiltration-based BMPs, and Better Site Design practices that protect forest and stream corridors.

In 2009, the Legislature directed the MPCA to develop performance and design standards or other tools to enable and promote the implementation of low-impact development and other stormwater management techniques. (Minn. Stat. 115.03, subd. 5c). That language defines low impact development as "an approach to stormwater management that mimics a site's natural hydrology as the landscape is developed. Using low-impact development approach, stormwater is managed on-site and the rate and volume of predevelopment stormwater reaching receiving waters is unchanged. The calculation of predevelopment hydrology is based on native soil and vegetation."

Working off the principles of low impact development, a diverse group of stakeholders from the public and private sectors and the Minnesota Stormwater Steering Committee worked with the MPCA to develop a Minimal Impact Design Standards (MIDS) package. This included: 1) volume performance goals, 2) a method to determine credits for those goals, 3) a user-friendly calculator to input site conditions and credits, 4) design specifications for a variety of LID practices, and 5) an ordinance package to help developers and communities implement MIDS.

Nature of concern related to groundwater

Several BMPs infiltrate treated stormwater into the soil, where it can recharge groundwater aquifers. The management of stormwater runoff is increasingly relying upon these infiltration practices.

Several field and laboratory studies conducted over the past 10 years provide information on the fate of pollutants in water as the water goes through infiltration practices. Trojan et al. (2018) provide an extensive review of groundwater impacts from stormwater infiltration practices. While recent studies provide considerable information to better guide the use of infiltration practices, several information gaps remain, including the following:

- Because soils have finite retention capacities, we need a greater understanding of the processes and timing of pollutant breakthrough.
- Pollutant transport and retention in underground infiltration systems is poorly understood.
- We need a greater understanding of chloride dynamics in urban runoff and resulting fate and transport of chloride in infiltration systems.
- We need additional monitoring for organic pollutants (e.g., hydrocarbons, pesticides) and pathogens in the region beneath infiltration systems.

We have a poor understanding of the hydrology of infiltration practices, specifically understanding and quantifying the fate of infiltrated water.

Contaminants of concern

Stormwater runoff, including snowmelt, contains pollutants such as nutrients, pathogens, heavy metals, solids, organic compounds such as oil and pesticides, and chlorides. Properly constructed and maintained BMPs are effective at attenuating most pollutants. The following conditions or pollutants represent a potential risk to groundwater from infiltrated stormwater runoff.

- Chloride is mobile and will not be retained by stormwater BMPs.
- Pathogens are also mobile in infiltration systems constructed in highly permeable soils with low organic matter content.

- Stormwater hotspots are locations where activities have the potential to produce high levels of pollutants in runoff.

Program practices used to protect groundwater

The SWP incorporates required stormwater practices into permits; provides guidance, tools, and outreach on stormwater management; and conducts and supports stormwater research efforts. Examples of these include the following:

- Stormwater permits regulate the discharge of stormwater and snowmelt runoff through administration of a general permit, and in some cases, individual permits, for MS4, construction activities, and industrial facilities. Permit requirements include performance goals (e.g., infiltrating 1 inch of runoff from new impervious surfaces for post-construction), BMPs (e.g., the 6 Minimum Control Measures), development of stormwater pollution prevention plans and programs (SWPPPs), and annually reporting progress toward meeting Total Maximum Daily Load requirements.
- The Minnesota Stormwater Manual is an innovative, online, interactive and user-friendly tool that provides guidance on BMP design, construction, operation, maintenance, and assessment. Specifically, the manual contains two sections addressing stormwater infiltration and infiltration practices. The manual includes information and guidance on tools, such as model ordinances and water quality models, and was developed using a wiki application to allow for easy editing and powerful search abilities. Included in the manual is information on MIDS, including a link to the calculator, guidance and examples for using the calculator, and a MIDS ordinance package. Information on stormwater infiltration and infiltration practices can be found in the stormwater manual wiki, available at: https://stormwater.pca.state.mn.us/index.php?title=Main_Page.
- The SWP is currently conducting research on pollutant fate in infiltration systems and infiltration characteristics of swales. The SWP regularly collaborates with the University of Minnesota and others conducting stormwater research.
- The SWP regularly provides outreach through webinars, newsletters, presentations, and meetings with stakeholders.

Table 3. Summary of typical risk of groundwater (GW) contamination by pollutant, increasing groundwater risk, and management strategies for reducing risk

Pollutant	Risk of GW contamination from infiltration practices	Conditions when pollutant may represent a risk to GW or surface water receiving groundwater inputs	Management strategies for sites where conditions may represent a risk
Nitrate	Low-moderate	Nitrogen fertilizer used historically, and where turf is being established; use of media with organic nitrogen that can convert to nitrate	Pretreatment to remove organic Nitrogen; reducing infiltration rates by using finer texture material; relocating high Nitrogen practices away from drinking water receptors
Chloride	High	Areas receiving applications of chloride-based deicers	Reducing chloride deicer application. Encouraging infiltration may reduce peak concentrations in surface waters, but overall loading remains unchanged
Phosphorus	Low	Infiltration practices having a high concentration of organic matter discharging to shallow GW near surface receiving waters	Ensure concentration does not exceed 30 mg-P/kg-soil; construct layer at bottom of the practice to attenuate phosphorus using elemental iron
Toxic metals	Low	Practices with low adsorption capacity; low pH media; large inputs of chloride; receiving high concentration of metals in runoff	Replace top few inches of soil or media in the infiltration practice; test soil to ensure proper pH; limit chloride loads to the practice
Pathogens	Low-moderate	Practices with low adsorption capacity (e.g. low organic content) & rapid infiltration rates; areas with high concentration of bacteria (like Enteroviruses)	Utilize infiltration practices having greater concentrations of organic matter; avoid underground infiltration in very coarse soils if bacteria concentrations are high
Organic chemicals	Low-medium (varies by chemical)	Practices having low adsorption capacity (often low organic content) & rapid infiltration rates; nearby large terrestrial sources of soluble contaminants	Add organic matter to soil or media
Temperature	Low-moderate	Infiltration practices with very rapid infiltration rates and located adjacent to temperature-sensitive receiving waters	Locate practices representing a risk away from temperature-sensitive waters or slow infiltration rates by adding organic matter or fine-textured material

Program data needs

- Promote the creation of statewide GIS data layers to evaluate options to infiltrate stormwater in new development and redevelopment areas in relation to wellhead protection zones, extremely vulnerable aquifers (e.g. sand/gravel outwashes over bedrock), depth to shallow groundwater, and hydrologic soil groups (A, B, C, and D).
- Incorporate research and case studies of groundwater impacts from stormwater infiltration practices into guidance (e.g., the Minnesota Stormwater Manual). This involves collaboration with outside partners, such as municipalities, watershed districts, and other state agencies. Specific focus areas include:
  - Obtaining a better understanding of the fate of chloride and pathogens in infiltration systems.
  - Obtaining a better understanding of infiltration volumes and fate of infiltrated water.
  - Assessing changes in shallow groundwater that relate to potential issues for buried utilities and structure basement flooding (e.g. groundwater mounding potential).
  - Identifying locations of BMPs relative to wellhead protection areas and their emergency response areas for source water protection.
  - Evaluating failed infiltration projects to determine causes.
  - Obtaining a better understanding of infiltration at Brownfield sites.
- Improve data collection and management for stormwater infiltration projects. Components of this effort could include:
  - Advancement of standardized data collection protocols through development of recommendations and guidelines for sample collection and analysis.
  - Collection of monitoring data for input to a common database that allows for access by outside stakeholders.
  - Data interpretation and reporting.

F. Biosolids Program

This program review identifies program practices implemented by the MPCA Biosolids Program (MBP) to prevent the contamination of groundwater. It also identifies whether additional data are needed to better evaluate the effectiveness of biosolids program practices to protect groundwater resources and notes other areas of potential concern related to the land application of biosolids and groundwater quality.

Overview

The MBP oversees the land application and storage of municipal sewage sludge or biosolids for beneficial use as a soil amendment in accordance with Minn. R. ch. 7041. Biosolids are a nutrient-rich solid, semisolid, or liquid organic material that results from the treatment of domestic wastewater (sewage sludge) by municipal treatment plants. Biosolids are land applied to improve the fertility of cropland and forestland, as well as to restore and revegetate land impacted by the mining of iron and taconite (Western Lakes Superior Sanitary District and other facilities).

In Minnesota, there are approximately 280 facilities generating biosolids on a regular basis; this number has not changed substantially over the last 10 years. The total biosolids produced in 2016 was approximately 148,825 dry tons; 21% was land applied, 61% was incinerated, and 18% was landfilled.

Table 4. Biosolids in Minnesota in 2016

Method	Amount	Percent	# of Facilities
Incinerated	90,873 Dry tons	61%	3
Land Applied	30,951 Dry tons	21%	137
Land filled	27,001 Dry tons	18%	18

On a tonnage basis, the majority of Minnesota biosolids are incinerated in St. Paul and Eagan, while a larger number of municipal wastewater treatment facilities land apply their biosolids. There are a few facilities like Grand Rapids that landfill their biosolids on a continual basis. In 2016, biosolids (class B) were land applied on 16,733 acres, approximately 1,800 fewer acres than in 2009. A majority of biosolids are applied to agricultural fields planted to field corn and soybeans. The total acreage of land where biosolids are applied in the state represents less than 0.001% of the approximately 23,000,000 acres used as cropland in Minnesota, in any given year.

Nature of concern related to groundwater

Biosolids contain nutrients (nitrogen and phosphorus), pathogens, trace metals and trace amounts of persistent organic compounds. They are routinely applied to agricultural lands as a soil amendment. If biosolids are improperly applied, some pollutants such as nitrogen could potentially leach past the soil/crop treatment zone and negatively impact groundwater quality.

The primary concern with the improper land application of biosolids to groundwater quality is from nitrate/nitrogen impacts, and to a lesser degree, pathogens. However, the conservative management requirements for land-applied biosolids make the likelihood of impacting groundwater quality negligible. The MPCA requires that all land-applied biosolids be processed and tested before use and be low in potential contaminants and treated to reduce the levels of pathogens and odor.

The conservative management of land-applied biosolids, and the relatively small acreage they are applied to, suggests a limited risk to groundwater quality, as long as they are managed in accordance with the BMPs set forth in Minn. R. ch. 7041.

Contaminants of concern

The contaminants of concern in biosolids include: nutrients (nitrogen and phosphorus primarily), trace metals, pathogens, and trace amounts of persistent organic compounds. The nitrogen content of the biosolids typically drives their application rates which are set to meet the agronomic needs of crops grown on the land they are applied. Setting the biosolids application rates to meet agronomic cropping needs helps avoid over application that could lead to nitrate impacts to groundwater quality. The phosphorus content of biosolids is usually not considered to be a threat to groundwater quality because phosphorus adsorbs to soil and typically will not leach to groundwater in appreciable quantities. Pathogens are treated in biosolids prior to land application and receive further treatment in the soil when land applied, and trace metals are tracked and regulated to prevent their excess accumulation at biosolid application sites. Nutrients, pathogens, and trace metals are regulated by MBP requirements and should not create groundwater contaminant problems if BMPs are followed.

Persistent organic compounds that include pharmaceuticals, personal care products, steroids, and hormones show high affinities for organic carbon in biosolids and preferentially accumulate in them (Kumar et al., 2017), as can be seen in the results of the Environmental Protection Agency's (EPA) Targeted National Sewage Sludge Survey of 2009. In addition, PFAS has also been detected in biosolids, biosolids amended soils, and in the environment adjacent to biosolids, application sites (Lindstrom et al., 2011; Blaine et al., 2013; Sepulvado et al., 2011; Higgins, 2017).

In general, organic contaminants tend to accumulate in biosolids in the part per billion to part per million-concentration range (Kumar et al., 2017). The relative risk of organic contaminants in land-applied biosolids is currently being debated by the water quality professionals who treat the wastewater and manage biosolids, toxicologists who set contaminant limits for food and water, and research scientists who are studying the presence of these contaminants in food crops, soils receiving biosolids applications and nearby surface water and groundwater. Ultimately, the EPA will be need to provide some regulatory direction or guidance for biosolids management, considering these contaminants, which has been provided for nutrients, metals and pathogens, under the current biosolids regulations in 40 CFR part 503 (see https://www.epa.gov/biosolids/select-biosolids-regulatory-processes).

Persistent organic chemicals are not specifically addressed within the scope of the MBP and the MBP relies on the EPA to provide regulatory guidance for biosolids management as set forth under 40 CFR part 503. The current MPCA biosolids rules (Minn. R. ch. 7041) incorporate all of the 40 CFR Part 503 requirements for land applying public and private biosolids. In the event the EPA promulgates new requirements for biosolids related to persistent organic compounds, it is reasonable to assume these requirements will be incorporated into MBP BMPs.

Program practices used to protect groundwater

The MBP applies Minn. R. ch. 7041 to biosolids land application operations in Minnesota. Minn. R. ch. 7041 includes all of EPA's 40 CFR Part 503 requirements for land applying public and private biosolids. Together these rules:

- Regulate the pathogen and vector attraction treatment standards and chemical monitoring of biosolids that are land applied.
- Establish criteria for the permitting, land application site approval, storage, pollutant limits, management practices and limitations, recordkeeping and reporting of biosolids that are land applied in Minnesota.

Biosolids land application must follow minimum design requirements. A number of these requirements provide specific protection of groundwater and several provide indirect protection of groundwater resources through management practices that prevent releases of pollutants to the environment, as follows:

- Stricter management practices are required for highly permeable soils that receive biosolids. Nitrogen application rates must comply with agronomic application rate requirements set in federal rule. The agronomic rate is the sludge application rate, which is designed to 1) provide the amount of nitrogen needed by the food crop, feed crop, fiber crop, or vegetation grown on the land, and 2) to minimize the amount of nitrogen in the biosolids that passes below the root zone to the groundwater.
- Biosolids rules require a minimum separation distance to bedrock and the seasonal high water table of three to five feet to allow for soil conditions, which are necessary to treat the biosolids, as well as provide a good growing environment for crops.
- Biosolids may not be applied within 1000 feet of a public water supply well or within 200 feet of private wells to avoid possible direct contamination of a well or water supply.
- Biosolids applications are prohibited on fallow land because there is no crop growing which will remove the nitrogen supplied by the biosolids.
- A crop must be growing on the site if biosolids are applied in June, July, and August so that any nitrogen applied is taken up by the crop rather than potentially lost to groundwater.
- Biosolids application is not allowed on cropland when the soil phosphorus test is greater than 200 part per million unless a federal Natural Resources Conservation Service conservation plan is in place.

Program data needs and recommendations

The MBP deals with data from about 280 facilities and thousands of land application sites associated with these facilities. Since June of 2015, site approval information and annual report data has not been entered into an official MPCA database. As of early 2019, all Biosolids annual reports have been scanned into Tempo; however, the data is not currently entered in a manner that facilitates use of the data. In addition, in approximately 2013, MPCA staff discontinued entering in metal loading rates into the now-retired Delta database. Site approval information and annual report data exists since the program started in 1982; while all of the information is in paper form, only some information is in electronic form, making it challenging to easily access data when needed.

Several years ago, concerns were raised that biosolids may have been a source of groundwater contamination in Lynden Township south of St. Cloud. Several area wells in close proximity to the City of St. Cloud's biosolids land application sites were found to have elevated concentrations of metals. A follow-up analysis of biosolids loading data and additional well analysis was needed to reach the conclusion that biosolids were not the source of any groundwater contamination and the original testing of these wells was in question.

- The MBP needs to have all of its biosolids land application locational information and metals loading data entered into the MPCA's Tempo database or another database, to allow for ready access and data analysis. This is necessary to address data request concerns related to groundwater quality concerns, as identified in Lynden Township, and from a program management standpoint to better track nutrient and metals concerns related to biosolids land application activities.
- There is a program interest to better understand the fate of and human health risks associated with persistent organic compounds likely to be present in biosolids (pharmaceuticals, personal care products, steroids, and hormones). However, the financial and staff resources necessary to conduct this type of work are beyond the scope of the program's resources. Currently, the testing of persistent organics in biosolids is being conducted by the EPA. It is reasonable to expect the Biosolids Program will stay current with EPA's research in this area and look for results from any risk analysis or development of pollutant limitations resulting from EPA's work.

Blaine, A.C., Rich, C.D., Hundal, L.S., Lau, C., Mills, M.M., Harris K.M., Higgins, C. 2013. Uptake of Perfluoroalkyl acids into Edible Crops via Land Applied Biosolids: Field and Greenhouse Studies. Environ. Sci. Technol., 47: 14062-14069.

Higgins, C.P. Accumulation of Perfluoroalkyl Acids in Food Crops. Colorado School of Mines. April 19th, 2017 presentation.

Kumar, K., Lakhwinder, S. H., Bastian, R.K., and Davis, B. Land Application of Biosolids: Human Health Risk Assessment Related to Micro-constituents. Water Environment Federation, 2017.

Lindstrom B.A., Strynar, M.J., Delinsky, A.S., Nakayama, S. F., McMillan, L., Libelo, E.L., Neill, M., Thomas, L. Application of WWTP Biosolids and Resulting Perfluorinated Compound Contamination of Surface and Well Water in Decatur, Alabama, USA. 2011. Environ. Sci. Technol., 2011, 45, 8015-8021.

Sepulvado, J.G.; Blaine, A.C., Hundal, L.S.; Higgins, C.P. Occurrence and fate of perfluorochemicals in soil following the land application of municipal biosolids. Environ. Sci. Technol. 2011, 45 (19), 8106-8112.

G. Inflow and Infiltration

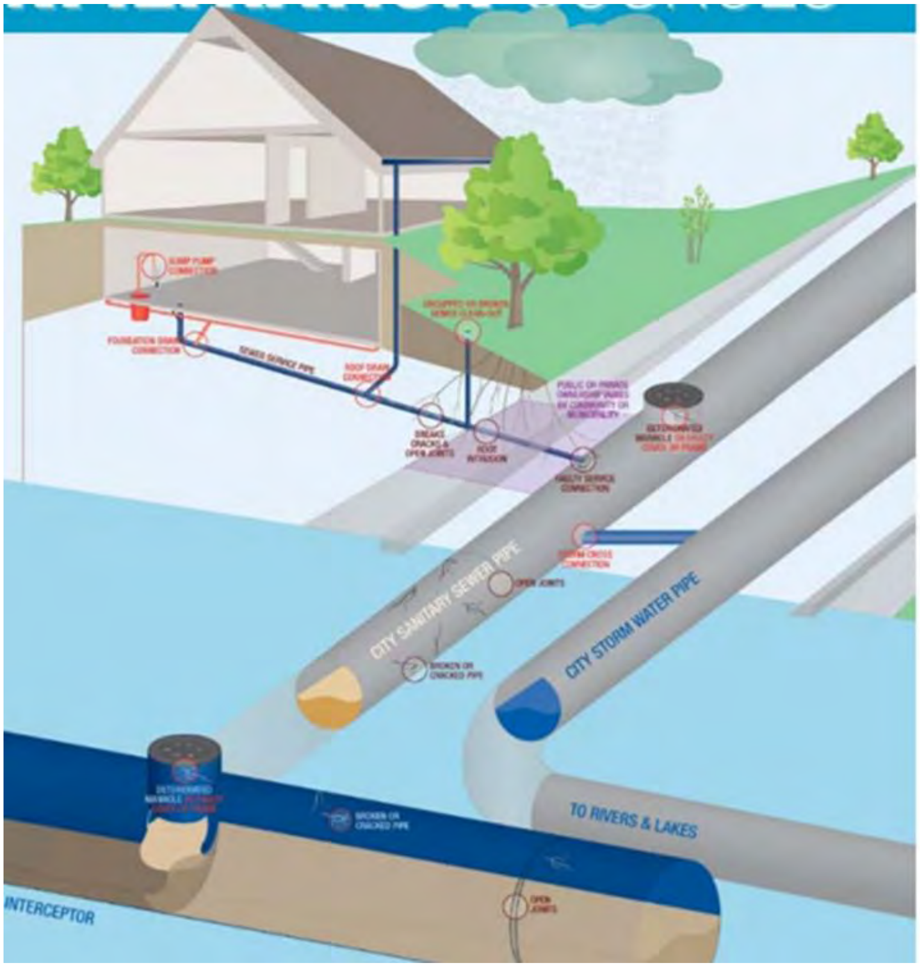


Figure credit: Metropolitan Council

Nature of concern related to groundwater

The concern has been raised that leakage from municipal wastewater piping systems or city sewers may be contributing to groundwater pollution and should be addressed within the scope of a review of MPCA groundwater protection practices. Basic definitions of inflow and infiltration (I&I): inflow is a plumbing choice (e.g. a storm drain or gutter connected to a sewage system); while infiltration is a leakage due to wear or breakage, where water is forced into pipe by external positive pressure. City sewers are known to have problems with I&I, or excess water entering sewer systems from groundwater and stormwater through holes, cracks, joints and faulty connections. However, the reverse process of wastewater leaking out of sewer pipes or exfiltration may also affect groundwater quality. The following comments were gathered from conversations with MPCA staff in the Municipal Wastewater Section.

There are thousands of miles of city sewer piping and infrastructure in various conditions throughout the state; however, there are no known volumes of wastes that can realistically be estimated as impacting groundwater from systems that do leak. Inflow and infiltration could be occurring anywhere there are city sewer systems, so it is probable this would be occurring within wellhead protection areas and vulnerable aquifers. There is no list of sites where I&I impacts to groundwater are being investigated or targeted for investigation.

I&I is recognized as a concern from the wastewater engineering perspective when groundwater leaking into old or broken sewer pipes increases the volume of water going to the publicly owned treatment works (POTW). There is a wastewater infrastructure-funding program that funds sewer rehabilitation projects where I&I may be a problem. These projects are ranked on the Clean Water Project Priority List and are overseen by the Minnesota Public Facilities Authority and other state agencies, including the MPCA. Rehabilitation projects fix leaky sewer problems, and new sewer systems are tested for sewers for leakage when they are installed. Sewer rehabilitations use materials that are less likely to leak than materials used in the past and sanitary sewer piping is separated from stormwater piping systems.

The main contaminants in sewage include bacteria measured as fecal coliform, biological oxygen demand (BOD), nitrogen, phosphorus, and numerous other parameters from improper disposal of household wastes and industrial wastes that could contain contaminants of emerging concern (CECs).

The MPCA staff noted the biggest potential impacts to groundwater from city sewers would likely be from a complete pipe failure; however, that would likely result in a sewer back up or overflow and would be identified. In addition, dry weather flow into the POTW can also be used to determine if significant leakage is occurring. If there is less flow volume than predicted by user inputs, the piping system probably leaks into the surrounding soils and groundwater.

Overall, the ability to locate and assess the impacts of leaking sewer pipes to groundwater would be very difficult to assess and monitor without exact locations of leakage. Leakage can flow along the pipe trench within the gravel sub base most pipes are laid in and enter soils or groundwater in a different area from that of the leakage. Methods such as dye tracing or video logs of piping could be used to locate leakage that may affect groundwater; however, as stated previously there is no list of sites that are being monitored or investigated for leakage impacts to groundwater.

Summary and next steps

A review of MPCA program documents and interviews with program staff indicate that several MPCA programs require groundwater quality monitoring data to verify whether their groundwater BMPs are protective of groundwater resources. More specifically, this includes groundwater monitoring of mid-sized septic systems (MSTS sites), select animal feedlot manure storage basins, stormwater infiltration sites, and enhanced monitoring at specific industrial wastewater land application sites.

In addition, analysis of existing groundwater quality data sets was also identified as a need to assess the impacts of program BMPs. The Demolition Landfill Program has a pressing need to conduct a statistical data analysis of groundwater monitoring data collected over the last eight to ten years from demolition landfills to assess the impacts of program BMPs contained in their Demolition Landfill Guidelines. The Animal Feedlot Program would also benefit from an analysis of a water quality database collected from larger permitted facilities collected from monitoring wells and tile drainage discharge stations.

Furthermore, program staff has identified a need to collect and store data in a database that allows for meaningful analysis and data sharing. Formerly, the bulk of data generated by the Solid Waste Demolition Landfill program and for the land application of industrial wastewaters and industrial by-products was stored in the now-retired Delta database. Once a decision is made concerning the restarting of the loading of this information into a MPCA database, data generated from the monitoring of stormwater infiltration sites should also be collected, assessed and made available to outside parties.

Summaries of the MPCA program data needs are provided in Appendix A in table form and more detailed descriptions are found at the end of each program write-up under the "Program BMPs and Data Needs Findings" section of the report.

Work plans

The next step in this process is to develop work plans to address program data needs that will enhance program groundwater BMPs. Developing work plans must be conducted with program staff, and management and will need to consider a number of factors. Some of these factors include available funding, staff resources, program readiness, scope or length of project, material costs, and whether the BMP evaluation should be conducted solely by the MPCA staff or jointly with outside stakeholders, consultants, responsible parties, other government entities, or contracted out entirely.

Several programs are moving forward with their priority data needs collection; however, these are limited by staffing resources. Both the Demolition Landfill and Stormwater Programs have taken initial steps to collect data for their priority needs, and the SSTS program and Industrial Waste land application programs have set their priority data needs and are looking for resources and outside partners to initiate data collection.

Appendix A

Table 1. Program data needs and recommendations

MPCA Programs	Program data needs and recommendations
Solid Waste Demolition Landfill	• Encourage reuse of demolition materials to reduce reliance on unlined facilities • Provide incentives to owners of unlined landfills to move to facilities that are more protective of degradation through using liners and leachate collection systems • Seek funding for these changes in the State of Minnesota 2018-19 Biennial Budget
Subsurface Sewage Treatment Systems (SSTS)	• Groundwater monitoring at MSTS sites • Assess impacts of smaller ISTS to groundwater monitoring for CECs • Reduce the intentional flushing of unused pharmaceuticals from home and farm
Animal Feedlot	• Follow-up testing and analysis of the drain tile discharge water sampling performed at feedlots, whose permits require testing • Evaluate older manure storage basins lacking double liners in SE Minnesota karst region • Investigate groundwater quality at larger manure storage basins
Land Application of Industrial Wastewaters and IBPs	• Unusual wastes and their environmental fate for land application scenarios are currently (2018) being investigated by the USGS Toxic Substances program • Loading rates at high BOD irrigation sites in Minnesota are much less than similar sites in other states such as MI, which may lead to further study • Site information related to application that used to be entered in the now-retired Delta database is not currently entered in its replacement, Tempo, as of 2018. There will be an attempt to once again capture this information in the future.
Stormwater	• Promote creation of statewide GIS layers to evaluate options to infiltrate stormwater in new development & redevelopment areas in context of vulnerable aquifers • Develop case studies to assess groundwater impacts for stormwater infiltration BMPs (e.g. the Minnesota Stormwater Manual; consider Cl, pathogens, infiltration at brownfields, etc.) • Data collection for stormwater infiltration projects
Biosolids	• No specific recommendations for groundwater monitoring • Biosolids annual reports have been scanned into Tempo, but the data is not in a readily accessible format. New biosolids site approvals and cumulative metals loading data have not been stored electronically since the switch to Tempo. There is a recognized program need to store this data within Tempo. • There is a recognition that the fate of persistent organic compounds (i.e. pharmaceuticals, personal care products, steroids, PFAS, and hormones) in biosolids is important; however, the financial and staff resources necessary to conduct this type of work are beyond the scope of the program’s current resources.
Inflow and Infiltration (I&I)	• Limited groundwater impact concerns. Concerns relate to groundwater leaking into wastewater infrastructure. • Investigating leakage to groundwater would be difficult and has not been done in the Municipal Program.

'Manure is complicated': 5 reasons you need a manure management plan

blog-crop-news.extension.umn.edu/2023/06/manure-is-complicated-5-reasons-you.html

By: Chryseis Modderman, Extension manure management educator

When applying manure, the main goals are to apply at an accurate rate and to avoid nutrient pollution. But this isn't always easy because manure, in general, is complicated. There are five main factors that make manure complicated; often, more complicated than commercial fertilizer. Following a manure management plan will help combat these challenges. Read on for the five challenging factors.

Overall nutrient content is low

Total nutrient content of manure is low – rarely above 10 percent – whereas commercial fertilizers have a much higher nutrient concentration by weight. The low nutrient content of manure is a potential problem because you need a lot more volume of manure than commercial fertilizer to achieve the same nutrient application rates. This increases time and transportation cost, making it more economical to apply to the field nearest the barn. Over time, repeated over-application to the same field can lead to nutrient build up and subsequent pollution. It is quite common to see fields nearest a livestock operation with very high soil test phosphorus levels.

Nutrient ratio is fixed

Unlike commercial fertilizers that can be mixed and adjusted to reach desired nutrient balance, manure nutrients are fixed. It is what it is. Let’s do some quick math to illustrate this. Let’s say you have turkey manure with 30 pounds of plant-available nitrogen and 40 pounds of plant-available phosphorus per ton, and your agronomist says to apply 180 pounds of nitrogen per acre for your corn crop. You’d need to apply manure at six tons per acre (180 / 30 = 6).

Does this application rate pose a risk for nutrient pollution? Yes. At 6 tons/acre, you will apply 240 lbs P/acre (40*6=240). Corn only uses 0.29 lbs P per yield unit. So, even a really high yield of 250 bu/ac corn would only require 72.5 lbs P/acre; and that’s including what is already in the soil. Adding 240 lbs of P is way too much! Over-application of phosphorus can lead to phosphorus buildup, which can lead to pollution.

Nutrient availability is difficult to estimate

Nutrient availability, especially the availability of nitrogen, can be challenging to accurately estimate. Manure supplies two forms of nitrogen: inorganic and organic nitrogen. The inorganic nitrogen is immediately available to the plant; while the organic nitrogen is not. Organic nitrogen can become inorganic nitrogen over time through a process called mineralization. The challenge is estimating how much organic nitrogen will become inorganic nitrogen, and how fast. This can be tricky because mineralization is a microbial process, meaning that how fast or slow it processes organic nitrogen depends heavily on the environment. And we know how fickle the environment can be!

Nutrient content is not uniform

Unlike commercial fertilizers that are fairly uniform throughout, manure uniformity varies spatially and over time. This can make accurate rate calculations tricky. To meet this challenge, it is very important to take a good representative manure sample for testing. But even then, it is likely that slight over- or under-application can occur.

Nutrient timing may not be ideal

In a perfect world, manure would only be applied when the nutrients are necessary and when it poses the least risk to the environment. Unfortunately, we don’t live in a perfect world. Often, manure application timing is driven by storage limitations and working around wet weather, harvest, or planting rather than when it is best for the crop and environment. Nutrient loss from manure is higher when application occurs in late winter, around the time of snowmelt.

How to meet these challenges

While we may never be 100 percent perfect with manure management, there are ways to minimize these challenges. The most significant is to have a manure management plan which encompasses best management practices such as accurate rate calculations, sampling, setbacks and buffers, spreader calibration and more!

This post was originally published by Manure Manager and has been republished here with permission.

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June 18, 2024

VIA EMAIL

Stephen M. Jann, Manager
Permits Branch, Water Division
U.S. EPA Region 5
77 W Jackson BLVD
Chicago, IL 60604

RE: U.S. Environmental Protection Agency Review of Pre-Public Notice Draft Feedlot NPDES General Permit (MNG440000)

Dear Stephen M. Jann:

The Minnesota Pollution Control Agency (MPCA) reviewed the U.S. Environmental Protection Agency's (EPA) comments and recommendations of Minnesota's Pre-Public Notice Draft Feedlot National Pollutant Discharge Elimination System (NPDES) General Permit (Permit), fact sheet, and supporting documents submitted to the MPCA on May 9, 2024. After thoughtful consideration, the MPCA offers the following response.

Comment 1
EPA has direct implementation for the NPDES program in Indian Country. The Permit should contain language excluding concentrated animal feeding operations (CAFOs) located within Indian Country from coverage under the Permit.

Response 1
The *Permit Eligibility* section of the Permit will be modified to exclude facilities in Indian Country from coverage under the Permit.

Comment 2
The Permit needs to specify the required contents of the notice of intent for coverage under the Permit. 40 C.F.R. § 122.28(b)(2)(ii).

Response 2
The MPCA's permit application for coverage under the Permit is Minnesota's equivalent to the notice of intent for coverage (NOC). The permit application includes all the required contents of the specified federal regulation and applicants for NPDES permit coverage must use this application. The definition of *permit application* will be modified in the Permit to clarify the permit application includes all the information required by the specified federal regulation.

Comment 3
The Permit needs to specify the deadlines for submitting notices of intent for coverage under the Permit. 40 C.F.R. § 122.28(b)(2)(iii).

Response 3
Minnesota's equivalent to the specified federal regulation is found in Minn. R. 7020.0505. This rule part specifies a deadline of at least 180 days for submitting a permit application for new or expanding facilities. A requirement will be added to the Permit that is consistent with Minn. R. 7020.0505 and the specified federal regulation. Additionally, the *Permit Coverage* section of the Permit specifies a deadline of at least 180 days for submitting a permit application to maintain continuous permit coverage and for modifications.

Comment 4
Permit Part 1.4 allows for suspension of the Permit in accordance with Minn. R. 7001.0170 through 7001.0190; however, the referenced state rules do not include suspension of permits. Federal regulations do not recognize suspension of permits; federal regulations recognize modification, revocation and reissuance, or termination of permits. The word "suspended" needs to be removed. 40 C.F.R. §§ 122.62 and 124.5.

Response 4
The word suspended will be removed from the specified part of the Permit.

Comment 5
Permit Part 2.5 contains requirements regarding the change of ownership or control of the facility. Minn. R. 7020.0405 only allows a change of ownership or control of an animal feeding operation or manure storage area through a permit modification. Therefore, Part 2.5 needs to be revised to conform with 40 C.F.R. § 122.63, by requiring that a permit modification request include a written agreement with a specific date for transfer of permit responsibility, coverage, and liability between the current and new permittees.

Response 5
As noted in the comment, the transfer of permit responsibility, coverage, and liability is managed through the MPCA's permit modification process. Through this process, the specific date for transfer of permit responsibility, coverage, and liability are transferred from the current and new permittee at the time coverage under the Permit is issued to the new owner/operator of the facility. Additionally, the Permit stipulates in the *General Conditions* section, "The permit is not transferable to any person without the express written approval of the agency …," and in the *Facility Modifications* section, "if ownership or control changes without an assignment of coverage under this Permit, the original Permittee may still be held liable for violations and the new owner/operator may be held liable for operating without a permit." To ensure the specified federal regulation is satisfied, the MPCA's application for a permit modification will be revised to clarify the specific date for transfer of permit responsibility, coverage, and liability occurs at the time coverage under the Permit is issued to the new owner/operator of the facility.

Comment 6
When manure is transferred, Permit Part 9.4 requires that the permittee provide to the manure recipient, at the time of transfer of ownership, a "Manure Transfer Tracking" form that is generated by the Nutrient Management Tool. This form does not include the date of manure transfer but should. 40 C.F.R. § 122.42(e)(3).

Response 6
The Nutrient Management Tool will be modified to include the date of manure transfer.

Comment 7

Permit Part 10.2 requires the CAFO to use Minnesota's Nutrient Management Tool to develop and maintain the Manure Management Plan (MMP). The Minnesota Nutrient Management Tool does not conform with the following requirements of 40 C.F.R. § 122.42(e)(1) nor does the Permit include specific conditions that conform with these federal requirements. Conditions addressing these federal requirements need to be included in the Permit or the Minnesota Nutrient Management Tool could be updated to include these federal requirements.

Response 7

The Permit will be modified to address the specified federal regulation in the following ways.

Comment 7a

The Permit does not specifically prohibit the disposal of mortalities in storm water storage systems. 40 C.F.R. § 122.42(e)(1)(ii).

Response 7a

The *Requirements for Operation and Maintenance of the Facility* section of the Permit will be modified to prohibit disposal of mortalities in stormwater storage systems.

Comment 7b

The Permit does not specifically require that clean water be diverted, as appropriate, from the production area., 40 C.F.R. § 122.42(e)(1)(iii).

Response 7b

The *Requirements for Operation and Maintenance of the Facility* section of the Permit will be modified to ensure clean water is diverted, as appropriate, from the production area.

Comment 7c

The Permit does not specifically prohibit the disposal of chemicals and other contaminants handled on-site into storm water storage systems. 40 C.F.R. § 122.42(e)(1)(iv).

Response 7c

A requirement will be added to the *Requirements for Operation and Maintenance of the Facility* section of the Permit to prohibit the disposal of chemicals and other contaminants handled on-site into storm water storage systems.

Comment 8

Permit Part 15.1 contains land application setback requirements. Federal regulations require that manure, litter, and process wastewater not be applied closer than 100-foot to any down-gradient surface waters, open tile intake structures, sinkholes, agricultural well heads, or other conduits to surface waters unless a compliance alternative is exercised. Part 15.1 includes setbacks for several land features; however, Part 15.1 does not include a setback for the broader term "other conduits to surface waters" which would ensure setback requirements apply to all conduits to surface waters rather than just those identified in the Permit. 40 C.F.R. § 412.4(c)(5).

Response 8

A requirement will be added to the *Land Application of Manure - Setbacks* section of the Permit to include a 100 ft setback for other conduits to surface waters.

Comment 9
Permit Parts 16.2 and 16.3 require "that the production area is designed, constructed, operated, and maintained to contain all manure, manure-contaminated runoff, or process wastewater, and all direct precipitation" (Emphasis added). To conform with federal regulations, the word "or" needs to be removed from Parts 16.2 and 16.3. Federal regulations require that production areas are designed, constructed, operated and maintained to contain all manure, litter, and process wastewater (Emphasis added). 40 C.F.R. Part 412.

Response 9
The word *or* will be removed from the specified part in the *Requirements for Operation and Maintenance of the Facility* section of the Permit.

Comment 10
Permit Part 26.5 does not conform to the federal requirements because it does not identify an overflow as a discharge. In order to conform with federal regulations, Part 26.5 needs to be revised to read "... unless the discharge is an overflow of manure or process wastewater that is caused by a precipitation event ..." (Emphasis added). 40 C.F.R. Part 412.

Response 10
The specified part in the *Effluent Limitation* section of the Permit will be modified to read "... unless the discharge is an overflow of manure or process wastewater that is caused by a precipitation event ...".

Comment 11
Federal regulations require that each NPDES permit (1) include monitoring requirements to ensure compliance with permit limitations and (2) specify required monitoring including type, intervals, and frequency sufficient to yield data which are representative of the monitored activity. 40 C.F.R. §§ 122.44(i) and 122.48. Permit Part 27.5 requires the permittee to ensure that all discharges, spills, or overflows associated with the facility do not cause or contribute to non-attainment of water quality standards. The Permit needs to require monitoring of discharges, spills, or overflows to ensure compliance with Part 27.5. In order to assess compliance with the reference to water quality standards in Part 27.5, monitoring of discharges to surface waters from a production area for volume, duration, pH, phosphorus, NH3-N, BOD, TSS, dissolved oxygen, and E.coli should be required.

Response 11
A part will be added to the *Discharge, Spills, and Overflows* section of the Permit to require monitoring of discharges to surface waters. The requirement will include actions to obtain grab samples of the discharge within a specified time of discovery, and one sample per day thereafter until the discharge is stopped. The requirement will also include actions to obtain analysis for pH, total nitrogen, ammonia nitrogen, total phosphorus, E. coli, five-day biochemical oxygen demand (BOD5), and total suspended solids. This section of the Permit already includes a requirement to monitor discharge volumes.

Though the MPCA values monitoring and its importance for assessing water quality and determining compliance, the MPCA understands the challenges this requirement presents due to the acute and overland nature of discharges from permitted CAFO in Minnesota. To assist Minnesota and other delegated states, the MPCA requests USEPA to provide guidance documents and training videos on monitoring and sample collection for discharges from CAFOs.

Comment 12
The federal definition of "production area" includes bedding material in the raw materials description, while the definition of "Production Area" in Permit Part 30.47 does not include "bedding materials" in the raw materials description. Part 30.47 definition of "Production Area" needs to be revised to conform with the federal definition. 40 C.F.R. § 122.23(b)(8) and 40 C.F.R. § 412.2(h).

Response 12
The definition of production area will be modified to include "bedding materials" in the raw materials description.

Comment 13
The Standard Conditions of 40 C.F.R. § 122.41 are not incorporated by reference into the Permit. The Permit does not contain the following standard conditions or words used to describe particular conditions do not adequately conform with the following federal standard conditions:

a. Duty to Comply § 122.41(a);
b. Permit Actions § 122.41(f);
c. Duty to Provide Information § 122.41(h);
d. Monitoring and Records § 122.41(j);
e. Signatory Requirement § 122.41(k);
f. Reporting Requirement - Permit Transfers § 122.41(l)(3);
g. Reporting Requirement - Compliance Schedules § 122.41(l)(5);
h. Reporting Requirement - Twenty-Four Hour Reporting § 122.41(l)(6);
i. Reporting Requirement - Other Information § 122.41(l)(8);
j. Reporting Requirement - Identification of the initial recipient for NPDES electronic reporting data § 122.41(l)(9);
k. Bypass § 122.41(m); and
l. Upset § 122.41(n).

Response 13
The Permit will incorporate by reference the specified federal regulations in the *General Conditions* section of the Permit. Additionally, Minnesota's equivalent to the specified federal regulations is found in Minn Rule 7001.0150, subp. 3. These conditions are included in the *General Conditions* section of the Permit.

In addition to the comments included above, EPA included comments identified in Enclosure A of the letter in order to improve the overall Permit .

Enclosure A, Comment 1

It is recommended that the Permit include a requirement to identify, in the MMP, subsurface drain tiles on all fields where manure or process wastewater is land applied, and to require observation of subsurface drain tile outlets prior to, during and following land application of manure or process wastewater for volume/rate of flow and color, turbidity, foam, and odor to identify any discharges that may violate effluent limitations.

Response Enclosure A, Comment 1

The MPCA's Nutrient Management Tool, that will be used by permittees to develop manure management plans, requires the permittee to identify the presence of subsurface drain tile inlets on fields where manure and process wastewater will be applied. This indication will automatically generate, and alert the permittee to, the applicable drain tile inlet requirements from the *Land Application of Manure – Setback* section of the Permit. Additionally, a requirement to monitor field tile inlets at or near land application sites during and after land application events was added to *the Land Application of Manure – Inspections* section of the Permit. Though the MPCA values monitoring and its importance for assessing water quality and determining compliance, requiring observations of subsurface drain tile outlets to identify any discharges that may violate effluent limitations presents challenges in Minnesota. Many tile systems in Minnesota are complex networks that connect to other systems before daylighting, miles downstream of the original system. Due to this complexity, discerning the source of effluent volume/rate of flow and color, turbidity, foam, and odor is very difficult. Minnesota will continue to focus on preventing manure and manure contaminated runoff from entering drain tile intakes through measures such as planning, setbacks, buffers, incorporation of manure, and inspections.

Enclosure A, Comment 2

Permit Part 1.2 authorizes the Permittee to operate the facility in compliance with the requirements of Minn. R. 7020, and Minn R. 7020.2015 prohibits animals from entering waters of the State. The Permit could be improved by including a requirement that specifically prohibits the direct contact of confined animals with waters of the United States. 40 C.F.R. § 122.42(e)(1)(iii).

Response Enclosure A, Comment 2

Minnesota's equivalent to the specified federal regulation is found in Minn. R. 7020.2015. This rule part prohibits animals of a CAFO from entering waters of the state. A requirement will be added to the *Requirements for Operation and Maintenance of the Facility* section of the permit that is consistent with Minn. R. 7020.2015 and the specified federal regulation.

Enclosure A, Comment 3

Federal regulations require that manure, litter, and process wastewater not be applied closer than 100-foot to any down-gradient surface waters, open tile intake structures, sinkholes, agricultural well heads, or other conduits to surface waters unless a compliance alternative is exercised. 40 C.F.R. § 412.4(c)(5)(ii) provides that a CAFO may demonstrate that an alternative conservation practice or field-specific conditions will provide pollutant reductions equivalent or better than the reductions achieved by a 100-foot setback. Permit Parts 15.4 through 15.7 include alternative conservation practices. Permit Part 10.2 requires that the manure management plan developed by a Permittee contain requirements of land application of manure sections of the Permit, this would include Parts 15.4 through 15.7. EPA recommends that the State require Permittees selecting to use one of the alternative conservation practices included in Parts 15.4 through 15.7 include a demonstration in the MMP that the alternative conservation practice implemented on a specific land application area will provide pollutant reductions equivalent or better than the reductions achieved by a 100-foot setback.

Response Enclosure A, Comment 3

During the development of the MPCA's 2006 NPDES general permit, the MPCA conducted a literature review to demonstrate the alternative setbacks listed in the *Land Application of Manure – Setbacks* section of the Permit are equivalent to the reductions achieved by the 100 ft setback of the specified federal regulation for all land application areas in Minnesota. The literature review is recorded in the MPCA's summary document, *Runoff Reductions with Incorporated Manure*. The alternative setbacks have been included in subsequent MPCA NPDES CAFO general permits with the implication the specified federal regulation is satisfied for permittees. To clarify this, the *Land Application of Manure – Setbacks* section of the Permit will be modified to explain the listed setbacks are equivalent to the 100 ft setback of the specified federal regulation.

Enclosure A, Comment 4

If a production area is designed, constructed, operated and maintained consistent with federal regulations, the need for emergency manure application should be rare, if at all. It seems a need should only arise, if at all, at the end of the design storage period of the collection of storage devices (i.e., just before crop harvest in the fall and just before the lifting of winter land application restrictions). Permit Part 30.20 defines Emergency Manure Application, and Permit Parts 13.2 and 13.6 authorize emergency land application. Weather is inherently variable. EPA recommends that the definition of emergency manure application provide further clarification on what constitutes "unusual weather conditions" and expand the definition to include opportunities to manage manure other than storage, i.e., treatment, before emergency manure application is allowed.

Response Enclosure A, Comment 4

Instances of emergency manure application under the specified parts of the Permit are rare. The *Additional Requirements for Operation and Maintenance of Liquid Manure Storage Areas (LMSA)* section of the Permit requires permittees to notify the MPCA within 24 hours of encroachment into the freeboard of liquid manure storage areas. This requirement provides the opportunity for MPCA staff and the permittee to explore alternatives to emergency land application of manure such as transporting manure to a different storage area. The MPCA will continue to rely on communication with permittees to manage instances of emergency manure application in the most protective way possible.

Thank you for the thorough review of Minnesota's Pre-Public Notice Draft Feedlot NPDES General Permit (Permit), fact sheet, and supporting documents. The numerous meetings and frequent communication with your staff were appreciated. The MPCA will provide a copy of the final permit and Minnesota's response to any significant comments received during any public notice period as specified in your May 9, 2024 letter.

Sincerely,

Glenn Skuta

This document has been electronically signed.

Glenn Skuta
Division Director
Watershed Division

GS/LS:rjp

cc: Michael Kuss, EPA R5-WD-Permits (electronic)
Lisa Scheirer, MPCA
George Schwint, MPCA
Randy Hukriede, MPCA
Steve Schmidt, MPCA

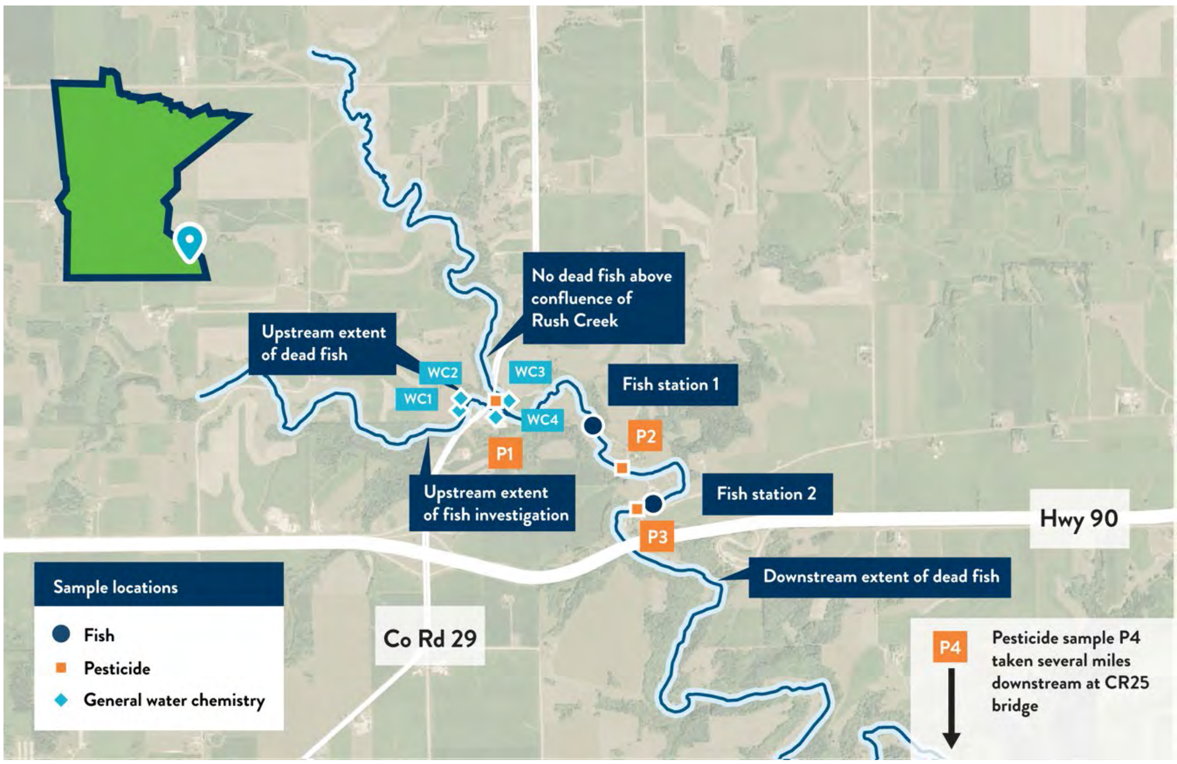
MINNESOTA

Pollution Control Agency | Department of Natural Resources | Department of Agriculture

Rush Creek fish kill response — Winona County

Summary

Rush Creek is a cold-water trout stream that begins just south of the city of Lewiston in Winona County. It flows in a southerly direction into Fillmore County and eventually joins the Root River at the city of Rushford. Rush Creek is highly valued by trout anglers.



Rush Creek investigation map

On the evening of July 25, 2022, the Minnesota Duty Officer (MDO) received a report of several dead fish in Rush Creek. Local staff from the Minnesota Department of Natural Resources (MDNR) and Minnesota Pollution Control Agency (MPCA) began coordinating a response immediately. The field response began the following morning, July 26, and included staff from Winona County, the Minnesota Department of Agriculture (MDA), MDNR, and MPCA.

Fisheries staff from the MDNR estimated that more than 2,500 fish were killed, including at least 1,900 brown trout. The remaining species included white sucker and mottled sculpin. The responding agencies concluded that the fish kill likely happened after a significant runoff-producing local rainfall event on July 23, 2022 (1.5 inches to 2 inches that fell in a short period of time). Several factors may have contributed to the fish kill including warm temperatures, recent upstream applications of manure and pesticides, and low-flow conditions in the creek prior to the rainfall, resulting in limited dilution of the contaminated runoff.

Two branches of Rush Creek converge in the area of the fish kill; one from the north in the direction of Lewiston, the other from the west. Because no dead fish were observed in the branch from the north, it was concluded that the contaminated runoff came from the 10 square-mile area that drains to the western branch. This eliminated from consideration a wastewater discharge from the City of Lewiston.

First report, response, extent, and size of fish kill

Following the report to the Minnesota Duty Officer, local staff from DNR and MPCA began coordinating a response on the evening of July 25, 2022.

On July 26, MDNR Fisheries staff, MPCA feedlot staff and water monitoring staff, MDA pesticide monitoring staff, and Winona County feedlot staff were all on site. MDNR Fisheries staff walked the stream to determine the geographic extent of the fish kill and to document the type, size, and number of fish lost. MPCA and Winona County feedlot staff evaluated livestock facilities and a manure application field in the vicinity of the fish kill and began a broader survey of livestock facilities in the larger upstream drainage area. MPCA and MDA monitoring staff made visual observations, took field measurements, and collected water chemistry samples as well as macroinvertebrates at multiple locations on Rush Creek.

White sucker fish found in Rush Creek

MDNR Fisheries staff determined that the fish kill occurred over two miles of Rush Creek from just upstream of Winona County Road 29 to downstream of Interstate Highway 90. Their survey of 1,050 feet of Rush Creek collected 162 brown trout, 27 white sucker, and 23 mottled sculpin. The estimated total number of fish killed were 2,523 including 1,921 brown trout, 325 white sucker, and 277 mottled sculpin. *For information about fish by location, type, size, and quantity, see Tables 1-3 in the Appendices.*

On the morning of July 27, DNR Fisheries staff noticed after a second, smaller rainfall event, that the western branch of Rush Creek was cloudy and discolored as compared to the branch from the north. Fisheries staff collected water samples for analysis by MPCA and MDA.

In subsequent days, additional investigatory visits were made to the area, including a visit on August 4 that included a stream ecologist from Winona State University accompanying MDNR Fisheries staff surveying aquatic macroinvertebrates in Rush Creek.

Water sample results

MPCA and MDA staff coordinated water quality sampling on July 26 at multiple locations on Rush Creek. The samples were analyzed for 182 different pesticide analytes (including fungicides and insecticides) and 13 different general water chemistry analytes (*see Table 4 in Appendices*) typically measured during fish kills. None of the analytes were detected at elevated levels.

Additional samples were also taken on July 27, after a small rain event. This rain event produced observed runoff and stream response, so a sample was collected to gain information about potential sources that may have still been present in the watershed. Elevated levels of E. coli bacteria (an indicator of manure or sewage) and phosphorus were present in this sample, but the remaining general water quality parameters were not found at elevated levels. Compared to the July 26 sample, some additional pesticides were detected, but not at elevated levels. The results showed organic pollution, which is common for a runoff event in this region. *See Table 5 for pesticide sample results.*

Organic pollution results from the decomposition of living organisms and their by-products. This includes decaying plant material, manure and human sewage, livestock feed, and waste products from the food processing industry. Organic pollution can be directly or indirectly toxic to fish and other aquatic life.

Typically, water quality impacts from fish kill events are difficult to capture unless samples are collected within a short period of time (i.e., ideally within 24 hours). Streams will often fall back to “normal” water chemistry levels very quickly after storms due to constant inflows of new groundwater. By the time water samples were taken on Rush Creek (two to three days after the storm event), the contamination that killed the fish had already moved downstream and/or was significantly diluted, making it difficult to detect in water quality samples.

Aquatic macroinvertebrate sample results

There were two primary purposes for the macroinvertebrate sampling conducted by a stream ecologist from Winona State University and MDNR Fisheries staff. The first purpose was to help understand whether there would be broader or lingering ecological impacts to Rush Creek beyond the fish that died at the end of July. Macroinvertebrates play a key role in a stream’s food chain. In simple terms, they eat algae and other organic matter and become food for fish. While fish are highly mobile and can recolonize rapidly, it would take some time for macroinvertebrates to return to an area where they were severely impacted. The second purpose for the sampling was to provide clues to possible causes of the fish kill, as fish and macroinvertebrates have different susceptibilities to pollutants.

The intent of the macroinvertebrate sampling was to assess conditions at multiple locations in the fish kill zone, and to compare these results with a sample from the non-impacted north branch of Rush Creek. There was also a limited opportunity to compare with previous macroinvertebrate sampling on Rush Creek.

The macroinvertebrate sampling results indicate that whatever killed the fish in Rush Creek did not harm the macroinvertebrate community in an appreciable way. A comparison of the macroinvertebrate data collected on Rush Creek above and below the confluence with the South Tributary stream did not show any differences that suggest an impact to the macroinvertebrate community. Similarly, a comparison between the data collected in the South Tributary, to the data collected on the upstream and downstream reaches did not show any discernable differences. There were subtle differences in the data, but not more than would be expected to occur naturally.

Combined with the pesticide water sample results, the lack of impact to the macroinvertebrate community may suggest pesticides were less of a factor in the fish kill as compared to organic pollution.

Feedlot and pesticide use survey results

MPCA and Winona County staff conducted multiple feedlot inspections and in-field land application inspections in the area of the fish kill on July 26, July 27, and Dec 12, as well as a stockpile investigation on Aug 11. These inspections included feedlot facility inspections, review of land-application of manure records, and in-field land-application inspections. Winona County feedlot staff requested land application of manure records from all facilities located within the 10 square-mile watershed in the western branch of Rush Creek. Of the 100 landowners contacted regarding manure application and manure stockpiling activities, Winona County received more than 60 responses. Winona County determined that those who did not respond were not feedlot owners, were small feedlot owners who were not required to maintain land-application records or were small land/feedlot owners whose land did not directly impact the stream (meaning the land was in the watershed, but any run-off from the land would flow overland across others property prior to making it into a Rush Creek).

The inspections and records review showed that two facilities within the watershed had inadequate or incomplete records, as well as setback violations from sinkholes and special protection areas. This resulted in notices of violation issued to these two facilities. However, during the course of the in-field land-application inspections, no evidence of direct discharge to Rush Creek was found. The MDA surveyed property owners in the vicinity of Rush Creek to identify potential pesticide applications in the area. During the MDA's investigation, they identified cropland that had received pesticide applications around the time of the rain event on July 23. After reviewing application records and applicator interviews, the MDA found no label violations associated with these applications.

Fish kill cause: Burst of rain; contaminated runoff; low creek flows

Responding state agencies concluded that contaminated runoff following a significant rainfall event on July 23 likely caused the fish kill. As discussed previously, several factors may have contributed to the fish kill including warm temperatures, recent upstream applications of manure and pesticides, and low-flow conditions in the creek prior to the rainfall, resulting in limited dilution of the contaminated runoff. It is difficult to determine how a mix of contaminants might interact to harm fish. Warm summer temperatures and lower flows may also elevate stream temperatures; this in turn may stress cold-water fish species and make them more susceptible to mortality, although there is no direct evidence that this was the case here.

Infectious disease may also be an important factor associated with fish kills in Minnesota, and opportunistic bacterial pathogens are implicated in multiple freshwater fish mortality events each year. However, infections disease was ruled out as a major contributing factor to the Rush Creek mortality event since standard pathological inspection (including parasite screening, viral and bacterial culture) did not uncover any infectious agents.

Fish community recovery

As we have observed in recent fish kills, fish will continue to return to the section of stream where the kill occurred, but it will take years to replace the larger fish that previously resided in this section of stream. Rush Creek is known for having abundant brown trout, is larger than most area streams, and is over 22 miles long. These are all factors that increase resiliency, but brown trout are a sensitive fish species. A fish kill of this magnitude will certainly disrupt the size structure, species diversity, and numbers of catchable size trout. If pollution events continue, there could be detrimental effects to the entire stream long-term.

Also, despite the apparent resiliency observed in Minnesota driftless-region trout streams so far, large scale mortality events are evidence of severe stressors that are concerning, including the possibility of increased frequency of extreme weather events. Minnesota waters are expected to continue their warming trends and be impacted by increased frequency of severe precipitation events. Thus, it is imperative to identify and work to mitigate stressors associated with large scale mortality events in these vulnerable fisheries.

Next steps

This is the fourth significant trout stream fish kill in this part of southeastern Minnesota since 2015. The other fish kills occurred on the South Fork of the Whitewater River, Garvin Brook, and Trout Valley Creek. Certain common conditions and risk factors have emerged. These include low stream flow, warm air temperature, elevated water temperatures, thunderstorms, and the presence of certain types of pollutants that are susceptible to runoff.

Unauthorized releases and permit violations that lead to fish kills are preventable and unacceptable. To mitigate the fish kill risk, the MPCA, MDNR, and MDA are working to summarize and proactively communicate these risk factors as part of an interagency effort. An emphasis of this communication effort will be on the use of weather and runoff forecasting tools to help plan the timing of manure and pesticide applications. Additional strategies include inspections of livestock facilities, including land application of manure records and field reviews, in areas where fish kills have occurred, and the precise identification of high-risk runoff pathways on agricultural fields in a part of Minnesota characterized by steep slopes and karst topography.

For more information

It is critical for anyone that observes a fish kill to report it immediately to increase the chances of identifying the cause or source for a fish kill. If you see something, contact the MDO at 800-422-0798. If there is an immediate threat to life or property, call 911 first.

There is more information on fish kills in Minnesota on the MPCA website. You can also learn more on the DNR website.

Appendices — Rush Creek fish kill

Table 1. Universal Transverse Mercator (UTMs) of stations on Rush Creek, July 26, 2022. Station 1 and 2 were counting dead fish and fish kill extent is the entire reach dead fish were observed (12,437 ft).

Station	Station length (feet)	Downstream UTMs (easting, northing)	Upstream UTMs (easting, northing)
Fish station 1	536	591071, 4865976	591017, 4866125
Fish station 2	514	591528, 4865304	591670, 4865369
Fish kill extent	12,437	592004, 4864755	590280, 4866074

Table 2. Species and length of dead fish collected in Station 1 and 2 (1,050 ft) on July 26, 2022.

Species	Length category	Number
Brown trout	3-5 inches	33
Brown trout	6-10 inches	112
Brown trout	11-15 inches	15
Brown trout	16-20 inches	2
White sucker	ALL	27
Mottled sculpin	ALL	23
	TOTAL	**212**

Table 3. Estimated numbers of dead fish in Rush Creek (12,437 ft).

Species	Estimated number	% of total
Brown trout	1,921	76%
White sucker	325	13%
Mottled sculpin	277	11%
TOTAL	**2,523**	

Table 4. General Water Chemistry Sample Results

	Water Sample Station			
	WC1	WC2	WC3	WC4
Date	7/26	7/26	7/26	7/27
	all values in mg/l			
Ammonia-N	0.10	<	<	0.06
Unionized ammonia	0.011*	na	na	na
Chloride	25.3	25.7	34.9	23.4
NO2/NO3	<	12.0	8.7	7.9
TSS	490	5.2	10	28
TSVS	100	<	3.2	9.0
TP	2.06	0.068	0.102	0.491
Ortho-P	1.42	0.059	0.089	0.301
TKN	9.07	<	<	1.04
CBOD (5-day)	25.7	0.78	0.99	na
Comments	Standing water near stream; 1L given to MDH for pesticides; some analyses not available	South (west) trib.	North trib.	South (west) trib.; repeat sample by DNR next day after 0.5 inches rain; preserved late.; E. coli out of hold - 24000 MPN/100ml

< = below reporting limit, non-detect
All field parameters (temperature, pH, dissolved oxygen, conductivity) taken were normal on 7/26
*Chronic WQ standard for unionized ammonia for cold-water streams (0.016 mg/L; 16 ug/L)

Table 5. Rush Creek Fish Kill Pesticide Samples

Analyte	P1 - CR 29 South Tributary		P2 - CR 5 North	P3 - CR 5 South	P4 - CR 25	Lowest available aquatic life fish benchmark or MN state standard
All results and reference values are in ng/L						
2022 Dates sampled	**7/26**	**7/27**	**7/26**	**7/26**	**7/26**	
2,4-D	< 8.3	9.15	22.6	16	18.4	79,200
Acetochlor ESA	31.8	162	98.3	96.6	99.5	> 90,000,000
Acetochlor OXA	< 33.3	296	98.6	96.6	< 33.3	No benchmark available
Alachlor ESA	< 41.6	< 41.6	178	165	595	> 52,000,000
Atrazine	32.2	60.7	33.9	< 30	46.4	3,400†
Azoxystrobin	< 10	36.7	< 10	< 10	< 10	147,000
Deethylcyanazine Acid	< 25	< 25	< 25	< 25	28.8	No benchmark available
Desethylatrazine	92.9	72.4	97.1	98.9	84.6	1,000,000*
Didealkylatrazine	155	151	206	199	151	> 50,000,000
Hydroxyatrazine	13.7	58.8	29.1	28.1	18.6	> 1,500,000
Metolachlor ESA	455	258	546	504	425	24,000,000
Metolachlor OXA	< 10	36.1	28.4	26.6	16.1	> 46,550,000
Propiconazole	< 10	25.6	< 10	< 10	< 10	15,000
Pydiflumetofen	< 10	49.0	< 10	< 10	< 10	42,000‡

† Class 1B, 2A and 2Bd waters; protected for cold water aquatic life and drinking water
* No fish benchmark available; used the non-vascular plant benchmark value for reference
‡ No fish benchmark available; MDA calculated an insect-based value based on toxicity data from the EPA Environmental Fate and Effects Division (EFED)

FRONTIER: EATING THE METAPHORICAL ELEPHANT: MEETING NITROGEN REDUCTION GOALS IN UPPER MISSISSIPPI RIVER BASIN STATES

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HIGHLIGHTS

- Meeting nutrient reduction goals will be a massive effort with many challenges.
- No one practice or group of practices will meet the goals; a mix of multiple practices is needed.
- Edge-of-field practices become increasingly important as implementation level increases.
- Understanding the scale of the challenge is a necessary step toward meeting the challenge.

Keywords. *Gulf of Mexico, Hypoxia, Nitrate, Nutrient reduction, Subsurface tile drainage.*

The hypoxic zone (dissolved oxygen concentration <2 mg L^{-1}) in the Gulf of Mexico is the world's second largest (Altieri and Diaz, 2019) and is a persistent ecological concern. The Hypoxia Task Force (HTF) plan to reduce the zone's size directed states in the Mississippi River basin (MRB) to develop nutrient reduction strategies (NRS) to reduce nitrogen (N) and phosphorus (P) loads to the gulf by 45% from a baseline period (1980 to 1996). The goal of the reductions is to shrink the five-year average area of the zone to ≤5,000 km^2 (USEPA, 2008). State-level NRS recommend a suite of approaches to reduce N loads from agriculture, including in-field management, land-use change, and edge-of-field practices. However, the scale of implementation needed, along with economic and other barriers, make this a "grand challenge," and progress toward meeting the N reduction goal has been minimal (IDALS, 2020; IEPA, 2021; MPCA, 2020).

To better understand the scale of the challenge, we looked at levels of nutrient-reduction conservation practice (simplified to "conservation practice" or "practice" henceforth) implementation needed to meet the N reduction goal. Iowa, Illinois, and Minnesota are the three upper MRB states that included science assessments as part of their NRS and are estimated to contribute 36% of the delivered N load to the Gulf of Mexico from the MRB (IDALS, 2013; IEPA, 2015; MPCA, 2014; Robertson and Saad, 2021). The states' science assessments and NRS documents were used to quantify the performance of conservation practices and implementation needs to meet the N reduction goal. Nitrogen reductions were estimated for different levels of implementation for: (1) individual in-field management (nutrient management and cover crops), changes in land use, and edge-of-field conservation practices and (2) the stacking or combining of these practices.

APPROACH

We selected practices consistent across states (fig. 1), grouping them as: (1) in-field management (nutrient management and cover crops), (2) changes in land use (CRP/perennialization and conversion of unprofitable land), and (3) edge-of-field (buffers, saturated buffers, [denitrification] bioreactors, and wetlands). For each conservation practice, we categorized implementation in each state into four increasingly challenging levels: benchmark, low, medium, and high. Benchmark estimates were based on implementation data available from the time the states' NRS were written (2012 or 2013). We used estimates from this timeframe rather than the baseline period (1980 to 1996) because of uniformity of the available information. The high implementation level was set as an estimate of maximum achievable adoption. First, values were taken from NRS documents when possible. If the NRS did not report a maximum value, literature was used to set an upper limit (cover crops and unprofitable land conversion). Finally, professional judgement was used when literature was not available. The low and medium implementation levels were chosen as described in the

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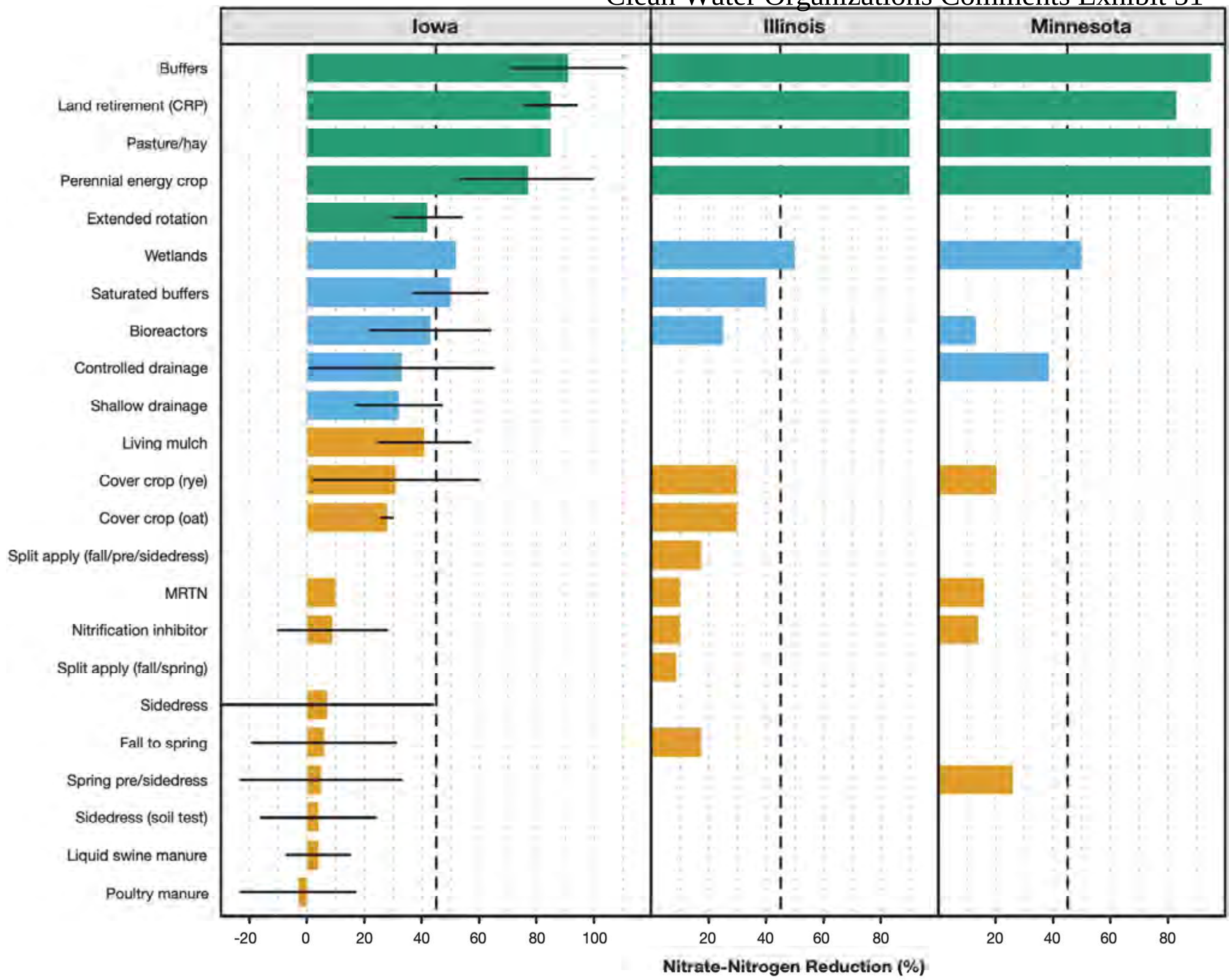

Figure 1. Estimated mean nitrate-N reductions for various in-field management (orange), edge-of-field (blue), and land-use change (green) practices included in the Iowa, Illinois, and Minnesota nutrient reduction strategies (MRTN = maximum return to N rate of fertilization). Error bars for Iowa represent ±1 standard deviation from the mean. Error bars were not available from the Illinois and Minnesota documents.

subsequent discussion of individual practices and are shown in table 1.

Iowa and Illinois developed example scenarios to attain 45% N reductions, whereas Minnesota determined that 45% could be approached but not achieved. The HTF plan goal focuses on total N reduction; however, because nitrate-N is the predominant form of N in water, we refer to nitrate-N reduction henceforth.

Each state used a unique accounting system to determine loads leaving state boundaries. The accounting system may have included distinguishing between source areas (e.g., areas with vs. without tile drainage). Because no effort was made here to recreate the accounting system for each state, relative reductions with respect to the baseline period were used. For example, if a state listed a conservation practice as having a 30% nitrate-N reduction and our analysis called for the practice to be implemented on 50% of the row crop area (defined henceforth as the corn and soybean area), nitrate-N reduction was calculated as 30% × 50% = 15% (fig. 2). Total nitrate-N reductions, as percentages, for each strategy and for each level of implementation were calculated on a state-area-weighted basis. In Minnesota and Illinois, this included only the portion of the state draining to the MRB.

Conservation practice implementation data during the benchmark period were acquired from state-specific reports developed to support HTF efforts (IDALS, 2013; IEPA, 2015; MPCA, 2014). In most cases, benchmark implementation estimates were negligible compared to scenarios outlined by each state necessary to meet HTF goals.

The areas affected by each of the eight individual practices assessed for the low-, medium-, and high-level implementation scenarios are shown in figure 3. Note that the row crop area, the maximum area available for conservation practice implementation, was greatest for Iowa, followed by Illinois and Minnesota, with 9.03, 8.29, and 6.31 million ha, respectively (fig. 3a, "High" column).

In-Field Management

Nitrogen Management

The primary N management practice examined across the three states' NRS was N application rate. Because other fertilizer/manure N management practices provide inconsistent

Table 1. Nitrate-N reduction by conservation practice and state, and area impacted [and nitrate-N reduction] at four levels of implementation (benchmark, low, medium, and high) for individual conservation practices. The bottom segment of the table shows the total nitrate-N reduction, after adjusting for conservation practice stacking, by state and level of implementation, and the area-weighted averages across all three states.

Nitrate-N Reduction by Practice and State[a]	Area Impacted (ha) [and Nitrate-N Reduction] for Each Level of Conservation Practice Implementation			
	Benchmark	Low Level	Medium Level	High Level
In-Field Management				
Nitrogen management		75% of row crop area is at maximum return to N (MRTN)	90% of row crop area is at MRTN	100% of row crop area is at MRTN
Iowa: 10%	2,709,000 [3%]	6,771,000 [8%]	8,126,000 [9%]	9,028,000 [10%]
Illinois: 10%	2,489,000 [3%]	6,223,000 [8%]	7,468,000 [9%]	8,298,000 [10%]
Minnesota: 16%	1,892,000 [5%]	4,729,000 [12%]	5,675,000 [14%]	6,306,000 [16%]
Total	7,090,000 [3%]	17,724,000 [9%]	21,269,000 [10%]	23,632,000 [12%]
Cover crops[b]		No-till area	All area rotating from corn to soybeans	Estimated maximum[c]
Iowa: 31%	154,000 [1%]	2,814,000 [10%]	3,596,000 [12%]	6,862,000 [24%]
Illinois: 30%	129,000 [0%]	2,450,000 [9%]	3,333,000 [12%]	5,062,000 [18%]
Minnesota: 10%	165,000 [0%]	331,000 [1%]	2,772,000 [4%]	2,838,000 [5%]
Total	448,000 [0%]	5,595,000 [7%]	9,701,000 [10%]	14,761,000 [17%]
Land Use				
Perennial conversion (CRP)[d]		Historic high	Increase by 25% over historic high	Increase by 50% over historic high
Iowa: 85%	665,000 [6%]	892,000 [8%]	1,115,000 [11%]	1,338,000 [13%]
Illinois: 90%	417,000 [5%]	440,000 [5%]	550,000 [6%]	660,000 [7%]
Minnesota: 83%	630,000 [8%]	744,000 [10%]	930,000 [12%]	1,115,000 [15%]
Total	1,712,000 [6%]	2,076,000 [7%]	2,595,000 [9%]	3,114,000 [11%]
Conversion of unprofitable land[e]		Convert 30% of unprofitable land	Convert 60% of unprofitable land	Convert 90% of unprofitable land
Iowa: 85%	5,000 [0%]	135,000 [1%]	271,000 [3%]	406,000 [4%]
Illinois: 90%	4,000 [0%]	124,000 [1%]	249,000 [3%]	373,000 [4%]
Minnesota: 83%	3,000 [0%]	95,000 [1%]	189,000 [2%]	284,000 [4%]
Total	12,000 [0%]	354,000 [1%]	709,000 [3%]	1,063,000 [4%]
Edge-of-Field				
Buffers		10% increase over benchmark from NRS maximum minus benchmark	10% increase over benchmark from NRS maximum minus benchmark	NRS maximum[a]
Iowa: 91%	1,000 [0%]	17,000 [0%]	81,000 [1%]	162,000 [2%]
Illinois: 90%	253,000 [3%]	300,000 [3%]	487,000 [5%]	722,000 [8%]
Minnesota: 95%	125,000 [2%]	131,000 [2%]	152,000 [2%]	179,000 [3%]
Total	379,000 [1%]	447,000 [2%]	721,000 [3%]	1,063,000 [4%]
Saturated buffers		10% of estimated maximum	50% of estimated maximum	Estimated maximum[f]
Iowa: 50%[g]	[0%]	109,000 [1%]	547,000 [3%]	1,093,000 [6%]
Illinois: 40%[h]	[0%]	108,000 [1%]	540,000 [3%]	1,080,000 [5%]
Minnesota: 44%[f]	[0%]	30,000 [0%]	151,000 [1%]	303,000 [2%]
Total	[0%]	248,000 [0%]	1,238,000 [2%]	2,476,000 [5%]
Denitrifying bioreactors		10% of NRS maximum	50% of NRS maximum	NRS maximum[a]
Iowa: 43%	[0%]	402,000 [2%]	2,010,000 [10%]	4,020,000 [19%]
Illinois 25%	[0%]	180,000 [1%]	901,000 [3%]	1,802,000 [5%]
Minnesota: 13%	[0%]	16,000 [0%]	79,000 [0%]	158,000 [0%]
Total	[0%]	598,000 [1%]	2,990,000 [5%]	5,980,000 [9%]
Wetlands		10% of NRS maximum	50% of NRS maximum	NRS maximum[a]
Iowa: 52%	0 [0%]	518,000 [3%]	2,590,000 [15%]	5,180,000 [23%]
Illinois: 50%	0 [0%]	126,000 [1%]	631,000 [4%]	1,261,000 [8%]
Minnesota: 50%	0 [0%]	63,000 [1%]	316,000 [3%]	631,000 [5%]
Total	0 [0%]	707,000 [2%]	3,536,000 [8%]	7,072,000 [14%]
Stacked Practices				
Total nitrate-N reduction by state (adjusted for stacking)				
Iowa	[10%]	[31%]	[50%]	[72%]
Illinois	[11%]	[25%]	[36%]	[49%]
Minnesota	[15%]	[22%]	[31%]	[37%]
Total nitrate-N reduction (adjusted for stacking)	[12%]	[26%]	[40%]	[55%]

[a] IDALS (2013), IEPA (2015), and MPCA (2014).
[b] USDA-NASS (2012).
[c] Kladivko et al. (2014).
[d] USDA-FSA (2020).
[e] Brandes et al. (2016).
[f] Chandrasoma et al. (2019).
[g] IDALS (2017).
[h] IEPA (2021).

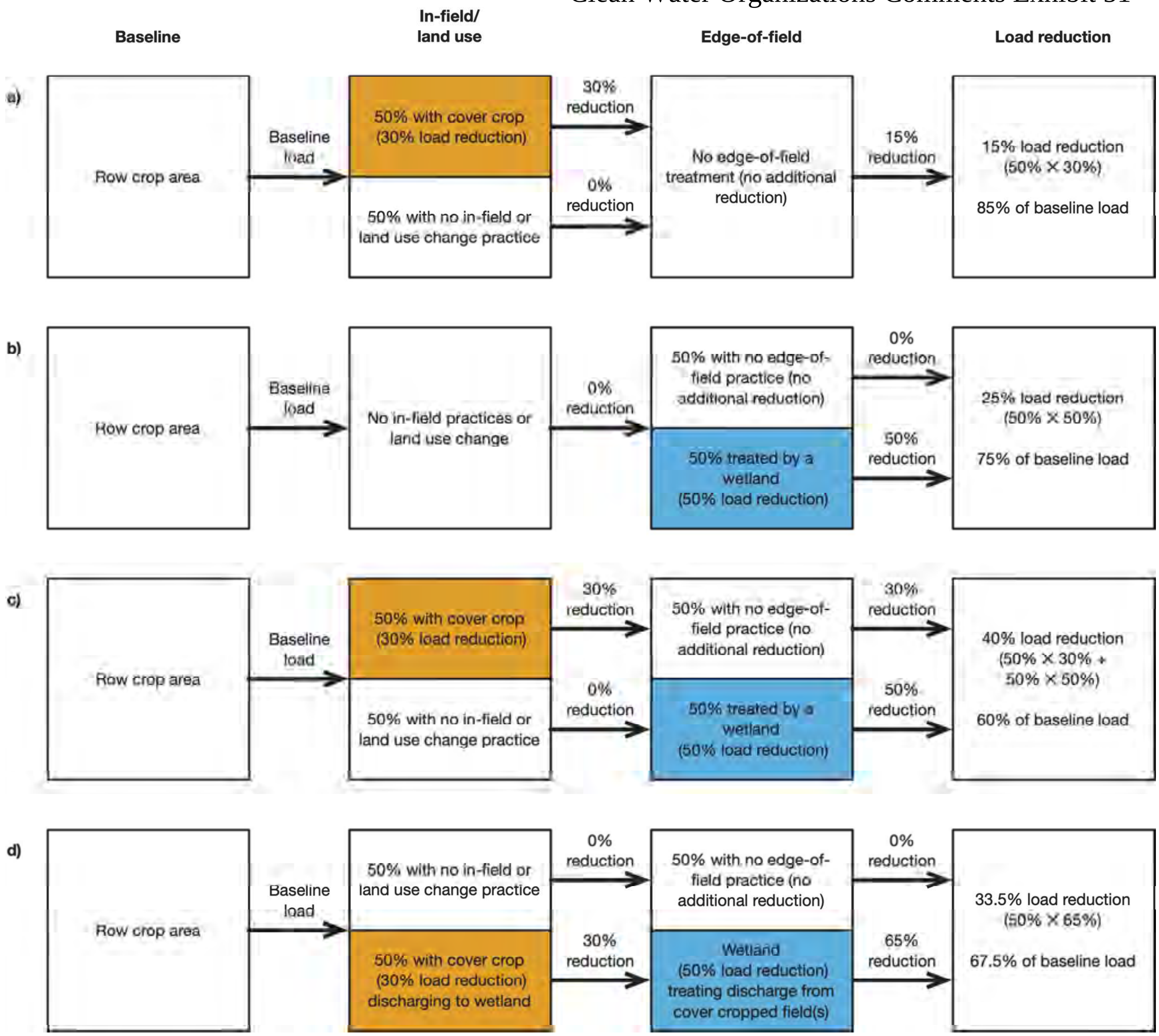

Figure 2. Calculation of N reductions with examples for: (a) individual in-field or land use practices, (b) individual edge-of-field practices, (c) combination of in-field or land-use change and edge-of-field practices on separate land areas, and (d) combination of in-field or land use and edge-of-field practices on the same land area (stacked). For stacked practices (example d), the load reductions are not additive (e.g., not 15% + 25%), and the total load reduction (33.5%) is less than the load reduction from the combined practices with no overlap (example c, 40%) for the same total area because the edge-of-field practice is treating the reduced load from the in-field practice. Example load reductions used (cover crops and wetlands) were from the Illinois NRS.

and low nitrate-N loss reductions (note the error bars in fig. 1 for Iowa) and were not common across the NRS, they were omitted from the analysis. Each state had difficulties assessing benchmark N management implementation due to lack of available data on fertilizer sales and animal units. We assumed that 30% of farmers were applying N at a rate of maximum return to N (MRTN) during the benchmark period (Anderson and Kyveryga, 2016). All states estimated the impact of reducing average N application to the MRTN rate on all areas, which we used as the high implementation level for N management. In Iowa and Illinois, this was estimated to reduce nitrate-N loss by 10%, but the loss reduction was greater in Minnesota (16%), as shown in table 1. Across all states, reducing application rates to MRTN on all areas was estimated to reduce nitrate-N load by 12% (fig. 4a). The low- and medium-level implementation scenarios were estimated to reduce nitrate-N load by 9% and 10%, respectively (fig. 4a).

Cover Crops

Theoretically, cover crops could be implemented on all crop land; however, the added management required to effectively reduce N loss and minimize risk for cash crops, coupled with short growing-season challenges in northern areas, suggest that effective universal implementation is unlikely. To establish the high level of implementation, maximum cover crop area estimates from Kladivko et al. (2014) were extrapolated from the study watersheds to the state level. Based on these assumptions, nearly 14.8 million ha (63% of row crop ha) could host a cover crop in the three-

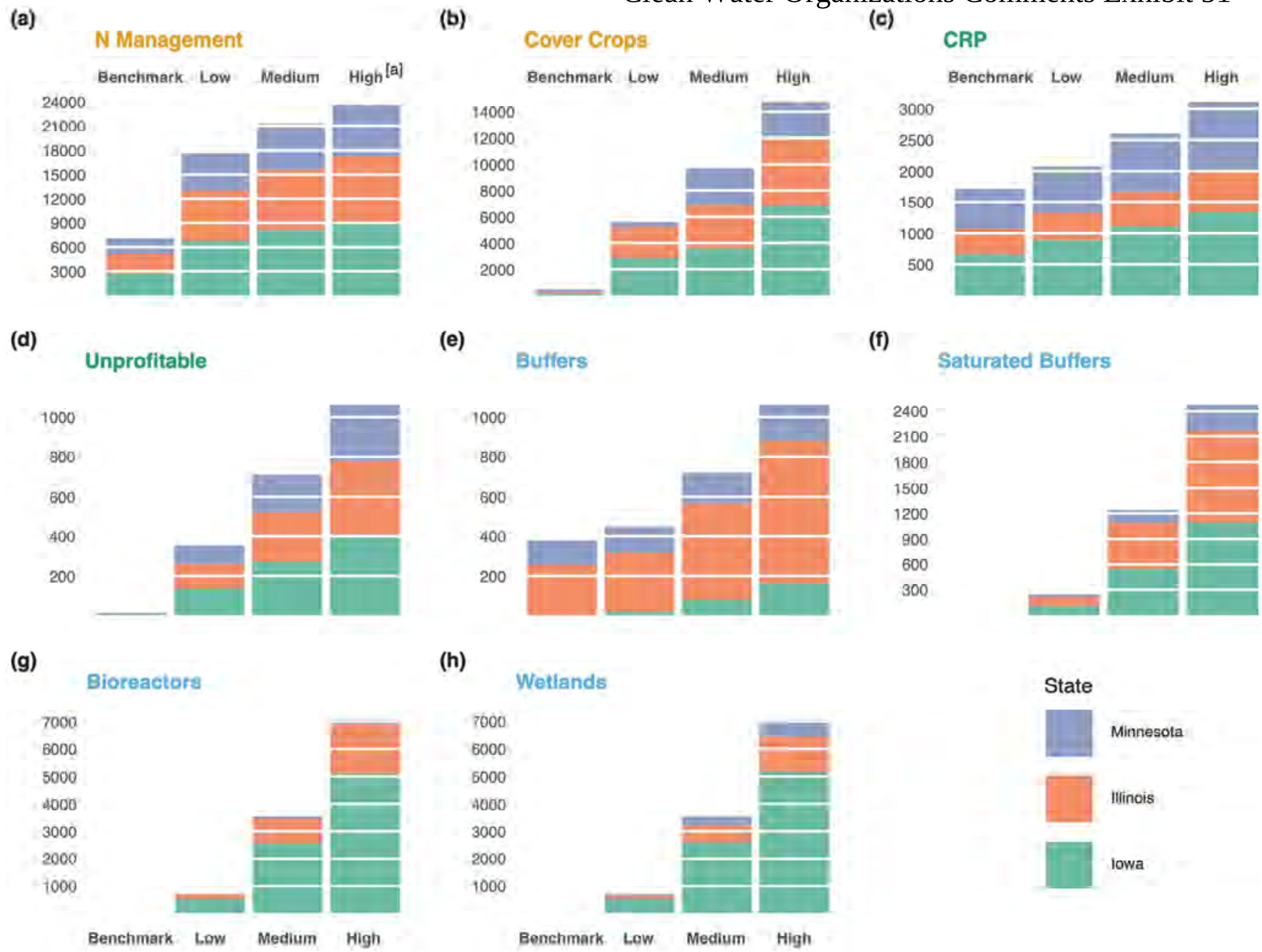

Figure 3. Areas (thousand ha) affected by each of the eight individual practices assessed for benchmark, low-, medium-, and high-level implementation. Practice groupings are denoted by title color: (a-b) in-field, (c-d) land-use change, and (e-h) edge-of-field.
[a] In graph (a), the areas for the "High" column for N management represent the total row crop areas for each state because it was assumed that N management would be implemented on all available row crop areas at the high level.

state region (fig. 3b), with an estimated 17% nitrate-N loss reduction (fig. 4a). The low and medium levels of implementation for cover crops were based on a blend of approaches from the state NRS. The low implementation level was based on no-till farmers adopting cover crops (MCCC, 2021). The medium implementation level was based on planting cover crops after corn harvest transitioning into soybeans (SARE, 2007; Kaspar and Licht, 2019). During the benchmark period, few cover crops were implemented, although accelerated adoption of the practice occurred subsequently (fig. 3b). Because few other in-field practices provided comparably high N reductions, all three states' NRS relied heavily on cover crop implementation to meet water quality goals.

Land Use

Perennial Conversion (CRP)

Land use conversion from row crops to perennial vegetation was consistently among the practices with the greatest nitrate-N loss reductions on a per area basis across the three states' NRS (fig. 1). The year with the greatest Conservation Reserve Program (CRP) enrollment by state (USDA-FSA, 2020) was used as the basis for the low-level implementation, which had origins in two of the states' NRS scenarios. Medium- and high-level implementations for CRP were arbitrarily set as the low implementation level plus 25% and 50%, respectively. The term CRP here includes both land set aside in government programs and land converted to perennial use that would provide similar ecosystem benefits. Starting with historically high CRP acreages (low-level implementation) and expanding beyond that (medium- and high-level implementation) results in potential nitrate-N loss reductions of 7% to 11% (fig. 4b). Implementing the high-level scenario would require substantial increases in CRP funding, new programs and funding mechanisms, or major market shifts to incentivize perennial production.

Conversion of Unprofitable Areas

Our estimate of potential area for the conversion of unprofitable row-cropped land to perennial coverage was based on research in Iowa (Brandes et al., 2016) and the assumption that the relative amount of unprofitable land was similar in each state. Brandes et al. (2016) highlighted that high-risk areas like floodplains tend to be highly unprofitable, losing more than \$250 ha^{-1} year^{-1}. At the 2013 peak of the four-year

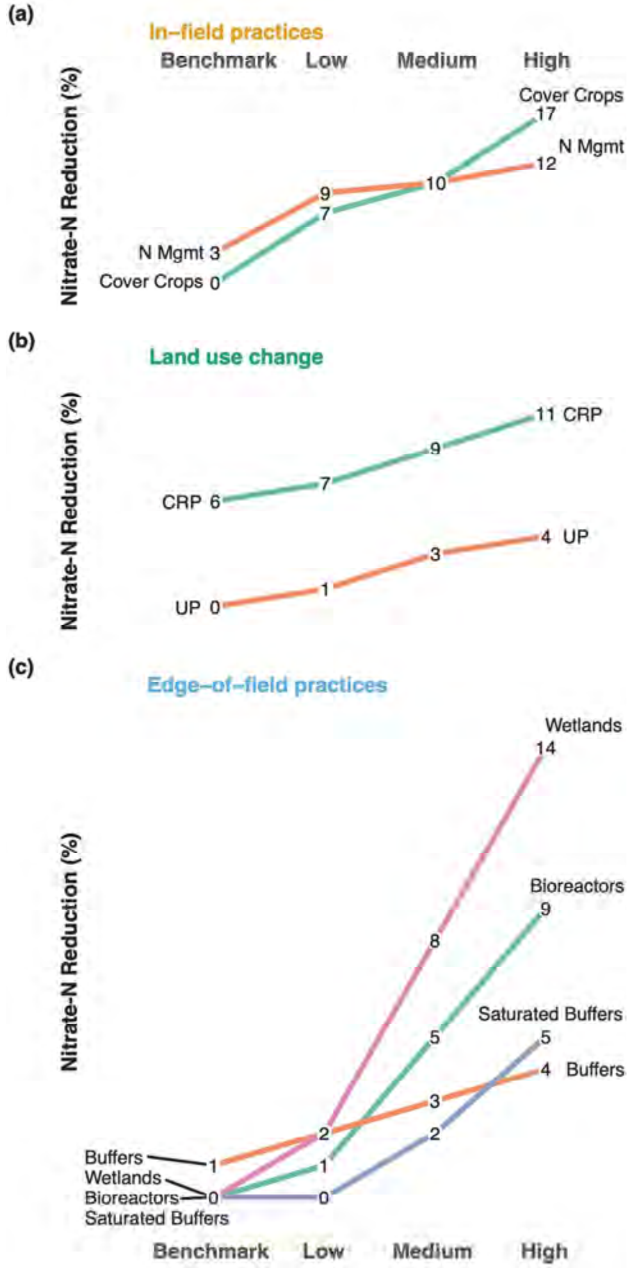

Figure 4. Area-weighted average nitrate-N reductions (%) for Iowa, Illinois, and Minnesota for individual practices, grouped by type, for the benchmark, low, medium, and high levels of implementation.

study, nearly 11% of farmland was considered highly unprofitable in Iowa, with a 2010 to 2013 average of about 3% (range 0.2% to 11%). Due to the dynamic nature of this measure, the authors selected 5% of the row crop area of each state as potentially highly unprofitable. Of that 5%, we assumed that 90% (or 4.5% of row crop area) would be an appropriate high-level implementation target because much of this land could be in small pockets and unsuitable to farm around. Based on high-level implementation of the unprofitable land strategy, we estimated a 4% reduction in nitrate-N losses (fig. 4b). The high-level implementation area represents 1.06 million ha in the three states, which is roughly one-third the area of the high-level implementation of CRP. There are substantial uncertainties associated with the unprofitable land strategy due to the uncontrollable and fluctuating factors of market forces and weather.

Edge-of-Field Practices

For many of the edge-of-field practices, NRS documents listed scenarios highlighting potential statewide implementation, which corresponded to the high-level implementation scenario. These NRS values were used for buffers, bioreactors, and wetlands. Benchmark-level implementation for saturated buffers and bioreactors was set at zero because nearly all installations during this period were research sites. No effort was made here to determine the feasibility of maximums in strategy documentation or state scenarios, although potential overlaps from stacking or combining practices on the same area are addressed below.

Buffers

Buffers (also known as riparian buffers), whether installed or naturally present, are an edge-of-field practice for treating surface runoff, but they also can greatly reduce (~90%) nitrate-N concentrations in water flowing laterally through the root zone (Douglas-Mankin et al., 2021). However, water interacting with the buffer root zone is likely only a small fraction of water generated from the adjacent field, particularly in a tile-drained landscape. Because estimation of the amount of water interacting with the root zone is difficult, each state made some general assumptions to quantify the potential area treated by buffers. Over the three-state region, approximately 1.1 million ha may be influenced by the presence of a buffer, with estimated nitrate-N reductions of approximately 4% for high-level implementation (fig. 4c). After the benchmark period, Minnesota instituted a buffer law that required buffers along all public waters and drainage ditches. Implementation of buffers is estimated at greater than 99% (Tom Gile, MPCA, personal communication) with model-predicted total N reductions of 1.0% to 1.6% (MPCA, 2019).

Saturated Buffers

Saturated buffers are a relatively new edge-of-field practice and thus were not discussed in the states' original NRS. Saturated buffers were added to the Iowa NRS in 2014 and were estimated to have similar performance effectiveness as treatment wetlands. Saturated buffers have lower installation costs and less management than other edge-of-field practices and treat subsurface drainage water that bypasses standard buffers. However, the use of saturated buffers is limited by site suitability constraints. Estimates of the maximum potential extent of saturated buffer deployment were obtained from Chandrasoma et al. (2019). Based on these assumptions, the high-level implementation of saturated buffers across the three states will result in a 5% nitrate-N reduction (fig. 4c). The potential impact is less in Minnesota than in Iowa and Illinois based on the criterion of proximity of crop production to perennial streams (table 1; Chandrasoma et al., 2019; USEPA, 2018).

Bioreactors

Estimated nitrate-N loss reductions using bioreactors for the high-level implementation averaged 9% over the three states (fig. 4c). The estimated results of bioreactor deployment varied more among states than for any other practice: 19%, 5%, and <1% for Iowa, Illinois, and Minnesota, respectively (table 1). Variability was attributed to assumptions regarding the row crop area treated by bioreactors and the nitrate-N load removal effectiveness of bioreactors. Minnesota estimated that 80% of tile-drained land considered suitable for bioreactors or wetlands would be treated by wetlands and 20% by bioreactors. Iowa assumed that all tile-drained row crop area could be treated with bioreactors. In practice, many sites have been deemed unsuitable for bioreactors, incorrectly inflating the potential benefit of this practice in Iowa.

Wetlands

Wetlands are an important practice for nitrate-N reduction from tile-drained row crop land and provide several co-benefits over other practices. The practice was included in all three states' NRS. Wetlands included in this study were those that specifically intercept and treat tile drainage. Each state estimated similar nitrate-N removal performance with wetlands (50% to 52%, within the range found by Messer et al., 2021), but their estimates of the area that could be treated by wetlands differed widely (fig. 3h). The high-level implementation scenario was estimated to reduce nitrate-N by 23%, 8%, and 5% for Iowa, Illinois, and Minnesota, respectively (table 1), which is equivalent to a 14% aggregated area-weighted average (fig. 4c). Aggregated nitrate-N load reductions were 2% and 8% for the low and medium implementation levels, respectively.

Stacked or Combined Practices

The above accounting does not consider potential overlaps of combining, or stacking, multiple practices on a given land area. Stacked practices have overall lower combined nitrate-N reductions than the sum of the individual practice reductions due to competition for N from a given land area. For example, if a field has both an in-field practice (fig. 2a) and an edge-of-field practice (fig. 2b), the reduction from the in-field practice will affect the N entering the edge-of-field practice (fig. 2d; Christianson et al., 2018). Effects of practice overlap were appraised using an N load estimate calculator (https://naturalresources.extension.iastate.edu/water-quality/N-load-estimate-calculator).

Estimated impacts for the land use and in-field management strategies were determined using the methods above, and the outcomes were used as inputs to adjust the edge-of-field strategy results. For example, when CRP/perennial area increased, row crop area decreased correspondingly. After the area was calculated, the nitrate-N load reductions for land-use change and in-field management were recalculated. This resulted in lower nitrate-N loads entering edge-of-field practices with subsequent lowering of the overall nitrate-N reduction potential for the edge-of-field practices. The calculator was set up for each state in hypothetical conventionally tile-drained watersheds with areas apportioned per statewide averages for N management, cover crop use, perennial vegetation, tile drainage, bioreactors, wetlands, buffers, and saturated buffers. Specific state percent reduction factors were consistent with figure 1.

Nitrogen reductions across the states, accounting for potential overlaps of practices stacked on the same area, were 26%, 40%, and 55% for the low, medium, and high levels of implementation, respectively (fig. 5, table 1). At the high implementation level, estimated nitrate-N reductions for Iowa, Illinois, and Minnesota were 72%, 49%, and 37%, respectively. The ratios of stacked nitrate-N reductions (fig. 5) to the sum of individual nitrate-N reductions (fig. 4) were 0.91, 0.82, and 0.74 for the low, medium, and high implementation levels, respectively, demonstrating the competition effect of stacking practices on nitrate-N loss reduction. We assumed that there was no overlap of reductions among the practices for the benchmark level.

Implications

Achieving the HTF goal of 45% reduction in N loading to the Gulf of Mexico will require a combination of the medium and high levels of implementation of in-field management, land-use change, and edge-of-field practices. Despite continuing investments in conservation practice adoption, current implementation remains at the benchmark level or between the benchmark and low implementation levels for any of the practices (IDALS, 2020; IEPA, 2021; MPCA, 2020). Additionally, precipitation amount and intensity in this region are increasing (USGCRP, 2018), and legacy effects are long-lasting (MPCA, 2020; Van Meter and Basu, 2017). Thus, potential progress toward the HTF goal will need to be measured in decades, not years, and results here suggest that multiple conservation strategies and many practices will be needed.

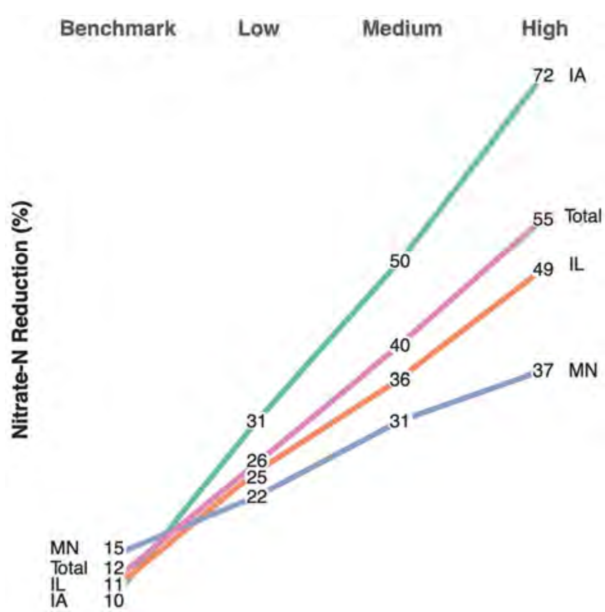

Figure 5. Nitrate-N reductions (%) for Iowa (IA), Illinois (IL), and Minnesota (MN) considering potential overlap of stacking multiple practices on a given land area. Data are shown for each state and the area-weighted average of all states (Total) for the benchmark, low, medium, and high levels of implementation.

Combined N reductions for high-level implementation of in-field management and land-use changes fell short of the 45% goal, even without accounting for overlaps of stacking practices in the same area. The importance of edge-of-field practices was evident as the implementation level increased. The ratio of reductions for the sum of edge-of-field practices to the sum of in-field management plus land-use change practices increased as the level of implementation increased from low to medium to high: 0.18, 0.50, and 0.72, respectively. Our findings that edge-of-field practices need to play a key role in meeting nutrient loss challenges is consistent with the assertion of others that "tackling nutrient loss challenges within the field is not enough" and that "stewardship practices at the edges of farm fields represent a crucial, but underutilized, conservation opportunity" (TNC, 2021).

Each state applied different assumptions when creating its respective NRS. Iowa emphasized cover crops and edge-of-field practices; Illinois emphasized cover crops, nutrient management, and buffers; and Minnesota emphasized land-use change and cover crops (fig. 3). The assumptions were applied with little consideration for overlapping practices. For example, the Iowa NRS does not mutually exclude areas from treatment by both wetlands and bioreactors, creating potential accounting overlap in edge-of-field practices. These scenarios require increased scrutiny and care in accounting. Further north than Iowa and Illinois, Minnesota carries a disadvantage with a shorter growing window for cover crops and lower temperatures for practices that depend on denitrification (e.g., bioreactors and saturated buffers).

Results from this work are consistent with what has been reported by others, i.e., reaching the goal of a 45% N reduction will require numerous combined practices at many locations (Zimmerman et al., 2019; McLellan et al., 2015). In particular, McLellan et al. (2015) found that the use of improved fertilizer management and cover crops would not meet the targeted 45% N load reduction. These researchers (McLellan et al., 2015) highlighted the need to tailor or target conservation practice implementation to local conditions and needs for maximum N load reduction benefit.

Challenges

Increasing precipitation trends will challenge N reduction efforts. Climate shifts have likely countered conservation efforts to mitigate hypoxia (Altieri and Diaz, 2019), and recent modeling has predicted that N loads need to be lowered by 59% to meet the HTF goal (Scavia et al., 2017). Climate projections in the three states indicate increasing precipitation in the winter and spring (USGCRP, 2018). This increase in precipitation immediately prior to or during spring (with its limited vegetative growth) could exacerbate N losses and may require greater practice implementation than noted herein. Additionally, the increase in the number of "mega rains" (storms of >15 cm depth over an area >2,600 km^2; MPCA, 2020) may overshadow gains from conservation practice deployment.

In addition to climate challenges, the impact of time lags on the realization of conservation practice benefits introduces uncertainty in demonstrating results and measuring progress. Time lags are a function of hydrologic travel times and release of accumulated N in the system. Of the former, much has been written, with travel times reported from one to several decades (Schilling and Wolter, 2007; Ilampooranan et al., 2019). Recently, research on biogeochemical time lags has received more focus with an estimated time of a few decades to deplete legacy N to sustainable and acceptable nitrate concentrations after N inputs have ceased (Fenton et al., 2017).

To date, the practices that effect nitrate-N removal also carry inherent risks. In certain years, the MRTN rate will jeopardize yields. Early adopters of cover crops were often highly motivated to ensure the practice was successful. There is a risk that, as a wider audience is incentivized to plant cover crops, the achieved N reductions will be less and primary crop yields will be negatively affected. Setting aside land (CRP and unprofitable land strategy) carries the risk that future events (e.g., market changes) will incentivize producers to convert area back into row crop production. Left unmanaged, edge-of-field practices will lose effectiveness over time. Lack of confidence that a practice will perform as expected can be a barrier to acceptance. Approaches that include development of all three existing reduction strategy categories (i.e., in-field management, land-use change, and edge-of-field) would balance these various risks.

Achieving greater levels of practice implementation challenges the capacity of support systems. For example, seeding and managing 9.7 to 14.8 million ha of cover crops (medium to high implementation scenarios) will require greatly expanded cover crop seed production and handling and custom applicators who can provide seeding and termination services. For edge-of-field practices, meeting the medium and high implementation levels by 2035, the target date for the HTF goal, would require completing from one practice every two days (medium) to one every day (high) of an assumed 150-working-day construction season in each of the 265 counties of the MRB in the three states based on typical treated drainage areas. Each project would require a contractor and crew, a design engineer and support staff, local conservation staff, and administrative staff for programmatic and financial support, as well as the supplies and equipment (e.g., water control structures and woodchips for bioreactors). Our analysis does not account for resource capacities needed to carry out implementation at a regional scale.

We have also not addressed the indisputable economic difficulties in executing even the low level of implementation. The states have proposed costs associated with their NRS (IDALS, 2013; IEPA, 2015; MPCA, 2014). We used these costs, without judgment as to how they were developed or what additional costs would be incurred (e.g., indirect costs for technical assistance, practice design, or program administration) to arrive at the following assessment. Annual cost estimates of implementation scenarios ranged from a low of \$51 million in Minnesota to a high of \$1.2 billion in Iowa. Summing annual costs for all three states results in estimates ranging from \$955 million to \$2.2 billion (\$40 to \$93 ha^{-1} year^{-1}). This range compares to an estimated infinite-life annual land value of \$19.2 billion for the three states using average per area land costs (USDA-NASS, 2020) and a 5% discount rate. As presented here, conservation practice implementation would represent between 5% and 12% of land value.

The cost frameworks and trade-offs vary for the different types of practices. Reducing N fertilization rate and taking unprofitable land out of production can potentially be advantageous economically. However, most of the strategies require monetary inputs that are not offset by increased agricultural output. For example, converting row crop land to perennials will often carry an opportunity loss cost. In-field practices require annual renewal with associated annual costs. Edge-of-field practices tend to have higher upfront costs but lower cost per mass of N removed (Christianson et al., 2013, 2018; Jaynes and Isenhart, 2019). The cost of maintaining practices and converted land also needs to be included in economic analyses. Given the magnitude of the need and the unlikelihood that federal and state budgets will expand to provide the financial resources required, it is unlikely that cost-share alone will meet the need. Emerging ecosystem service markets offer another potential approach to incentivize practice implementation.

Research efforts need to increase understanding of the effectiveness and potential of practices, how to optimize them, and how to increase their acceptance and adoption rates. Multi-objective optimization of levels of practice implementation is needed to answer questions about what combinations of practices are most affordable and provide the greatest environmental benefit. Understanding the human dimension of conservation planning and decision making is critical to realizing the potential benefits determined by physical research and modeling, and we encourage additional multi-disciplinary research to further understand how benefits can be achieved. Support for long-term research is critical to evaluating practice performance and maintenance needs under varying environmental conditions over time (Tomer et al., 2014). Additionally, there are large gaps in knowledge regarding the impact of stacking multiple practices on a given area.

Headway is being made on several practices (e.g., Christianson et al., 2021a; Douglas-Mankin et al., 2021; Liu et al., 2021; Messer et al., 2021) and on adjusting the dominant cropping system to support environmentally sustainable agricultural intensification. Beneficial advances continue in precision N management (Jin et al., 2019). Excellent work is progressing in the use of cover crops, although climate limitations exist (Christianson et al., 2021b). Living mulch systems that provide environmental benefits of perennials yet permit corn-soybean row cropping are a promising development (Moore et al., 2019). Drainage water recycling is an emerging practice that provides production benefits as well as downstream N reduction and increases landscape water storage (Hay et al., 2021).

While the current assessment focused on practices implemented primarily within a corn-soybean cropping system, diverse crop rotations in which growing vegetation remains on the land a greater percentage of the year have substantial potential for reducing nitrate-N loss (Koropeckyj-Cox et al., 2021). However, for these systems to be implemented, there needs to be a demand for their various products, whether they be small grains, oilseeds, perennials, and/or forage. Future work should continue to examine how new systems can be implemented and if there are opportunities to reimagine rural landscapes to provide broad environmental services and increased economic sustainability.

Speculation of how future advancements may change the nitrate-N loss situation is highly uncertain. However, history holds examples of advancements that ameliorate problems. Revolutionary changes are difficult to predict, but potential developments include new markets for perennial crops, development of high-production perennial grains or N-fixing maize, more landscape water storage, re-envisioned landscapes with cascading water and nutrient flows, and revolutionary treatment practices. Artificial lighting and plant breeding advancements are revolutionizing indoor production of vegetables and high-value crops (Eigenbrod and Gruda, 2015). It seems unlikely that this revolution could impact land use at the large scale; however, the systems can inform us about water and nutrient recycling and low-environmental-release food production.

Conclusions

Meeting nutrient reduction goals to reduce the hypoxic zone in the Gulf of Mexico will be a massive effort. We have shown that no one practice or strategy will meet the goals and that multiple strategies and practices with widespread adoption are required. Pernicious issues and barriers to implementation demand pressing forward in search of environmental and economic solutions for existing practices as well as revolutionary advancements. The scale of the effort, without other revolutionary changes, includes changes to in-field management for all or nearly all row crop areas, marked increases in perennial land use, and other conservation practices implemented across a majority of row crop acres. Understanding the scale of the N reduction challenge is a necessary step toward meeting it.

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References

Altieri, A. H., & Diaz, R. J. (2019). Chapter 24 - Dead zones: Oxygen depletion in coastal ecosystems. In C. Sheppard (Ed.), *World seas: An environmental evaluation, Vol. III: Ecological issues and environmental impacts* (2nd Ed., pp. 453-473). Amsterdam, Netherlands: Elsevier. https://doi.org/10.1016/B978-0-12-805052-1.00021-8

Anderson, C. J., & Kyveryga, P. M. (2016). Combining on-farm and climate data for risk management of nitrogen decisions. *Climate Risk Mgmt., 13*, 10-18. https://doi.org/10.1016/j.crm.2016.03.002

Brandes, E., McNunn, G. S., Schulte, L. A., Bonner, I. J., Muth, D. J., Babcock, B. A., ... Heaton, E. A. (2016). Subfield profitability analysis reveals an economic case for cropland diversification. *Environ. Res. Lett., 11*(1), article 14009. https://doi.org/10.1088/1748-9326/11/1/014009

Chandrasoma, J. M., Christianson, R. D., & Christianson, L. E. (2019). Saturated buffers: What is their potential impact across the US Midwest? *Agric. Environ. Lett., 4*(1), article 180059. https://doi.org/10.2134/ael2018.11.0059

Christianson, L. E., Cooke, R. A., Hay, C. H., Helmers, M. J., Feyereisen, G. W., Ranaivoson, A. Z., ... von Ahnen, M. (2021a). Effectiveness of denitrifying bioreactors on water pollutant reduction from agricultural areas. *Trans. ASABE, 64*(2), 641-658. https://doi.org/10.13031/trans.14011

Christianson, L., Tyndall, J., & Helmers, M. (2013). Financial comparison of seven nitrate reduction strategies for Midwestern agricultural drainage. *Water Resour. Econ., 2-3*, 30-56. https://doi.org/10.1016/j.wre.2013.09.001

Christianson, R., Christianson, L., Wong, C., Helmers, M., McIsaac, G., Mulla, D., & McDonald, M. (2018). Beyond the nutrient strategies: Common ground to accelerate agricultural water quality improvement in the upper Midwest. *J. Environ. Mgmt., 206*, 1072-1080. https://doi.org/10.1016/j.jenvman.2017.11.051

Christianson, R., Fox, J., Law, N., & Wong, C. (2021b). Effectiveness of cover crops for water pollutant reduction from agricultural areas. *Trans. ASABE, 64*(3), 1007-1017. https://doi.org/10.13031/trans.14028

Douglas-Mankin, K. R., Helmers, M. J., & Harmel, R. D. (2021). Review of filter strip performance and function for improving water quality from agricultural lands. *Trans. ASABE, 64*(2), 659-674. https://doi.org/10.13031/trans.14169

Eigenbrod, C., & Gruda, N. (2015). Urban vegetable for food security in cities: A review. *Agron. Sustain. Dev., 35*(2), 483-498. https://doi.org/10.1007/s13593-014-0273-y

Fenton, O., Mellander, P. E., Daly, K., Wall, D. P., Jahangir, M. M. R., Jordan, P., ... Richards, K. G. (2017). Integrated assessment of agricultural nutrient pressures and legacies in karst landscapes. *Agric. Ecosyst. Environ., 239*, 246-256. https://doi.org/10.1016/j.agee.2017.01.014

Hay, C. H., Reinhart, B. D., Frankenberger, J. R., Helmers, M. J., Jia, X., Nelson, K. A., & Youssef, M. A. (2021). Frontier: Drainage water recycling in the humid regions of the U.S.: Challenges and opportunities. *Trans. ASABE, 64*(3), 1095-1102. https://doi.org/10.13031/trans.14207

IDALS. (2013). Iowa Nutrient Reduction Strategy: A science and technology-based framework to assess and reduce nutrients to Iowa waters and the Gulf of Mexico. Des Moines, IA: Iowa Department of Agriculture and Land Stewardship, Iowa Department of Natural Resources, and Iowa State University.

IDALS. (2017). Iowa Nutrient Reduction Strategy: A science and technology-based framework to assess and reduce nutrients to Iowa waters and the Gulf of Mexico. Des Moines, IA: Iowa Department of Agriculture and Land Stewardship, Iowa Department of Natural Resources, and Iowa State University. Retrieved from http://www.nutrientstrategy.iastate.edu/sites/default/files/documents/2017%20INRS%20Complete_Revised%202017_12_11.pdf

IDALS. (2020). Iowa Nutrient Reduction Strategy: 2018-19 annual progress report. Des Moines, IA: Iowa Department of Agriculture and Land Stewardship, Iowa Department of Natural Resources, and Iowa State University. Retrieved from https://www.nutrientstrategy.iastate.edu/sites/default/files/documents/NRS2019AnnualReportDocs/INRS_2019_AnnualReport_PartsOneAndTwo_Final_R20200701.pdf

IEPA. (2015). Illinois Nutrient Loss Reduction Strategy. Springfield, IL: Illinois Environmental Protection Agency, Illinois Department of Agriculture, and University of Illinois Extension. Retrieved from https://www2.illinois.gov/epa/Documents/iepa/water-quality/watershed-management/nlrs/nlrs-final-revised-083115.pdf

IEPA. (2021). Illinois Nutrient Loss Reduction Strategy: Biennial report 2019-2020. Springfield, IL: Illinois Environmental Protection Agency, Illinois Department of Agriculture, and University of Illinois Extension. Retrieved from https://www2.illinois.gov/epa/topics/water-quality/watershed-management/excess-nutrients/Documents/NLRS-2021-Biennial-Report-final.pdf

Ilampooranan, I., Van Meter, K. J., & Basu, N. B. (2019). A race against time: Modeling time lags in watershed response. *Water Resour. Res., 55*(5), 3941-3959. https://doi.org/10.1029/2018WR023815

Jaynes, D. B., & Isenhart, T. M. (2019). Performance of saturated riparian buffers in Iowa, USA. *J. Environ. Qual., 48*(2), 289-296. https://doi.org/10.2134/jeq2018.03.0115

Jin, Z., Archontoulis, S. V., & Lobell, D. B. (2019). How much will precision nitrogen management pay off? An evaluation based on simulating thousands of corn fields over the US Corn-Belt. *Field Crops Res., 240*, 12-22. https://doi.org/10.1016/j.fcr.2019.04.013

Kaspar, T., & Licht, M. (2019). Iowa cover crop recipe-Post corn going to soybean: Use cereal rye. Midwest Cover Crops Council and Iowa State University Extension. Retrieved from https://mccc.msu.edu/iowa-cover-crop-recipe-post-corn-going-soybean-use-cereal-rye/

Kladivko, E. J., Kaspar, T. C., Jaynes, D. B., Malone, R. W., Singer, J., Morin, X. K., & Searchinger, T. (2014). Cover crops in the upper midwestern United States: Potential adoption and reduction of nitrate leaching in the Mississippi River basin. *J. Soil Water Cons., 69*(4), 279-291. https://doi.org/10.2489/jswc.69.4.279

Koropeckyj-Cox, L., Christianson, R. D., & Yuan, Y. (2021). Effectiveness of conservation crop rotation for water pollutant reduction from agricultural areas. *Trans. ASABE, 64*(2), 691-704. https://doi.org/10.13031/trans.14017

Liu, W., Yuan, Y., & Koropeckyj-Cox, L. (2021). Effectiveness of nutrient management on water quality improvement: A synthesis on nitrate-nitrogen loss from subsurface drainage. *Trans. ASABE, 64*(2), 675-689. https://doi.org/10.13031/trans.14078

MCCC. (2021). Cover crop recipes. Midwest Cover Crops Council. Retrieved from https://mccc.msu.edu/getting-started/cover-crop-recipes/

McLellan, E., Robertson, D., Schilling, K., Tomer, M., Kostel, J., Smith, D., & King, K. (2015). Reducing nitrogen export from the corn belt to the Gulf of Mexico: Agricultural strategies for remediating hypoxia. *J. American Water Resour. Assoc., 51*(1), 263-289. https://doi.org/10.1111/jawr.12246

Messer, T. L., Moore, T. L., Nelson, N., Ahiablame, L., Bean, E. Z., Boles, C., ... Schlea, D. (2021). Constructed wetlands for water quality improvement: A synthesis on nutrient reduction from agricultural effluents. *Trans. ASABE, 64*(2), 625-639. https://doi.org/10.13031/trans.13976

Moore, K. J., Anex, R. P., Elobeid, A. E., Fei, S., Flora, C. B., Goggi, A. S., ... Weyers, S. L. (2019). Regenerating agricultural landscapes with perennial groundcover for intensive crop production. *Agron.-Basel, 9*(8), article 458. https://doi.org/10.3390/agronomy9080458

MPCA. (2014). The Minnesota nutrient reduction strategy. St. Paul: MN: Minnesota Pollution Control Agency. Retrieved from https://www.pca.state.mn.us/sites/default/files/wq-s1-80.pdf

MPCA. (2019). Best management practice modeling scenarios for the Minnesota River basin sediment strategy. St. Paul: MN: Minnesota Pollution Control Agency. Retrieved from https://www.lrl.mn.gov/docs/2021/other/210546.pdf

MPCA. (2020). Five-year progress report on Minnesota's Nutrient Reduction Strategy. St. Paul: MN: Minnesota Pollution Control

Agency. Retrieved from https://www.pca.state.mn.us/water/five-year-progress-report

Robertson, D. M., & Saad, D. A. (2021). Nitrogen and phosphorus sources and delivery from the Mississippi/Atchafalaya River basin: An update using 2012 SPARROW models. *J. American Water Resour. Assoc., 57*(3), 406-429. https://doi.org/10.1111/1752-1688.12905

SARE. (2007). *Managing cover crops profitably* (3rd Ed.). College Park, MD: Sustainable Agriculture Research and Education. Retrieved from https://www.sare.org/resources/managing-cover-crops-profitably-3rd-edition/

Scavia, D., Bertani, I., Obenour, D. R., Turner, R. E., Forrest, D. R., & Katin, A. (2017). Ensemble modeling informs hypoxia management in the northern Gulf of Mexico. *Proc. Natl. Acad. Sci., 114*(33), 8823-8828. https://doi.org/10.1073/pnas.1705293114

Schilling, K. E., & Wolter, C. F. (2007). A GIS-based groundwater travel time model to evaluate stream nitrate concentration reductions from land use change. *Environ. Geol., 53*(2), 433-443. https://doi.org/10.1007/s00254-007-0659-0

TNC. (2021). Leading at the edge: A roadmap to advance edge of field practices in agriculture. Arlington, VA: The Nature Conservancy, Meridian Institute, and Soil and Water Conservation Society. Retrieved from https://www.nature.org/content/dam/tnc/nature/en/documents/EOF_Report_LORES_SPREADS.pdf

Tomer, M. D., Sadler, E. J., Lizotte, R. E., Bryant, R. B., Potter, T. L., Moore, M. T., ... Walbridge, M. R. (2014). A decade of conservation effects assessment research by the USDA Agricultural Research Service: Progress overview and future outlook. *J. Soil Water Cons., 69*(5), 365-373. https://doi.org/10.2489/jswc.69.5.365

USDA-FSA. (2020). Conservation Reserve Program statistics. Washington, DC: USDA Farm Service Agency. Retrieved from https://www.fsa.usda.gov/programs-and-services/conservation-programs/reports-and-statistics/conservation-reserve-program-statistics/index

USDA-NASS. (2012). Table 50: Land use practices by size of farm. In 2012 Census of Agriculture. Washington, DC: USDA National Agricultural Statistics Service.

USDA-NASS. (2020). Land values 2020 summary. Washington, DC: USDA National Agricultural Statistics Service. Retrieved from https://www.nass.usda.gov/Publications/Todays_Reports/reports/land0820.pdf

USEPA. (2008). Gulf hypoxia action plan 2008 for reducing, mitigating, and controlling hypoxia in the northern Gulf of Mexico and improving water quality in the Mississippi River basin. Washington, DC: U.S. Environmental Protection Agency, Mississippi River/Gulf of Mexico Watershed Nutrient Task Force. Retrieved from https://www.epa.gov/ms-htf/gulf-hypoxia-action-plan-2008

USEPA. (2018). NHDPlus (National Hydrography Dataset Plus). Washington, DC: U.S. Environmental Protection Agency. Retrieved from https://www.epa.gov/waterdata/basic-information

USGCRP. (2018). *Fourth national climate assessment, Vol. II: Impacts, risks, and adaptation in the United States.* Washington, DC: U.S. Global Change Research Program. https://doi.org/10.7930/NCA4.2018

Van Meter, K. J., & Basu, N. B. (2017). Time lags in watershed-scale nutrient transport: An exploration of dominant controls. *Environ. Res. Lett., 12*(8), article 84017. https://doi.org/10.1088/1748-9326/aa7bf4

Zimmerman, E. K., Tyndall, J. C., & Schulte, L. A. (2019). Using spatially targeted conservation to evaluate nitrogen reduction and economic opportunities for best management practice placement in agricultural landscapes. *Environ. Mgmt., 64*(3), 313-328. https://doi.org/10.1007/s00267-019-01190-7

NOMENCLATURE

CRP = Conservation Reserve Program
FSA = Farm Service Agency
HTF = Hypoxia Task Force
IDALS = Iowa Department of Agriculture and Land Stewardship
IEPA = Illinois Department of Environmental Protection
MCCC = Midwest Cover Crop Council
MPCA = Minnesota Pollution Control Agency
MRB = Mississippi River basin
MRTN = Maximum return to nitrogen (rate of nitrogen fertilization)
NRS = Nutrient reduction strategy
SARE = Sustainable Agriculture Research and Education
TNC = The Nature Conservancy
USGCRP = U.S. Global Change Research Program