U. S. STEEL MINNTAC
TWIN LAKES WILD RICE RESTORATION
OPPORTUNITIES PLAN
FINAL REPORT

FEBRUARY 28, 2019

PREPARED FOR

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Executive Summary

Department of the Army Wetland Permit Number 2011-00832-JCB (Permit) was issued to U. S. Steel on December 10, 2012 for proposed impacts to wetlands within the U. S. Steel Minntac "Progression", which allowed continued mining to the existing Permit to Mine boundary in the Minntac West Mine Pit. Special Conditions 9 and 10 of the Permit required the development and implementation of a Twin Lakes Wild Rice Restoration Opportunities Plan that included "the development of a five-year wild rice restoration and monitoring program for those areas of the Twin Lakes that show the greatest potential for restoration based on best information available in the time frame allowed…".

The Twin Lakes Wild Rice Restoration Opportunities Plan (Plan) was developed by U. S. Steel and Northeast Technical Services (NTS) to satisfy Special Condition 9 of the Permit and submitted to the U.S. Army Corps of Engineers (Corps) on April 11, 2013. The Plan was subsequently revised to address comments from the Corps and other interested parties, and resubmitted to the Corps on August 16, 2013. The Corps approved of the Plan on November 22, 2013. In anticipation of Corps approval, and to satisfy Special Condition 10 of the Permit, work on the Plan was initiated on October 9, 2013 with the deployment of a pressure transducer at the steel bridge separating Little Sandy and Sandy lakes to record fluctuations in lake levels. Additional activities were completed in 2013, although the overall scope was limited due to the lateness of the open water season. Monitoring activities continued each subsequent year, 2014 – 2018, from ice-out to mid- to late-Autumn. Descriptions of the activities and accomplishments from each Plan year, including 2013, are detailed in annual reports that have been submitted to the Corps by the end of each respective calendar year.

This final report represents the culmination of the Plan and that five-year effort, and provides a comprehensive evaluation of the monitoring efforts that have been conducted, a presentation of the various factors that influence wild rice growth in this setting, and analyses of the primary opportunities for restoration of wild rice in the Twin Lakes.

1.0 Introduction/Background

During the summer of 2013, U. S. Steel and NTS developed the Twin Lakes Wild Rice Restoration Opportunities Plan (Plan) to evaluate the opportunities for wild rice restoration within Little Sandy Lake and Sandy Lake, commonly referred to as the Twin Lakes. Little Sandy and Sandy lakes are connected by a narrow channel approximately 20 meters in width. Historically, a north-south trending county road was routed through this area and crossed the narrow channel between the Twin Lakes via a steel truss bridge. The county road is no longer used for typical vehicle travel, but instead is used as a regional snowmobile trail. According to 1966 documentation (Sternberg and Hope 1966a, b), the distribution of wild rice in Sandy Lake was described as being extensive at that time. Site maps created following field work associated with Sternberg and Hope (1966a, b) indicate that wild rice was present "throughout" Sandy Lake. Although the actual acreage was not reported, the stand was reported to be in good condition with "…several boats ricing on the lake." Wild rice was also reported throughout Little Sandy Lake, with a denser wild rice stand observed in the NE corner. Measured water depths ranged from 2.0 – 3.0 feet throughout these lakes (Sternberg and Hope 1966a, b), which are typically associated with wild rice areas, and is documented to be appropriate for wild rice growth. According to published literature sources water depths of 0.5 – 3.0 feet are more conducive to wild rice growth and propagation (MN DNR 2008; Vogt 2012). Historical water depths in Little Sandy and Sandy lakes appear to have been more favorable for wild rice growth than in more recent times. Vogt (2012) observed wild rice plants in Sandy Lake during 2006, 2007, 2010, 2011, and 2012 surveys. No surveys were completed in 2008 or 2009. The density of wild rice plants observed during each of these surveys was fewer than approximately 100 total plants. Wild rice in Little Sandy Lake was observed only during the 2006 and 2012 surveys. Subsequent wild rice surveys completed by the 1854 Treaty Authority identified areas of sparse wild rice plant density in variable locations within the Twin Lakes system. During 2015, three specific areas within each lake were used as wild rice test seeding areas for the Plan. During the 2016, 2017, and 2018 wild rice surveys, wild rice plants were observed in all six seeded areas and was reported to be present at variable densities.

For the purposes of the Plan, the entire area/volume of the Twin Lakes system was considered as the potential area within which wild rice restoration opportunities would be considered. Throughout the 5+ field seasons (approximately April – October) of the Plan, observations and datasets from the Twin Lakes were obtained and accumulated, as follows: specific physical characteristics of interest to successful wild rice restoration opportunities such as water depth, the presence of competing aquatic vegetation, and sediment type (e.g., sandy, more organic rich), were evaluated; surface water, sediment, and sediment pore water quality sampling events were completed each year of the study, many of which were above-and-beyond the scope of the Plan as approved, to define the chemical characteristics of the system; and hydrologic/hydraulic modeling of the Twin Lakes system was undertaken to determine the reasons behind the apparently high lake levels relative to what was historically observed.

As discussed above, historically when wild rice was reported as present throughout the Twin Lakes water depths were reported as 2.0-3.0 feet. This is within the appropriate water depth range for wild rice germination, growth, and development into mature seed producing plants. As this system has aged, competing perennial aquatic vegetation has become more dense within portions of both of the Twin Lakes, and in particular Sandy Lake, as well as in the Sand River downstream of Sandy Lake. Additionally, beavers have constructed and maintained several dams within the Sand River below Twin Lakes that have increased the water depths of the lakes. As a critical component of the Plan, beaver trapping and (beaver) dam removal efforts were completed in an effort to mitigate their influences on increasing water depth in the lakes. Although water depths around the internal periphery of the Twin Lakes can be more appropriate for wild rice growth and development, few if any wild rice plants have been observed in these areas. Based on historical wild rice density reports, the absence of wild rice in areas of more appropriate water depth was puzzling. If viable wild rice seeds were present in the sediment of these areas, wild rice plants would most likely be observed. Instead, based on yearly wild rice surveys completed by 1854 Treaty Authority personnel, wild rice plants were infrequently observed in areas of appropriate water depth, almost exclusively in Sandy Lake, and areas of sparse wild rice plants varied between years. Although this indicates wild rice seed can survive in Twin Lakes sediment over time, the spatial variability of wild rice plant observations has been confounding.

Records indicate that not only were historical water depths more favorable to wild rice growth and propagation, but that there were fewer perennial aquatic plants competing with wild rice for needed resources. Yearly aquatic plant surveys were completed as a required component of the Plan, during which several taxa of aquatic plants were observed and identified in areas conducive and non-conducive to wild rice growth. Perennial aquatic plants such as cattails have reproductive advantages, not available to wild rice as an annual, allowing them to tolerate water depth fluctuations. Additional perennial aquatic vegetation such as Coontail and pondweed can survive in water under ice and snow; and therefore, have a unique advantage to outcompete wild rice for resources such as light during and following spring melt. Historical and current non-managed growth, development, and increased distribution of perennial aquatic plants competing with wild rice has likely resulted in decreased availability of areas conducive to wild rice growth, development, and distribution.

Finally, historical distribution of wild rice within the Twin Lakes system would suggest that the sediment characteristics throughout this system would be conducive to wild rice growth and development. However, it appears that some areas within the Twin Lakes contain sediment with a greater proportion of sand and/or gravel rather than the organic-rich sediment type preferred by wild rice. This suggests that some areas within each of these lakes may not be conducive to wild rice growth and development, completely unrelated to any influence from water depth, competing aquatic vegetation, or characteristics of surface water or sediment pore water quality.

The objective of the Plan was to identify opportunities for wild rice restoration in the Twin Lakes. This final report details the specific factors influencing wild rice growth in the Twin Lakes and provides suggestions on opportunities for successful long-term restoration of wild rice in Sandy and Little Sandy lakes.

2.0 SURFACE WATER QUALITY

2.1 INFLOW/OUTFLOW MONITORING DESCRIPTIONS

U. S. Steel began sampling and testing surface water quality of the Twin Lakes starting in May 2014 as prescribed by the Plan. Surface water samples were collected during each month of open water through 2018. The location and parameters sampled varied over time depending on several factors, which is explained below for each designated location (see Figure 1). Prior to 2014, Twin Lakes surface water quality was monitored through a separate agreement between the Bois Forte Band of Chippewa (Bois Forte) and U. S. Steel. This work is discussed further in Section 2.2 below.

Water quality sampling sources included the inflows to Little Sandy Lake (Inflow 1, Inflow 2 and Inflow 3), a tributary to Sandy Lake from the north into its northeast arm (Culvert Inflow), another small tributary to Sandy Lake from the south (Sandy Lake South Inflow), and the Twin Lakes system outflow (Twin Lakes Outflow, previously referred to as Outflow 2 Sand River). It should be noted that the inflow samples referred to above were collected either from active, measurable inflow (Inflow 1, the Culvert Inflow and the Sandy Lake South Inflow) or from areas at the periphery of the lake in close proximity to what appears to be inflow channels from aerial photos (e.g., Inflow 2 and Inflow 3). Areas of discrete, measureable flow at the Inflow 2 and Inflow 3 locations were not accessible by canoe at any time during the course of the Plan primarily due to the density of vegetation present at the wetland channel/lake interface. Flow from the wetland channels corresponding to the Inflow 2 and Inflow 3 locations enters the lake in a diffuse manner, preventing the quantification of inflow to Little Sandy Lake from these sources. Therefore, samples were collected at the mouth of the inflow channels. Water was also sampled periodically from the approximate centers of Little Sandy and Sandy lakes to evaluate the general water quality within each lake. It should be noted that sampling from the Inflow 3 site was discontinued for the 2017 and 2018 monitoring seasons, since previous water quality characterization results indicated no significant difference between the water sampled at this location and samples collected from the middle of Little Sandy Lake. A description of each of the sampling sources, with the exception of the mid-lake samples, is provided here:

Inflow 1 – corresponds to the discharge of the Sand River into the southeast quadrant of Little Sandy Lake. Water quality samples are collected from the inflow channel approximately 20 meters downstream of a wooden suspension snowmobile bridge crossing the Sand River at the inlet.

Inflow 2 – is situated on the very west edge of Little Sandy Lake and represents flow entering the system from a wetland complex to the southwest that originates near the northeast corner of the Minntac tailings basin perimeter dike.

Inflow 3 – represents discharge to the system from general wetlands present north of Little Sandy Lake. The Inflow 3 sampling location is situated on the northwest side of Little Sandy Lake at the mouth of a north/south trending wetland complex. As noted above, water quality sampling from this location was discontinued after the 2016 monitoring season because no statistical difference was observed in the water quality results between Inflow 3 samples and samples collected from the middle of Little Sandy Lake (LSL Mid).

Culvert Inflow – represents tributary flow from the north entering the east end of Sandy Lake near the discharge into the Sand River. A culvert through the access road to the canoe landing was identified in 2014 on a stream that appeared to be the main source of flow to this tributary (previously referred to as "Outflow Trib 1"). The culvert is located roughly 1080 meters upstream from where the tributary discharges into Sandy Lake. Water quality sampling results from 2014 showed that there were no significant differences between the Outflow Trib 1 and Culvert Inflow samples, and therefore all subsequent sampling for this source was conducted at the culvert.

Sandy Lake South Inflow – represents tributary inflow from the south entering the southeast arm of Sandy Lake. This sampling point was identified during the aquatic plant survey in August 2016, after which water quality sampling and flow monitoring was implemented.

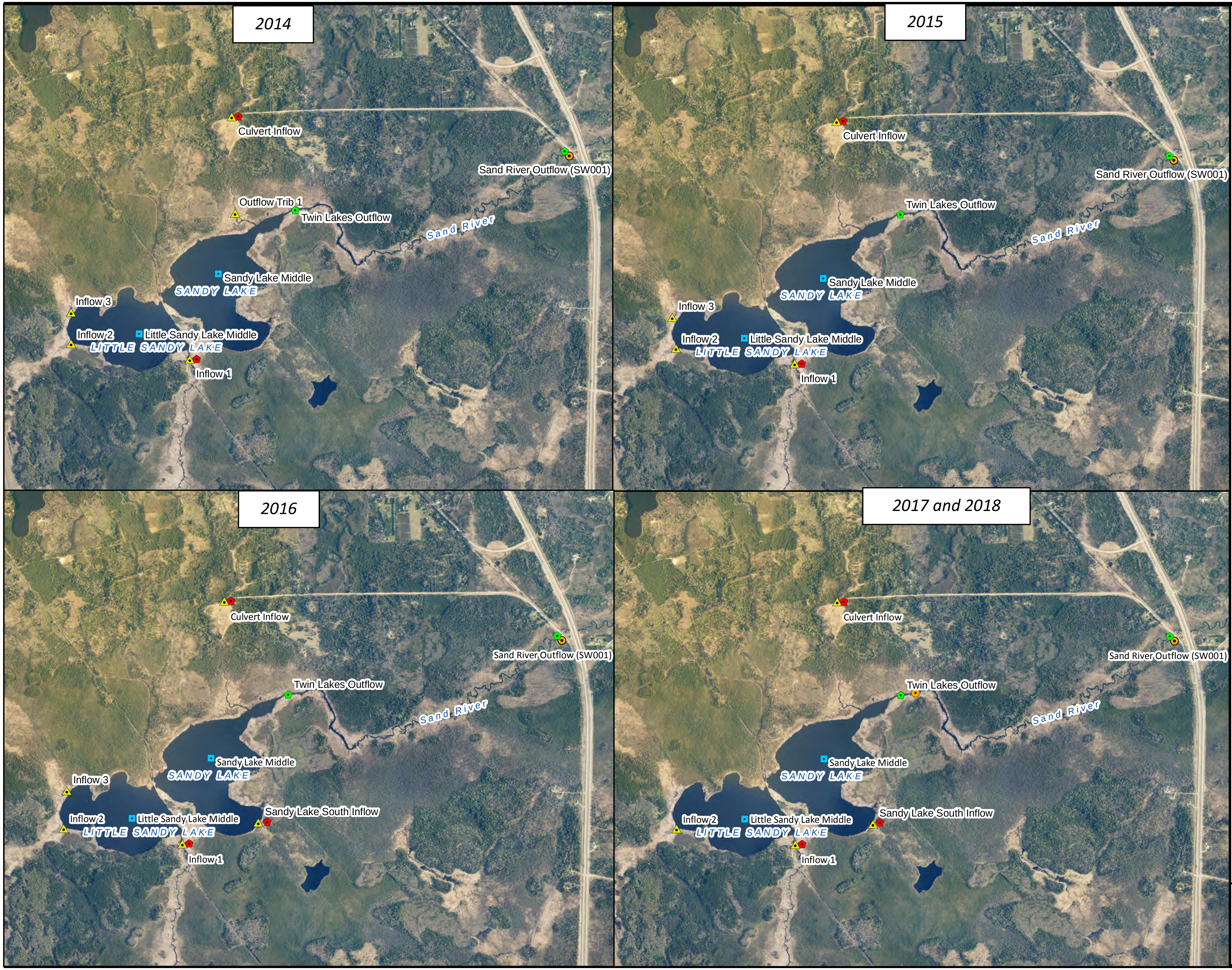
Twin Lakes Outflow – is located in the Sand River channel approximately 450 meters downstream from the mouth of the north tributary (characterized by Culvert Inflow / Outflow Trib 1). Water sampled at this location is representative of the total outflow from the Twin Lakes system.

With the minor exceptions described above, water samples were collected on a monthly basis during each open-water monitoring season of the Plan from the inflow sources to Little Sandy Lake (Inflow 1, Inflow 2 and Inflow 3), the identified inflow sources to Sandy Lake (Culvert Inflow and Sandy Lake South Inflow), the outflow from the system (Twin Lakes Outflow) and from the approximate center of each lake (see Figure 1 below). Analytical results from these monthly sampling events were tabulated by event date and are presented in Appendix A. In addition, summaries of the sampling results for each of the five years of Plan implementation are presented in Tables 1 – 5 below.

It should be noted that the list of analytical parameters changed over the five-year Plan. After each Plan year, the results were reviewed and parameters that were below detection limits or relatively unchanged were removed from the profile.

- Aluminum: Most results for aluminum were under 50 µg/L. Therefore, measurement of this parameter was discontinued prior to the fourth year (2017).
- Arsenic: During the first year, all water samples tested for arsenic were well below the applicable water quality standard. After the second sampling event of 2015 this parameter was discontinued.
- Barium: Concentrations of barium were typically between 20 and 30 ug/L and did not vary over the first seven sampling events conducted for the Plan. Analysis of this parameter was discontinued after the first sampling event of 2015.
- Gallium, Molybdenum, Silver: The first two sample events showed results below the detection limit for these three parameters at all locations. Therefore, analysis of gallium, molybdenum and silver were discontinued after the second sampling event of 2014.
- Cadmium, Lead, Zinc: The first two sample events of 2014 did not show results for cadmium, lead and zinc above the detection limit at any of the sampling locations except Culvert Inflow. After the second sampling event of 2014 these analyses were discontinued at all of the sampling locations with the exception of the Culvert Inflow source, which continued through the end of the 2014 sample season. Aside from that one result, no other samples resulted in values above the detection limit at the Culvert Inflow. Therefore, analyses of these three parameters was totally discontinued prior to 2015.
- Copper: The analytical results for copper followed the same trend as described above for Cd, Pb, and Zn. Aside from an elevated concentration of copper above detection at the Culvert Inflow, no other samples resulted in values above the detection limit. Therefore, analysis of these three parameters was totally discontinued prior to 2015.
- Nickel: The first two sample events showed results below the detection limit for nickel at all locations. Measurement of this parameter was discontinued after the second sampling event of 2014.
- Phosphorus: This parameter was sampled during the entire first year and showed results at or near the detection limit at all locations. Therefore, prior to 2015, analysis of this parameter was discontinued. Note that the low-level method of phosphorus analysis was not used and therefore, the detection limit reported by the lab was 0.10 mg/L.
- Strontium, Rubidium: These parameters were sampled the entire first year of the Plan (2014) and the first two sample events of the second year (2015). Results for strontium and rubidium were fairly consistent during this time, so this measurement was discontinued after the second sample event of 2015.
- Nitrogen: Since most of the nitrogen analysis showed results at or near detection limits at all locations, with the exception of Total Kjeldahl Nitrogen, all nitrogen analyses were discontinued after the second sample event of 2014. However, analysis of Ammonia Nitrogen was reestablished for the first sample event of 2015 and continued for the remainder of the Plan.
- Specific Ultraviolet Absorbance, Ultraviolet Absorbance (SUVA, UVA): SUVA is another way to measure Dissolved Organic Carbon in surface water. Since there was a Total Organic Carbon

measurement included in the sampling plan, running this test was viewed as redundant. Therefore, analysis of this parameter was discontinued after the second sample event of 2015.

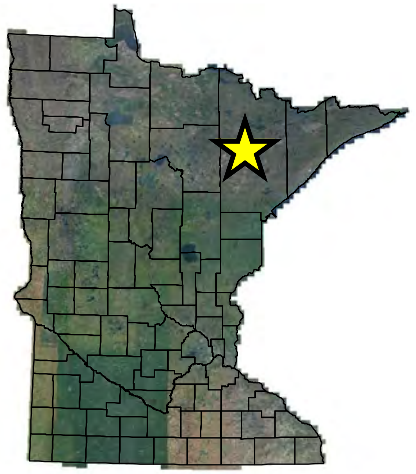


N

0 1,150 2,300 4,600

Feet

1 Inch = 2,340 Feet



Legend

- Inflow Gauging
- Outflow Gauging
- Inflow Water Sample
- Outflow Water Sample
- Lake Middle Water Sample

Figure 1
2014-2018 Twin Lakes
Inflow/Outflow Water Sampling and Flow Gauging Locations

Twin Lakes
US Steel Corporation -
Minnesota Ore Operations
Mt. Iron, Minnesota (St. Louis County)

NTS Environmental Science & Engineering
www.netechnical.com

Date Drawn : February 12, 2019	
Drawn By : T. Muck	1
NTS Project #: 10170E	

TABLE 1
TWIN LAKES WATER QUALITY 2014

	Reporting	Little Sandy Inflow 1			Little Sandy Inflow 2			Little Sandy Inflow 3			Little Sandy Middle			Sandy Middle			Culvert Inflow			Twin Lakes Outflow		
Analytes - Cations	**Units**	**Average**	**Min**	**Max**	**Average**	**Min**	**Max**	**Average**	**Min**	**Max**	**Average**	**Min**	**Max**	**Average**	**Min**	**Max**	**Average**	**Min**	**Max**	**Average**	**Min**	**Max**
Aluminum	µg / L	27.0	<20.0	52.0	15.8	<20.0	41.7	<20.0	<20.0	<20.0	30.6	30.6	30.6	37.7	37.7	37.7	NM	NM	NM	20.2	22.8	35.1
Arsenic	µg / L	0.75	<0.50	0.75	0.4	<0.50	1.1	0.60	<0.50	0.69	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	0.72	<0.50	1.10	0.60	0.51	0.92
Barium	µg / L	37.9	23.1	58.9	26.6	19.4	35.4	29.2	22.3	35.5	23.3	23.3	23.3	21.4	21.4	21.4	31.2	23.9	38.2	25.5	18.9	31.2
Calcium	mg / L	66.9	37.5	95.0	32.5	25.4	40.5	33.4	24.6	44.4	29.5	29.5	29.5	25.3	25.3	25.3	13.1	11.0	15.5	24.1	19.1	34.8
Iron	µg / L	860	229	1980	543	169	1100	258	173	459	717	717	717	800	800	800	4646	1870	7520	975	409	1470
Magnesium	mg / L	92.5	44.3	140	42.8	34.4	52.8	44.7	36.1	62.3	36.5	36.5	36.5	30.5	30.5	30.5	4.4	3.9	5.2	27.4	19.7	44.9
Manganese	µg / L	142	54.4	347	56.5	23.9	92.2	75.4	25.5	127	42.7	42.7	42.7	42.5	42.5	42.5	183	82.3	300	64.8	27.6	138
Phosphorus	mg / L	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Potassium	mg / L	6.1	2.5	11.4	3.3	1.7	4.0	3.2	2.2	3.7	3.7	3.7	3.7	3.5	3.5	3.5	1.4	0.93	1.9	2.9	2.2	3.4
Rubidium	µg / L	2.9	2.0	4.0	2.3	1.5	2.6	2.6	2.3	3.0	2.6	2.6	2.6	2.5	2.5	2.5	0.90	1.1	1.4	2.1	1.6	2.5
Sodium	mg / L	38.3	18.4	58.2	15.5	12.0	19.5	14.3	9.3	23.1	12.9	12.9	12.9	11.8	11.8	11.8	4.0	3.2	4.5	10.9	8.3	17.8
Strontium	µg / L	238	133	327	112	85.5	142	114	78.2	154	98.5	98.5	98.5	86.3	86.3	86.3	54.6	44.2	63.4	85.8	66.5	123
Analytes - Anions																						
Chloride	mg / L	57.3	9.5	103	21.3	15.8	28.5	21.3	8.0	30.1	17.1	17.1	17.1	15.7	15.7	15.7	10.3	6.4	13.1	16.6	13.3	25.8
Nitrogen, Kjeldahl, Total	mg / L	0.4	<0.50	0.75	0.92	0.66	1.2	1.0	0.59	1.8	0.72	0.72	0.72	0.74	0.74	0.74	1.1	0.9	1.2	0.70	<0.50	1.2
Ammonia as Nitrogen	mg / L	<0.50	<0.50	<0.50	<0.050	<0.050	<0.050	<0.050	<0.050	<0.50	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050
Unionized Ammonia, as Nitrogen	ug/L	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Sulfate	mg / L	328	107	540	125	89.3	162	104	9.9	156	121	121	121	98.6	98.6	98.6	0.60	<2.0	<2.0	80.3	44.6	124.0
Analytes - Other																						
Total Dissolved Solids	mg / L	829	431	1170	403	333	465	407	318	489	366	366	366	315	315	315	151	114	192	299	221	375
Alkalinity, Total as CaCO3	mg / L	191	95.7	259	142	69.0	253	132	90.2	188	95.3	95.3	95.3	74.1	74.1	74.1	38.2	32.1	45.9	85.9	53.4	129
Dissolved Organic Carbon	mg / L	16.6	10.3	20.5	22.7	15.6	26.5	24.3	20.2	28.6	22.0	22.0	22.0	22.0	22.0	22.0	20.5	8.5	30.4	21.8	16.7	26.2
Total Hardness by 2340B	mg / L	548	276	814	257	207	317	267	210	368	224	224	224	189	189	189	50.8	43.7	60.0	173	132	272
UV Absorbance @ 254 nm	mg / L	0.672	0.320	0.930	0.896	0.561	1.20	1.01	0.781	1.40	0.958	0.958	0.958	0.938	0.938	0.938	1.02	0.360	1.90	0.890	0.570	1.10
SUVA	cm^{-1}	3.9	3.1	4.5	3.9	3.6	4.6	3.8	2.3	4.7	4.4	4.4	4.4	4.3	4.3	4.3	3.9	1.3	5.2	4.2	3.6	5.0
YSI Probe Plus Data																						
pH	Units	7.4	7.0	8.6	7.5	6.6	8.4	7.8	6.9	8.5	7.6	7.6	7.6	7.7	7.7	7.7	6.6	6.6	6.8	7.6	7.0	8.6
Temperature	ºC	16.3	7.2	21.7	16.3	7.7	23.4	19.7	7.3	25.2	23.6	23.6	23.6	22.6	22.6	22.6	16.6	7.3	23.9	17.5	7.9	23.1
Specific Conductance	uS / cm	1098	569	1620	546	261	689	542	364	678	504	504	504	387	387	387	117	96.0	137	381	307	561

Note: To find each location's frequency of sampling, please review the 2014 Twin Lakes WRROP Annual Report under Twin Lakes Inflow/Outlfow Water Sampling Data.

TABLE 2

TWIN LAKES WATER QUALITY 2015

	Reporting	Little Sandy Inflow 1			Little Sandy Inflow 2			Little Sandy Inflow 3			Little Sandy Middle			Sandy Middle			Culvert Inflow			Twin Lakes Outflow		
Analytes - Cations	Units	Average	Min	Max	Average	Min	Max	Average	Min	Max	Average	Min	Max	Average	Min	Max	Average	Min	Max	Average	Min	Max
Aluminum	µg / L	69	29.7	124	15.4	10.1	54.3	<10.0	<10.0	16.4	<0.10	<0.10	<0.10	8.0	<50.0	18.1	25.4	<50.0	53.0	14.3	<50.0	35.8
Arsenic	µg / L	<0.05	<0.05	<0.05	<0.50	<0.50	<0.50	<0.50	<0.50	<0.50	NM	NM	NM	NM	NM	NM	0.38	<0.50	0.76	<0.50	<50.0	<0.50
Barium	µg / L	19.0	19.0	19.0	23.7	23.7	23.7	26.5	26.5	26.5	NM	NM	NM	NM	NM	NM	17.5	17.5	17.5	24.4	24.4	24.4
Calcium	mg / L	64	38.4	91.7	45.7	27.9	68.0	40.0	30.5	53.1	49.6	40.7	59.1	39.4	33.4	47.4	12.1	9.0	15.4	33.6	15.6	42.2
Iron	µg / L	963	407	2030	995	218	4170	235.7	80.0	448.0	121	121	121	268	171	315	2600	1180	3800	583	287	1200
Magnesium	mg / L	90	53	133	65.7	38.2	97	60.2	46.5	79.8	71.7	57.7	83.9	57.2	47.2	69.5	4.3	3.2	5.3	45.6	14.3	59.1
Manganese	µg / L	154	28.5	309	76.5	32.8	128	93.9	14.8	258	98.7	98.7	98.7	68.2	40.1	129	134	46.1	210	52.1	32.6	67.5
Phosphorus	mg / L	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	NM	NM	NM	NM	NM	NM	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Potassium	mg / L	7.6	5.6	11.6	4.1	1.78	5.73	3.2	1.6	4.4	5.1	5.1	5.1	4.4	4.1	4.8	1.5	1.2	1.9	4.2	1.8	6.0
Rubidium	µg / L	2.9	2.8	2.9	3.0	3.0	3.0	2.5	2.4	2.6	NM	NM	NM	NM	NM	NM	1.3	1.2	1.4	2.8	2.8	2.8
Sodium	mg / L	36.3	21.3	52.4	21.6	13.7	30.6	17.8	11.1	25.5	26.0	20.2	31.3	21.9	17.9	26.5	4.2	3.7	4.7	18.1	6.9	23.2
Strontium	µg / L	152	129	175	130.5	128	133	102	101	102	NM	NM	NM	NM	NM	NM	39.7	34.3	45.1	122	107	136
Analytes - Anions																						
Chloride	mg / L	54	31.4	85.4	30.7	23.6	43.5	23.2	13.2	33.9	37.8	31.4	47.6	32.2	28.5	39.1	10.5	8.2	13.4	27.0	12.1	35.4
Nitrogen, Kjeldahl, Total	mg / L	0.68	<0.50	0.98	1.1	0.73	1.6	0.90	0.59	1.2	0.85	0.72	1.1	0.85	0.65	1.1	0.40	<0.50	0.83	0.71	0.57	1.0
Ammonia as Nitrogen	mg / L	0.02	<0.10	0.10	0.03	<0.10	0.17	0.05	<0.10	0.12	<0.10	<0.10	<0.10	0.15	0.15	0.15	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10
Unionized Ammonia, as Nitrogen	ug/L	0.09	0.00	1.9	0.25	0.00	5.0	0.43	0.00	6.7	0.00	0.00	0.00	4.8	1.3	11.5	0.00	0.00	0.00	0.00	0.00	0.00
Sulfate	mg / L	326	191	498	227	157	340	179	52.5	250	240	219	279	187	162	223	2.5	<2.0	2.8	146	33.8	200
Analytes - Other																						
Total Dissolved Solids	mg / L	747	457	1040	549	399	737	473	309	623	572	475	649	467	399	546	121	95.0	166	388	174	473
Total Suspended Solids	mg / L	1.8	<1.0	3.6	1.7	<1.0	3.5	1.3	1.6	2.0	1.2	1.2	3.2	1.6	<1.0	4.0	3.3	1.2	5.2	1.9	<1.2	4.0
Alkalinity, Total as CaCO3	mg / L	162	93.1	233	143	105	221	148	92.6	201	145	110	178	117	93.7	153	36.7	24.6	46.2	97.5	47.4	134
Dissolved Organic Carbon	mg / L	14.3	9.4	18.4	19.4	12.9	28.5	20.5	14.7	30.7	18.3	17.0	20.1	18.8	17.0	20.3	12.8	7.5	16.3	16.2	10.8	19.3
Total Hardness by 2340B	mg / L	529	314	776	385	227	569	348	268	461	419	339	493	334	278	405	47.9	35.7	60.6	272	97.9	349
UV Absorbance @ 254 nm	cm^{-1}	0.466	0.429	0.502	0.476	0.408	0.544	0.574	0.468	0.679	NM	NM	NM	NM	NM	NM	0.525	0.478	0.572	0.422	0.360	0.484
SUVA	L / mg*m	3.5	3.4	3.5	3.3	3.3	3.3	3.4	3.3	3.4	NM	NM	NM	NM	NM	NM	4.5	4.4	4.6	3.4	3.3	3.5
YSI Probe Plus Data																						
pH	Units	7.3	6.9	7.7	7.5	7.0	7.8	7.5	6.9	8.1	8.1	7.9	8.4	8.0	7.8	8.2	6.9	6.7	7.1	7.7	7.0	8.1
Temperature	ºC	13.6	6.9	19.7	15.5	6.3	22.1	13.9	7.3	21.6	16.4	7.3	22.3	16.1	6.6	22.7	13.5	7.3	18.8	15.4	6.4	23.1
Specific Conductance	uS / cm	1038	632	1435	842	703	1150	698	476	943	831	730	949	670	610	746	112	85.0	130	554	219	698

Note: To find each location's frequency of sampling, please review the 2015 Twin Lakes WRROP Annual Report under Twin Lakes Inflow/Outlfow Water Sampling Data.

NM = Not Measured

TABLE 3

TWIN LAKES WATER QUALITY 2016

	Reporting	Little Sandy Inflow 1			Little Sandy Inflow 2			Little Sandy Inflow 3			Little Sandy Middle			Sandy Middle			Culvert Inflow			Twin Lakes Outflow		
Analytes - Cations	**Units**	**Average**	**Min**	**Max**	**Average**	**Min**	**Max**	**Average**	**Min**	**Max**	**Average**	**Min**	**Max**	**Average**	**Min**	**Max**	**Average**	**Min**	**Max**	**Average**	**Min**	**Max**
Aluminum	µg / L	96	<50.0	284	28	<50.0	111	11.5	<50.0	69.1	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	16.4	<50.0	132	19.0	<50.0	57.3
Calcium	mg / L	55.9	39.4	69.6	39.0	30.7	47.4	34.4	30.1	40.0	35.0	28.2	46.0	36.3	31.5	38.7	12.0	10.0	14.2	27.8	24.3	33.4
Iron	µg / L	4842	1150	20700	1155	442	2320	1060	268	3270	388	388	388	650	650	650	5498	1560	10700	1553	502	3280
Magnesium	mg / L	75.1	45.6	99.3	54.4	41.9	69.1	50.9	47.5	56.0	32.0	38.3	67.2	49.7	42.9	55.6	4.2	3.7	4.9	36.0	31.2	46.5
Manganese	µg / L	177	81.3	429	121	51.9	214	127	77.2	220	63.3	63.3	63.3	38.4	38.4	38.4	233	62.9	419	85.6	46.8	138
Potassium	mg / L	6.0	2.6	9.5	3.4	2.3	4.6	2.7	1.5	4.3	3.5	2.9	4.1	3.3	3.0	3.6	1.4	0.94	1.8	2.9	2.2	3.5
Sodium	mg / L	29.6	17.1	39.0	17.3	14.3	23.0	13.5	9.2	16.8	16.6	13.5	23.0	17.1	15.2	20.1	3.8	3.1	4.2	13.1	11.5	17.1
Analytes - Anions																						
Chloride	mg / L	43.6	20.9	56.5	23.9	17.9	33.7	18.0	12.5	21.7	23.8	17.8	34.7	24.3	18.4	30.2	9.1	7.1	10.6	19.2	15.4	26.1
Nitrogen, Kjeldahl, Total	mg / L	0.93	<0.60	2.6	1.2	0.70	2.1	1.0	0.60	1.6	0.72	<0.50	1.4	0.70	0.79	1.3	0.49	<0.50	1.3	0.87	<0.50	1.5
Ammonia as Nitrogen	mg / L	0.06	<0.10	0.36	0.09	0.15	0.29	0.06	<0.10	0.16	0.05	<0.10	0.15	0.04	<0.10	0.11	0.02	<0.10	0.12	0.11	<0.10	0.32
Unionized Ammonia, as Nitrogen	ug/L	0.20	0.00	3.2	0.48	0.14	9.8	0.31	0.00	2.3	1.08	0.00	14.3	0.78	0.00	7.8	0.04	0.00	1.0	1.0	0.00	7.9
Sulfate	mg / L	251	120	338	155	96.7	216	112	39.6	163	145	104	176	148	125	183	0.4	<2.0	2.3	92.3	64.3	114
Analytes - Other																						
Total Dissolved Solids	mg / L	660	431	836	465	407	561	409	367	473	439	363	548	421	389	460	133	113	155	330	276	392
Total Suspended Solids	mg / L	4.7	1.5	14	7.5	<2.5	22.0	3.5	<2.5	6.5	2.5	2.0	3.2	0.9	<1.0	1.6	9.4	3.2	26	2.0	<1.0	3.6
Alkalinity, Total as HCO3-	mg / L	196	149	278	192	120	251	198	140	255	148	106	222	151	127	179	39.7	34.8	48.4	128	92.4	152
Alkalinity, Total as CaCO3	mg / L	161	122	228	157	98	206	162	115	209	121	87	182	124	104	147	33	29	40	105	76	125
Dissolved Organic Carbon	mg / L	25.7	10.5	63.7	27.8	15.6	38.9	28.2	16.2	38.2	21.6	21.6	21.6	25.1	25.1	25.1	21.8	11.7	35.4	24.9	14.8	39.1
Total Hardness	mg / L	449	286	582	322	249	402	295	280	330	287	228	392	295	255	326	47.1	40.4	55.5	230	189	349
YSI Probe Plus Data																						
pH	Units	7.1	6.7	7.3	7.2	6.9	7.8	7.2	7.2	7.4	7.8	7.3	8.2	7.8	7.3	8.1	6.8	6.5	7.3	7.5	7.3	7.6
Temperature	ºC	15.2	5.8	21.4	16.9	6.0	24.2	16.0	5.4	23.6	18.4	7.6	25.1	18.0	7.3	24.8	15.4	5.8	20.0	16.7	6.5	25.0
Specific Conductance	uS / cm	915	547	1141	628	572	781	560	517	644	655	567	732	534	459	619	160	102	417	439	359	527

Note: Little Sandy Middle and Sandy Middle Locations were sampled only once for Aluminum, Iron, Manganese, Potassium and Dissolved Organic Carbon and there were three monthly events where Total Suspended Solids, Nitrogen-Kjeldahl and Ammonium as Nitrogen were analyzed. For the sampling frequency at each location, please review the Twin Lakes 2016 Inflow/Outflow Water Sampling Data in Appendix C.

TABLE 4
TWIN LAKES WATER QUALITY 2017

	Reporting	Little Sandy Inflow 1			Little Sandy Inflow 2			Sandy Lake So. Inflow			Little Sandy Middle			Sandy Middle			Culvert Inflow			Twin Lakes Outflow		
Analytes - Cations	**Units**	**Average**	**Min**	**Max**	**Average**	**Min**	**Max**	**Average**	**Min**	**Max**	**Average**	**Min**	**Max**	**Average**	**Min**	**Max**	**Average**	**Min**	**Max**	**Average**	**Min**	**Max**
Calcium	mg / L	55.8	47.0	74.6	40.6	30.0	49.5	9.1	4.8	14.7	42.8	37.3	47.1	34.5	27.3	37.3	12.3	10.8	15.9	29.5	25.8	32.1
Iron	µg / L	1422	831	1840	762	327	1160	4910	448	15000	414	233	722	580	208	1100	2932	1610	3550	797	450	1330
Magnesium	mg / L	78.3	63.1	109	60.7	44.1	69.9	10.3	5.8	14.6	63.7	53.1	71.1	50.2	38.3	56.0	4.2	3.6	5.2	40.3	34.7	45.2
Manganese	µg / L	65.2	18.5	106	73.2	32.7	141	163	59.6	313	64.3	24.7	121	61.4	22.7	111	132	87	158	67.2	38.5	125
Potassium	mg / L	5.3	3.7	7.2	3.0	2.2	3.4	1.4	0.7	2.3	3.7	3.0	4.8	3.4	2.9	4.0	1.4	1.0	1.7	3.0	2.5	3.4
Sodium	mg / L	30.0	24.4	42.0	17.3	12.5	21.2	8.0	5.6	9.3	19.8	17.3	22.6	16.8	12.6	18.8	4.3	4.0	4.7	14.1	11.7	15.6
Analytes - Anions																						
Chloride	mg / L	44.4	31.5	58.2	23.8	16.6	28.6	16.7	10.4	21.6	28.2	23.7	32.3	24.4	18.2	28.4	11.7	8.8	14.2	21.4	17.5	26.0
Nitrogen, Kjeldahl, Total	mg / L	0.74	<0.60	0.94	0.90	0.81	1.0	1.1	0.64	2.3	0.70	<0.60	0.79	0.91	0.70	1.3	0.57	<0.60	0.68	0.79	0.66	0.89
Ammonia as Nitrogen	mg / L	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	0.24	<0.10	0.62	<0.10	<0.10	0.10	<0.10	<0.10	0.18	<0.10	<0.10	0.16	<0.10	<0.10	<0.10
Unionized Ammonina, as Nitrogen	ug/L	0.00	0.0	0.00	0.00	0.00	0.00	0.33	0.00	4.3	0.00	0.00	9.6	0.00	0.00	10.4	0.00	0.00	4.4	0.00	0.00	0.00
Sulfate	mg / L	276	217	388	163	126	186	4.6	<2.0	<2.0	187	170	201	145	122	153	2.7	<2.0	3.0	114	99.5	128
Analytes - Other																						
Total Dissolved Solids	mg / L	613	360	863	451	314	511	141	74.0	218	457	367	507	386	281	437	94.2	61.0	116	331	269	390
Total Suspended Solids	mg / L	1.5	1.2	2.0	3.3	1.6	5.6	5.9	1.6	22.0	2.2	1.6	4.0	1.4	<1.0	1.6	4.0	2.0	6.0	1.9	1.2	3.0
Alkalinity, Total as HCO3-	mg / L	177	134	246	182	124	223	51.4	17.9	85.5	181	132	220	145	100	178	37.9	28.4	48.9	124	94.0	146
Alkalinity, Total as CaCO3	mg / L	145	110	202	149	102	183	42.1	14.7	70.1	149	108	180	119	82	146	31.1	23.3	40.1	102	77.0	120
Dissolved Organic Carbon	mg / L	20.8	13.1	25.6	24.3	23.3	25.6	32.2	19.4	55.6	20.9	15.2	23.8	22.1	16.2	26.2	15.8	12.0	21.8	21.2	15.5	24.7
Total Hardness	mg / L	462	377	636	351	257	411	65.0	36.0	96.6	369	312	409	293	226	324	47.9	41.9	61.0	239	207	264
YSI Probe Plus Data																						
pH	Units	7.3	7.2	7.4	7.4	7.0	7.8	6.8	6.5	7.3	8.0	7.6	8.3	7.7	7.3	8.1	7.0	6.7	7.9	7.7	7.6	7.8
Temperature	ºC	14.1	5.8	22.5	15.7	6.1	20.7	12.2	6.1	17.1	16.2	6.9	24.0	15.8	6.8	23.0	13.0	6.2	18.2	14.8	6.9	21.7
Specific Conductance	uS / cm	929	748	1228	667	496	796	160	97.1	219	729	620	802	605	472	721	107	65.5	143	496	430	558

Note: Little Sandy Inflow 3 was not sampled in 2017 due to lack of a channel. The sampling site "Sandy Lake South Inflow" replaced it in the table above.

Also, the alkalinity was changed in 2016 to analyze as HCO3-. This table and 2016 below were changed to include both HCO3- and CaCO3.

TABLE 5

TWIN LAKES WATER QUALITY 2018

	Reporting	Little Sandy Inflow 1			Little Sandy Inflow 2			Sandy Lake So. Inflow			Little Sandy Middle			Sandy Middle			Culvert Inflow			Twin Lakes Outflow		
Analytes - Cations	**Units**	**Average**	**Min**	**Max**	**Average**	**Min**	**Max**	**Average**	**Min**	**Max**	**Average**	**Min**	**Max**	**Average**	**Min**	**Max**	**Average**	**Min**	**Max**	**Average**	**Min**	**Max**
Calcium	mg / L	56.8	35.5	105.0	39.0	23.0	50.7	6.7	3.7	10.0	38.3	31.1	50.3	38.3	29.2	49.4	11.2	8.5	14.6	29.9	26.7	34.2
Iron	µg / L	1155	541	2100	1685	177	5760	4402	871	10900	657	144	2580	465	114	1120	2315	1010	3520	720	386	1320
Magnesium	mg / L	108.1	47.3	334.0	56.8	34.8	74.3	7.1	4.5	10.4	57.6	46.0	71.8	57.0	43.7	75.0	3.8	2.9	4.9	42.0	35.3	52.0
Manganese	µg / L	74.5	26.8	160.0	121.5	35.2	227.0	86.7	8.3	188.0	76.7	18.6	200.0	62.6	25.2	130.0	108.7	55.6	153.0	69.2	23.5	105.0
Potassium	mg / L	5.8	3.2	11.1	3.4	1.6	5.5	1.5	0.5	2.5	3.6	2.7	4.4	3.3	0.1	5.5	1.8	1.3	2.5	3.2	2.5	4.3
Sodium	mg / L	32.4	18.9	67.3	17.9	9.1	24.3	3.8	2.4	6.6	18.6	15.3	25.2	19.3	15.1	25.1	4.9	3.5	5.8	14.7	12.6	17.6
Analytes - Anions																						
Chloride	mg / L	50.7	27.1	111	28.0	20.7	38.2	6.6	2.8	16.1	28.4	24.1	41.1	30.2	21.3	37.3	13.3	8.0	17.9	19.7	1.0	27.4
Nitrogen, Kjeldahl, Total	mg / L	0.7	0.5	1.1	0.9	0.5	1.4	1.1	0.6	1.7	0.6	0.5	0.8	0.6	0.5	0.8	0.6	0.5	0.8	0.6	0.5	0.7
Ammonia, as Nitrogen	mg / L	0.13	0.10	0.18	0.15	0.10	0.23	0.42	0.13	1.10	0.13	0.11	0.18	0.13	0.11	0.18	0.1	0.1	0.2	0.2	0.1	0.2
Unionized Ammonia, as Nitrogen	ug/L	0.64	0.11	3.8	0.78	0.08	5.5	0.47	0.05	4.4	3.2	0.61	20.4	2.2	0.52	7.2	0.16	0.02	0.67	1.38	0.25	5.8
Sulfate	mg / L	293.5	164.0	652.0	171.2	131.0	220.0	2.3	2.0	3.8	165.2	121.0	241.0	177.2	113.0	223.0	2.6	2.0	4.1	96.5	6.0	165.0
Analytes - Other																						
Total Dissolved Solids	mg / L	725.2	459.0	1440.0	499.3	394.0	632.0	129.8	72.0	188.0	NM	NM	NM	NM	NM	NM	108.3	74.0	136.0	356.8	318.0	400.0
Total Suspended Solids	mg / L	1.4	1.0	2.0	3.2	1.0	7.0	6.8	1.0	15.0	NM	NM	NM	NM	NM	NM	3.3	1.0	7.3	2.2	1.0	4.7
Alkalinity, Total as HCO3-	mg / L	214.9	137.9	407.5	203.5	80.5	290.4	49.0	24.5	75.6	NM	NM	NM	NM	NM	NM	40.8	31.8	57.2	152.7	130.5	192.8
Alkalinity, Total as CaCO3	mg / L	176.2	113.0	334.0	166.8	66.0	238.0	40.2	20.1	62.0	NM	NM	NM	NM	NM	NM	33.5	26.1	46.9	125.2	107.0	158.0
Dissolved Organic Carbon	mg / L	18.6	10.7	28.8	26.9	15.5	37.2	32.5	21.9	52.1	NM	NM	NM	NM	NM	NM	13.9	6.8	22.0	20.0	14.2	28.4
Total Hardness	mg / L	478.3	283.0	986.0	331.0	201.0	429.0	46.2	27.6	67.7	NM	NM	NM	NM	NM	NM	43.8	33.3	55.6	247.5	214.0	297.0
YSI Probe Plus Data																						
pH	Units	7.3	7.1	7.8	7.3	6.8	7.8	6.6	6.3	7.1	7.9	7.7	8.4	7.8	7.6	7.9	6.7	6.3	7.1	7.5	7.3	7.8
Temperature	ºC	13.6	2.0	18.8	15.6	4.0	21.0	14.4	9.4	16.6	15.9	3.6	22.4	15.7	3.9	22.4	11.6	3.4	15.2	15.1	4.3	21.6
Specific Conductance	uS / cm	1004	625	1925	751	606	921	209	80	553	769	673	927	635	553	830	121.3	83.4	163.8	531	480	612

Note: Little Sandy Inflow 3 was not sampled in 2018.

NM = Not Measured

2.2 Bois Forte Sampling

As mentioned above, starting in 2010 and continuing through 2014, U. S. Steel funded a surface water monitoring program at Twin Lakes which was administered by Bois Forte. There were four open water monitoring locations sampled each month, which are described below:

Twin 1 – corresponds to Inflow 1 to Little Sandy Lake described in Section 2.1 above.

Twin 2 – corresponds to the center of Little Sandy Lake described in Section 2.1.

Twin 3 – corresponds to the center of Sandy Lake described in Section 2.1.

Twin 4 – corresponds to the Twin Lakes Outflow described in Section 2.1.

Please note that Bois Forte continued the monitoring program after 2014 and through 2018 using funding from the 1854 Treaty Authority.

This Report utilizes some of the Bois Forte sampling data to compare parameters from the above four locations over nine years of monitoring (2010 – 2018). The Bois Forte data that was used from the sources described above, will be referred to in this Report as Inflow 1, Little Sandy Lake Middle, Sandy Lake Middle and Twin Lakes Outflow.

2.3 Measured Exceedances of MN Water Quality Standards (2014-2018)

During the five years of Plan work, nearly 200 samples were collected for analysis of various water quality parameters. Some of these parameters are associated with water quality standards contained in Minnesota Rule 7050. Table 6 below describes applicable water quality standards along with exceedances of those standards found at the Twin Lakes sampling locations during the five-year period. It should be mentioned that one exceedance each for copper, lead and zinc came from the non-mining influenced source, Culvert Inflow, during the June 2014 sample event. As described in Section 2.1 above, testing for copper, lead and zinc continued for the remainder of the year at Culvert Inflow with no additional results above the detection limit.

In summary, there were two exceedances of aluminum out of 104 samples; 12 exceedances of hardness out of 192 samples; 5 exceedances of pH out of 200 samples (pH between 6.0 and 9.0 SU); 15 exceedances of Total Dissolved Solids (TDS) out of 192 samples; 13 exceedances of specific conductance out of 200 samples; 8 exceedances of alkalinity out of 190 samples and 153 exceedances of sulfate (10 mg/L, which is currently being disputed but is under agency review and subject to change) out of 200 samples. Table 7 presents the specifics concerning each exceedance (parameter, reported value, location and sample event date).

TABLE 6
EXCEEDANCES OF SURFACE WATER STANDARDS
TWIN LAKES MONITORING (2014 - 2018)

Parameter	Number of Samples	Water Quality Standards and Number of Exceedances									
		2B		3C		4A		4B		5	
		Standard	#	Standard	#	Standard	#	Standard	#	Standard	#
Aluminum *	104	125 ug/L	2								
Arsenic *	48	53 ug/L	0								
Copper	22	6.4 ug/L**	1								
Lead	22	1.3 ug/L**	1								
Zinc	22	59 ug/L**	1								
Hardness as CaCO3	192			500 mg/L	12						
pH	200	6.5-9.0 SU	3	6.0-9.0 SU	0	6.0-8.5 SU	2	6.0-9.0 SU	0	6.0-9.0 SU	0
Solids, Total Dissolved,	192					700 mg/L	10	1000 mg/L	5		
Specific Conductance	200					1000 umhos/cm	13				
Sulfate as SO4=	200					10 mg/L	153				
Unionized Ammomia as Nitrogen	168	40 ug/L	0								
Alkalinity as HCO3-	190					5 meq/L	8				
Chloride as Cl-	200	230 mg/L	0	250 mg/L	0						
Sodium as Na+	200					60% of Cation	0				

Note 1: This assessment includes the following monitoring locations: LSL Inflow 1, LSL Inflow 2, LSL Inflow 3, Twin Lakes Outflow, Sandy Lake Middle, Little Sandy Lake Middle, SL South Inflow and Culvert Inflow.

Note 2: SL South Inflow and the Culvert Inflow are non-mining impacted sources. The other locations mentioned are influenced by mining.

*** Aluminum and Arsenic were not analyzed over the entire five year period. Aluminum was included in the 2014, 2015 and 2016 season, while Arsenic was included only for the 2014 season.**

**** This WQS is based on Hardness, which 50 mg/L as CaCO3 was used.**

Table 7
Specifics of Twin Lakes Water Quality Exceedances

Parameter	Location	Date	Value	WQS	Units
Aluminum	Culvert Outflow *	7/22/2016	284	125	ug/L
Aluminum	Inflow 1	8/25/2016	132	125	ug/L
Copper	Culvert Outflow *	6/23/2014	11.4	6.4	ug/L
Lead	Culvert Outflow *	6/23/2014	12.8	1.3	ug/L
Zinc	Culvert Outflow *	6/23/2014	172	59	ug/L
Hardness	Inflow 1	8/22/2014	712	500	mg/L
Hardness	LSL Inflow 1	9/11/2014	721	500	mg/L
Hardness	LSL Inflow 1	10/13/2014	814	500	mg/L
Hardness	LSL Inflow 1	8/21/2015	560	500	mg/L
Hardness	LSL Inflow 1	9/25/2015	615	500	mg/L
Hardness	LSL Inflow 1	10/19/2015	776	500	mg/L
Hardness	LSL Inflow 1	5/26/2016	517	500	mg/L
Hardness	LSL Inflow 1	8/28/2016	582	500	mg/L
Hardness	LSL Inflow 1	10/20/2016	540	500	mg/L
Hardness	LSL Inflow 1	7/27/2018	636	500	mg/L
Hardness	LSL Inflow 1	8/29/2018	986	500	mg/L
Hardness	LSL Inflow 2	10/19/2015	569	500	mg/L
Dissolved Solids	LSL Inflow 1	7/21/2014	776	700	mg/L
Dissolved Solids	LSL Inflow 1	9/25/2015	838	700	mg/L
Dissolved Solids	LSL Inflow 1	8/21/2015	799	700	mg/L
Dissolved Solids	LSL Inflow 1	7/10/2015	752	700	mg/L
Dissolved Solids	LSL Inflow 1	10/20/2016	739	700	mg/L
Dissolved Solids	LSL Inflow 1	8/25/2016	836	700	mg/L
Dissolved Solids	LSL Inflow 1	5/26/2016	761	700	mg/L
Dissolved Solids	LSL Inflow 1	7/27/2017	863	700	mg/L
Dissolved Solids	LSL Inflow 1	7/27/2018	716	700	mg/L
Dissolved Solids	LSL Inflow 2	10/19/2015	776	700	mg/L
Dissolved Solids	LSL Inflow 1	8/22/2014	1030	1000	mg/L
Dissolved Solids	LSL Inflow 1	9/11/2014	1080	1000	mg/L
Dissolved Solids	LSL Inflow 1	10/13/2014	1170	1000	mg/L
Dissolved Solids	LSL Inflow 1	10/19/2015	1040	1000	mg/L
Dissolved Solids	LSL Inflow 1	8/29/2018	1440	1000	mg/L

Parameter	Location	Date	Value	WQS	Units
Spec. Conductance	LSL Inflow 1	8/22/2014	1347	1000	umhos/cm
Spec. Conductance	LSL Inflow 1	9/11/2014	1479	1000	umhos/cm
Spec. Conductance	LSL Inflow 1	10/13/2014	1620	1000	umhos/cm
Spec. Conductance	LSL Inflow 1	8/21/2015	1074	1000	umhos/cm
Spec. Conductance	LSL Inflow 1	9/25/2015	1224	1000	umhos/cm
Spec. Conductance	LSL Inflow 1	10/19/2015	1435	1000	umhos/cm
Spec. Conductance	LSL Inflow 1	5/26/2016	1109	1000	umhos/cm
Spec. Conductance	LSL Inflow 1	8/25/2016	1141	1000	umhos/cm
Spec. Conductance	LSL Inflow 1	10/20/2016	1057	1000	umhos/cm
Spec. Conductance	LSL Inflow 1	7/27/2017	1228	1000	umhos/cm
Spec. Conductance	LSL Inflow 1	7/27/2018	1024	1000	umhos/cm
Spec. Conductance	LSL Inflow 1	8/29/2018	1925	1000	umhos/cm
Spec. Conductance	LSL Inflow 2	10/19/2015	1150	1000	umhos/cm
Alkalinity	LSL Inflow 1	9/11/2014	316	305	mg/L
Alkalinity	LSL Inflow 1	10/13/2014	309	305	mg/L
Alkalinity	LSL Inflow 1	8/25/2016	339	305	mg/L
Alkalinity	LSL Inflow 1	8/29/2018	407	305	mg/L
Alkalinity	LSL Inflow 1	8/22/2014	312	305	mg/L
Alkalinity	LSL Inflow 2	10/13/2014	309	305	mg/L
Alkalinity	LSL Inflow 2	9/28/2016	306	305	mg/L
Alkalinity	LSL Inflow 3	9/28/2016	311	305	mg/L
pH	LSL Inflow 1	5/28/2014	8.6	6.5 - 8.5	
pH	TL Outflow	5/28/2014	8.6	6.5 - 8.6	SU
pH	SL South Inflow *	6/29/2018	6.4	6.5 - 8.7	SU
pH	SL South Inflow *	8/29/2018	6.3	6.5 - 8.8	SU
pH	Culvert Inflow *	10/22/2018	6.3	6.5 - 8.9	SU
					SU

* Non-mining influenced sources

Parameter	Note
Sulfate	Mining influenced locations were almost always above the 10 mg/l wild rice standard while non SL South Inflows and the Culvert Inflow were below.

2.4 Twin Lakes Water Quality – Nine Year Graphs

As stated above, monthly water quality data has been collected on Twin Lakes during the past nine open water seasons, between 2010 and 2018, by Bois Forte and U. S. Steel under two separate programs. Figures 2 through 9 show data for chloride, sulfate, specific conductance, TDS, ammonia, alkalinity, turbidity and pH at the Twin 1/Inflow 1, Twin 2/Little Sandy Lake Middle, Twin 3/Sandy Lake Middle and Twin 4/Twin Lakes Outflow locations.

The figures show that installation of a Seepage Collection and Return System (SCRS) on the east side of Minntac's Tailings Basin in 2011 resulted in a significant reduction in constituent concentration levels at all four locations. The sampling results also indicate that Inflow 1 has the highest concentration of constituents, which is not surprising as it is the expected primary source of seepage input from the Minntac tailings basin.

Little Sandy Lake Middle had the highest pH value, but doesn't follow the usual influence from Inflow 1, which tends to be the lowest in pH. The pH at the Sandy Lake Middle location is just slightly lower than Little Sandy Lake Middle. This trend seems to indicate that there are other factors influencing the pH at the middle of each lake whether due to other inflows or biological/chemical interactions. All locations show relatively low turbidity values. Ammonia was not measured on a consistent basis, therefore conclusions were not drawn from these data.

FIGURE 2

TWIN LAKES SURFACE WATER CHLORIDE

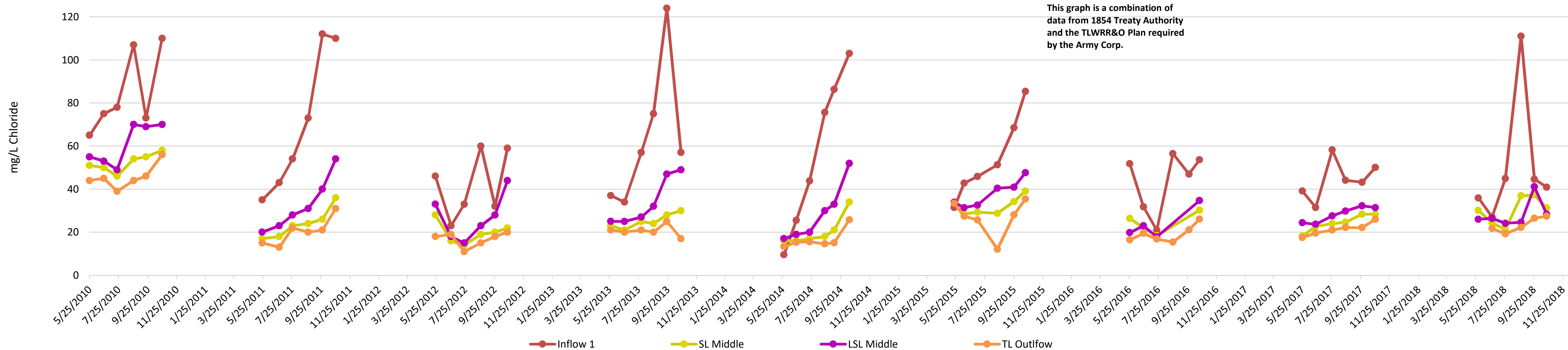


FIGURE 3

TWIN LAKES SURFACE WATER SULFATE

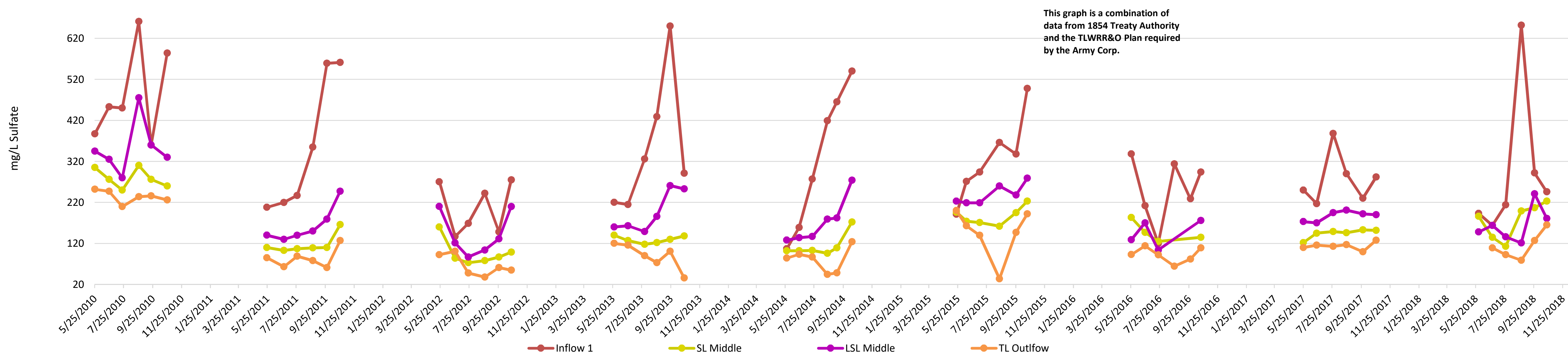


Figure 4
Twin Lakes Surface Water Specific Conductance

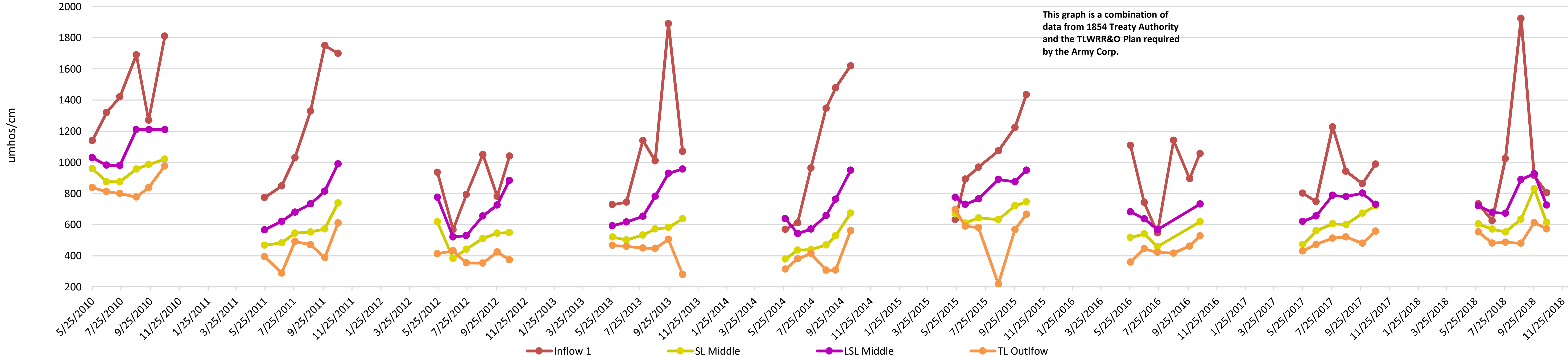


Figure 5
Twin Lakes Surface Water Total Dissolved Solids

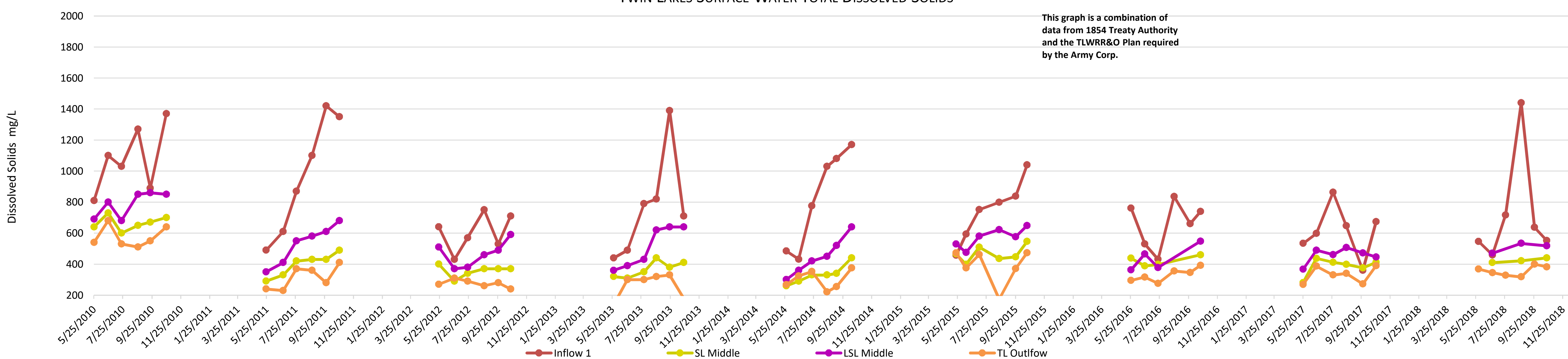


Figure 6

Twin Lakes Surface Water Ammonia as Nitrogen

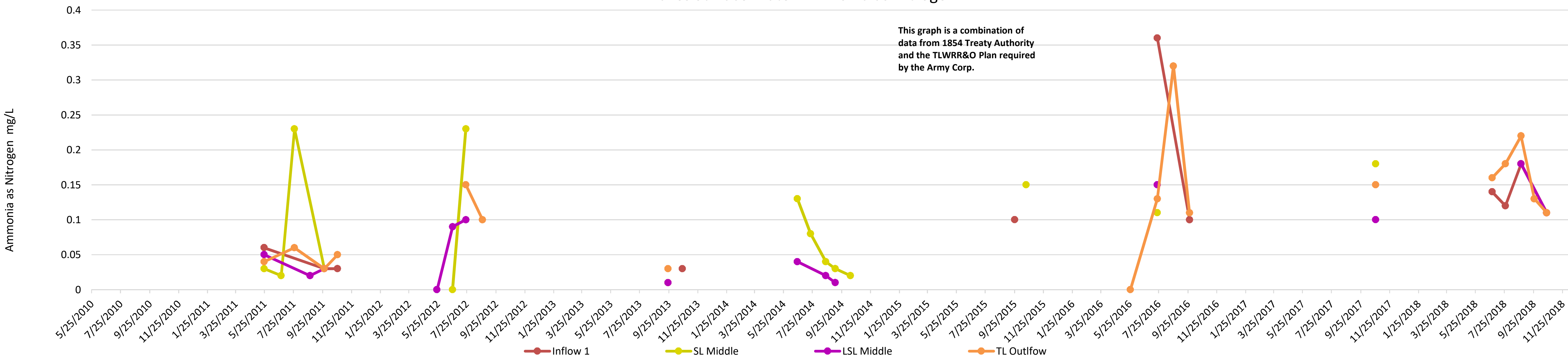


Figure 7

Twin Lakes Surface Water Alkalinity HCO_3^-

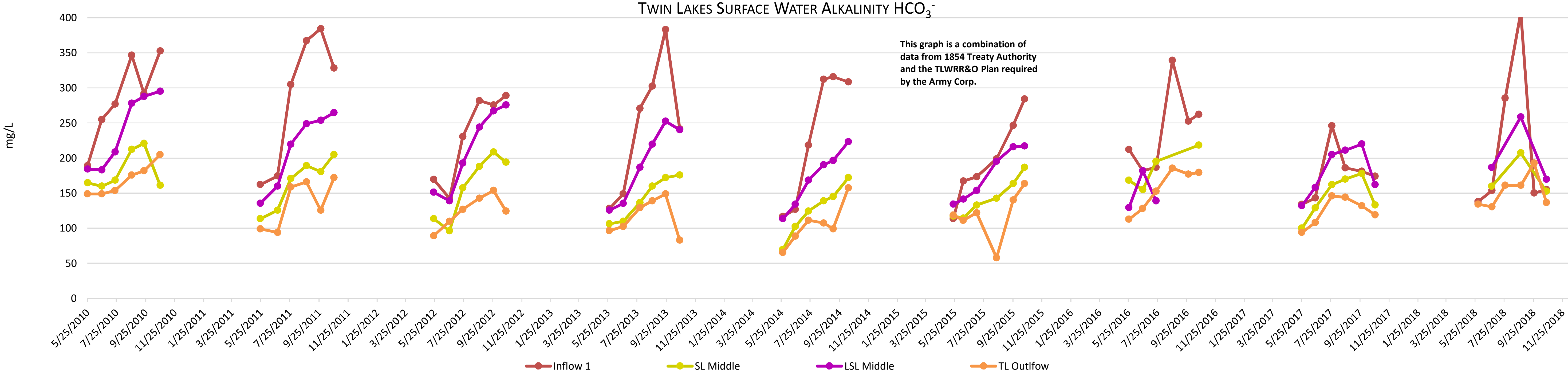


Figure 8
Twin Lakes Surface Water Turbidity

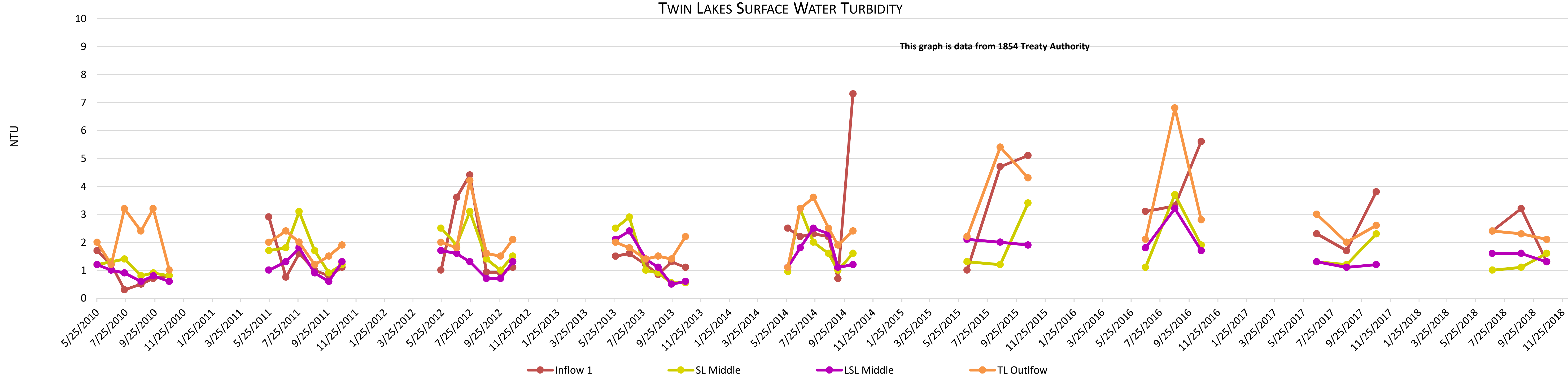
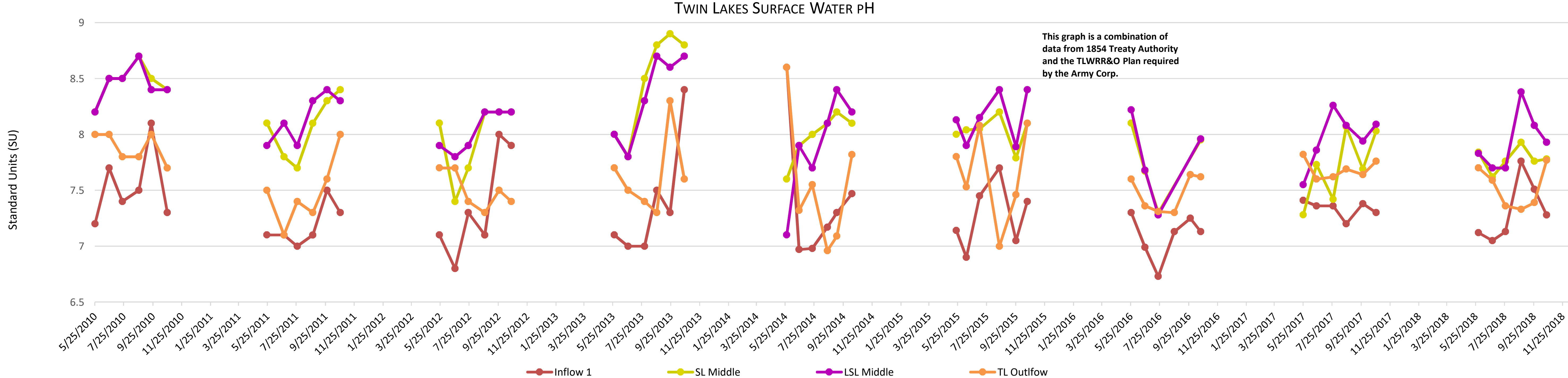


Figure 9
Twin Lakes Surface Water pH



2.5 TWIN LAKES WATER QUALITY – SEASONAL EFFECTS

A seasonal effect may be seen by comparing data from month to month and year to year. There were years when the concentrations of such parameters as chloride, sulfate and alkalinity continually increased from spring to fall. Other years show various up and down results without any correlation between years.

Mass loading of sulfate from Inflow 1 was developed from the five years of flow data that was consistently collected during each sample event (Figure 10). The sulfate mass loading analysis removes the dilution effect from precipitation. A review of the sulfate mass loading over each of the five years does seem to show a slight trend where the sulfate loading drops over the first few months of open water but spikes in August or September before it drops back down again. This was not as apparent in 2014 though with a small spike in October. There appears to be more variation in the amount of sulfate loading during the past two years (2017 and 2018) as compared with the first three years of monitoring.

The relationship that precipitation has on sulfate concentrations was also determined through data comparison at a number of locations in 2015 and 2018. Figures 11 and 12 show sulfate concentrations overlaid on daily precipitation data. Inflow 1 was seen in both years to have the highest sulfate concentration, as discussed in Section 2.4 above. It appears that there were larger rain events in 2018 than in 2015 and the overall concentration of sulfate was significantly lower during 2018. Dryer periods in both years did not seem to have a significant effect on increased sulfate concentrations nor did wet periods show significant reductions.

Figure 10
Little Sandy Lake Inflow 1 Surface Water Sulfate
(Kg/Day vs mg/L)

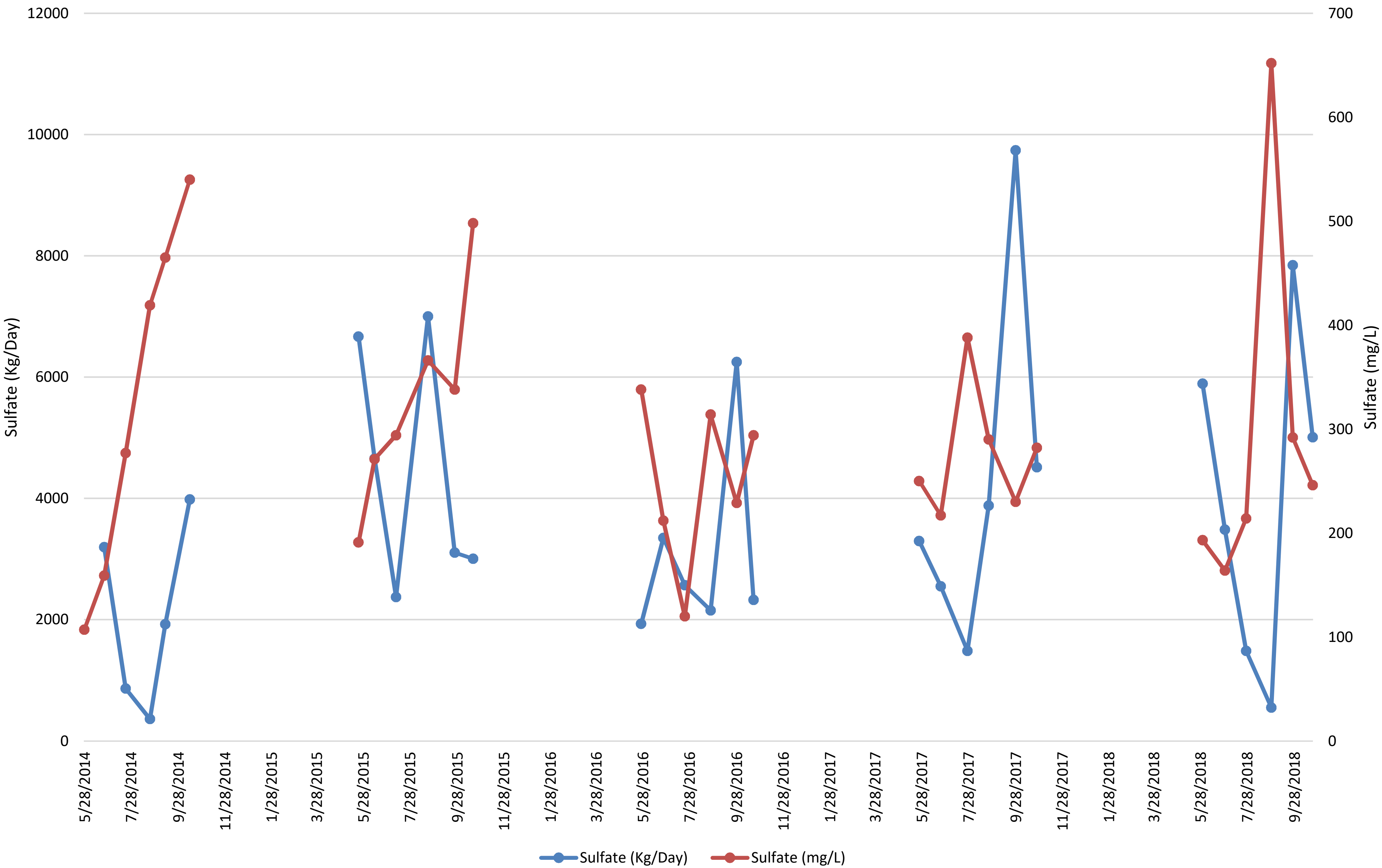


Figure 11
2015 Twin Lakes
Daily Precipitation and Sulfate

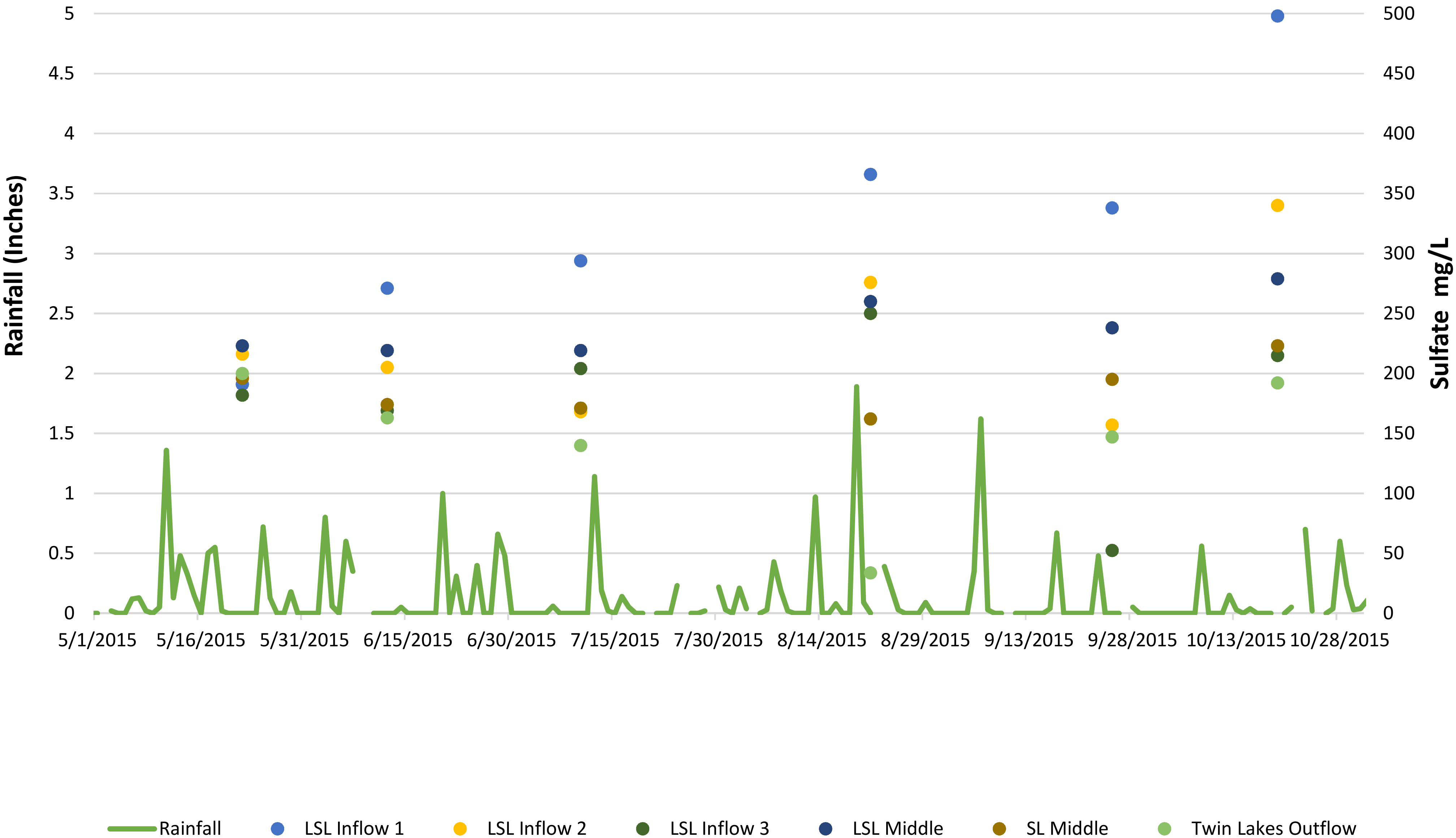
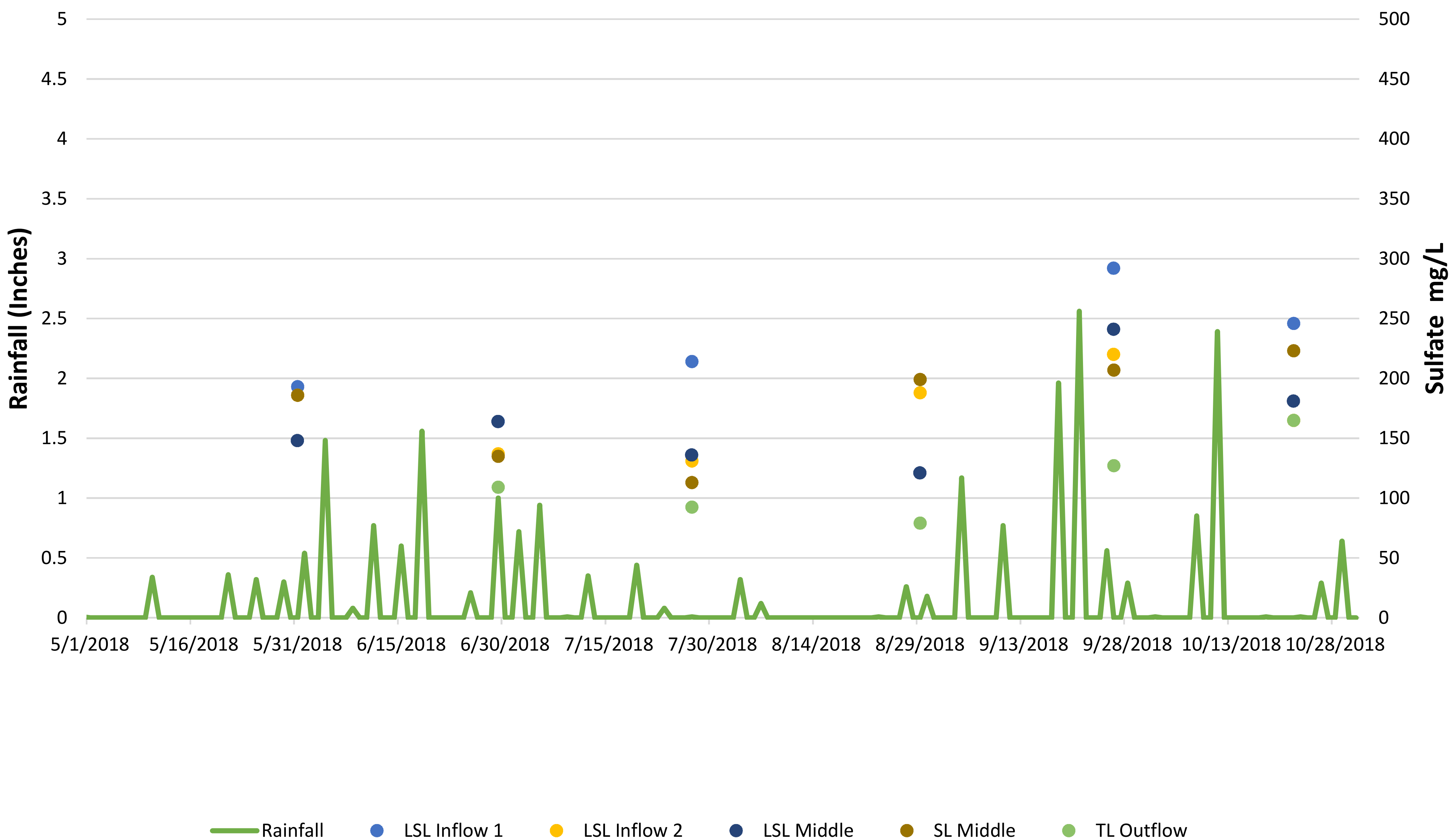


FIGURE 12
2018 TWIN LAKES
DAILY PRECIPITATION AND SULFATE



2.6 Twin Lakes Water Quality – Wild Rice Plots (2016)

The wild rice planted in the fall of 2015 was first observed growing in July of 2016 (see Figure 13). As defined by the Plan, water quality was to be evaluated at each wild rice location. The surface water at each wild rice plot was sampled on August 25, 2016 and on the September 28, 2016 (Tables 8 and 9). This included a site that was assumed to be natural growth and not intentionally planted (found on the South Side of Sandy Lake). The wild rice plots were given the following names: Sandy Lake Northwest, Sandy Lake East, Sandy Lake Southwest, Sandy Lake South (naturally seeded), Little Sandy Lake Northeast, and Little Sandy Lake South. No wild rice growth was found on what was called Little Sandy Lake Northwest in 2016.

U. S. Steel did not sample the middle of Little Sandy and Sandy Lakes during the August and September 2016 sampling events. However, Bois Forte did sample the surface water at the middle of both lakes approximately one day prior to the Plan August sampling event. The analytical results are included in Table 8. No samples from the middle of either lake were collected in September but Table 9 shows the September surface water chemistries from the wild rice plots. Figures 14 through 21 show the data from each wild rice plot in relation to each other.

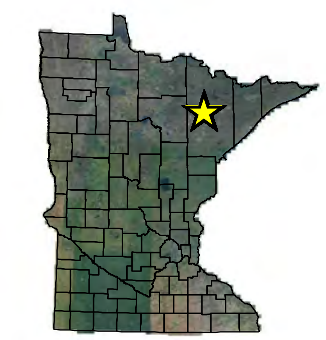
As stated above, the only data for comparison of Sandy Lake Middle and Little Sandy Lake Middle was from the August sampling event completed by Bois Forte. Although each location differs slightly, there appears to be no significant difference between the water quality within each plot and that of each lake middle sample. The sample results from the middle of each lake for chloride, sulfate, TDS, specific conductance and Total Kjeldahl Nitrogen appear to indicate an average of values found in each of the wild rice plots.

August and September data from all the wild rice plots did not seem to be significantly different from each other. However, the Little Sandy Lake wild rice plots tended to have slightly higher concentrations of chloride, sulfate, alkalinity and TDS, along with slightly higher specific conductance as compared to the Sandy Lake wild rice plots. The pH, Ammonia Nitrogen and Total Kjeldahl Nitrogen did not follow this trend and were lower in the Little Sandy Lake wild rice plots compared to those found in Sandy Lake. Although the Little Sandy Lake South wild rice plot had the highest concentrations of chloride, sulfate, alkalinity, and TDS, the pH, Ammonia Nitrogen and Total Kjeldahl Nitrogen did not follow this trend.

Sandy Lake South (natural growth) water chemistries were similar to the other wild rice plots for chloride, although this plot showed lower levels of sulfate, alkalinity, specific conductance and TDS. On the other hand, the Ammonia Nitrogen and Total Kjeldahl Nitrogen were somewhat higher. The pH for Sandy Lake Middle taken during the August sampling event was found to be lower than the samples indicated for the wild rice plots.

N

0 245 490 980
Feet
1 Inch = 490 Feet



Legend

- Natural Wild Rice Growth (2016-2018)
- Planted Wild Rice Growth (2016-2018)
- Planted Wild Rice Growth (2017-2018)

Figure 13
Twin Lakes 2016-2018
Wild Rice Growth Locations

Twin Lakes Survey
US Steel Corporation-
Minnesota Ore Operations
Mt. Iron, Minnesota (St. Louis County)

NTS Environmental Science & Engineering
www.netechnical.com

Date Drawn : September 19, 2018
Drawn By : T. Muck
NTS Project #: 10170E

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TABLE 8
AUGUST 25, 2016 WILD RICE PLOT SURFACE WATER SAMPLE DATA

	Units	Detection Limit	Sandy Lake East	Sandy LakeNW	Sandy Lake SW	Sandy Lake South*	Little Sandy Lake South	Little Sandy Lake NE
Ammonia as Nitrogen	mg/L	0.10	**0.35**	**0.36**	**0.39**	**0.48**	<0.10	**0.13**
Total Kjeldahl Nitrogen	mg/L	0.60	**1.7**	**1.6**	**1.8**	**2.1**	**1.3**	**1.3**
Aluminum	mg/L	50.0	**64.0**	**58.7**	**99.5**	**196**	<50.0	<50.0
Calcium	mg/L	0.50	**30.8**	**33.4**	**27.6**	**22.5**	**44.5**	**39.7**
Iron	ug/L	50.0	**2850**	**2760**	**4720**	**10800**	**1580**	**1630**
Magnesium	mg/L	0.50	**39.6**	**43.7**	**35.7**	**27.3**	**62.8**	**55.4**
Manganese	ug/L	10.0	**88.9**	**126**	**178**	**243**	**97.8**	**132**
Potassium	mg/L	0.50	**2.5**	**2.7**	**2.4**	**2.1**	**3.1**	**2.7**
Sodium	mg/L	0.50	**13.5**	**14.6**	**12.7**	**11.4**	**21.1**	**17.4**
Total Hardness	mg/L	3.3	**240**	**263**	**216**	**168**	**370**	**327**
Total Alkalinity	mg/L	6.1	**168**	**178**	**156**	**118**	**229**	**223**
Total Dissolved Solids	mg/L	10.0	**380**	**393**	**389**	**339**	**472**	**535**
Total Suspended Solids	mg/L	1.0	**2.8**	**2.0**	**2.0**	**16.7**	**2.0**	**3.6**
Chloride	mg/L	1.0	**17.2**	**18.0**	**17.2**	**17.5**	**27.9**	**21.9**
Sulfate	mg/L	2.0	**77.0**	**87.2**	**70.2**	**43.5**	**152**	**121**
Dissolved Organic Carbon	mg/L	1.0	**42.0**	**40.7**	**47.2**	**51.2**	**33.9**	**36.1**
pH	SU	± 0.2	**7.6**	**7.7**	**7.3**	**6.5**	**7.7**	**7.8**
Specific Conductance	uS/cm	± 1%	**469**	**498**	**439**	**277**	**725**	**648**
Temperature	C	± 0.1	**20.6**	**21.0**	**20.6**	**18.1**	**20.4**	**21.2**

* This location was not planted rice but was found emerging "naturally".

TABLE 9
SEPTEMBER 28, 2016 WILD RICE PLOT SURFACE WATER SAMPLE DATA

	Units	Detection Limit	Sandy Lake East	Sandy LakeNW	Sandy Lake SW	Sandy Lake South*	Little Sandy Lake South	Little Sandy Lake NE
Ammonia as Nitrogen	mg/L	0.10	**0.12**	**0.11**	**0.11**	**0.10**	<0.10	<0.10
Total Kjeldahl Nitrogen	mg/L	0.60	**1.2**	**1.0**	**1.0**	**0.87**	**0.81**	**0.80**
Aluminum	mg/L	50.0	**53.3**	**59.9**	**56.5**	NM	<50.0	<50.0
Calcium	mg/L	0.50	**34.3**	**38.0**	**35.3**	NM	**48.0**	**45.9**
Iron	ug/L	50.0	**1240**	**1110**	**1350**	NM	**565**	**569**
Magnesium	mg/L	0.50	**45.9**	**51.6**	**48.1**	NM	**65.9**	**63.8**
Manganese	ug/L	10.0	**42.3**	**56.8**	**55.9**	NM	**74.6**	**93.0**
Potassium	mg/L	0.50	**2.9**	**3.2**	**3.0**	NM	**4.2**	**3.7**
Sodium	mg/L	0.50	**16.4**	**18.2**	**17.1**	NM	**23.4**	**21.7**
Total Hardness	mg/L	3.3	**275**	**307**	**286**	NM	**391**	**377**
Total Alkalinity	mg/L	6.1	**188**	**189**	**172**	**52.7**	**221**	**221**
Total Dissolved Solids	mg/L	10.0	**393**	**461**	**403**	**198**	**541**	**516**
Total Suspended Solids	mg/L	1.0	**2.0**	**3.6**	**3.6**	NM	**1.6**	<1.0
Chloride	mg/L	1.0	**24.8**	**26.9**	**25.5**	**29.6**	**35.6**	**32.0**
Sulfate	mg/L	2.0	**100**	**123**	**108**	**12.9**	**176**	**159**
Dissolved Organic Carbon	mg/L	1.0	**31.5**	**30.0**	**31.2**	NM	**24.8**	**25.7**
pH	SU	± 0.2	**8.0**	**8.0**	**7.9**	**7.1**	**8.0**	**8.1**
Specific Conductance	uS/cm	± 1%	**559**	**619**	**572**	**295**	**786**	**741**
Temperature	C	± 0.1	**11.2**	**11.7**	**11.2**	**11.1**	**11.6**	**12.1**

* This location was not planted rice but was found emerging "naturally".

Figure 14
Wild Rice Plot Chloride

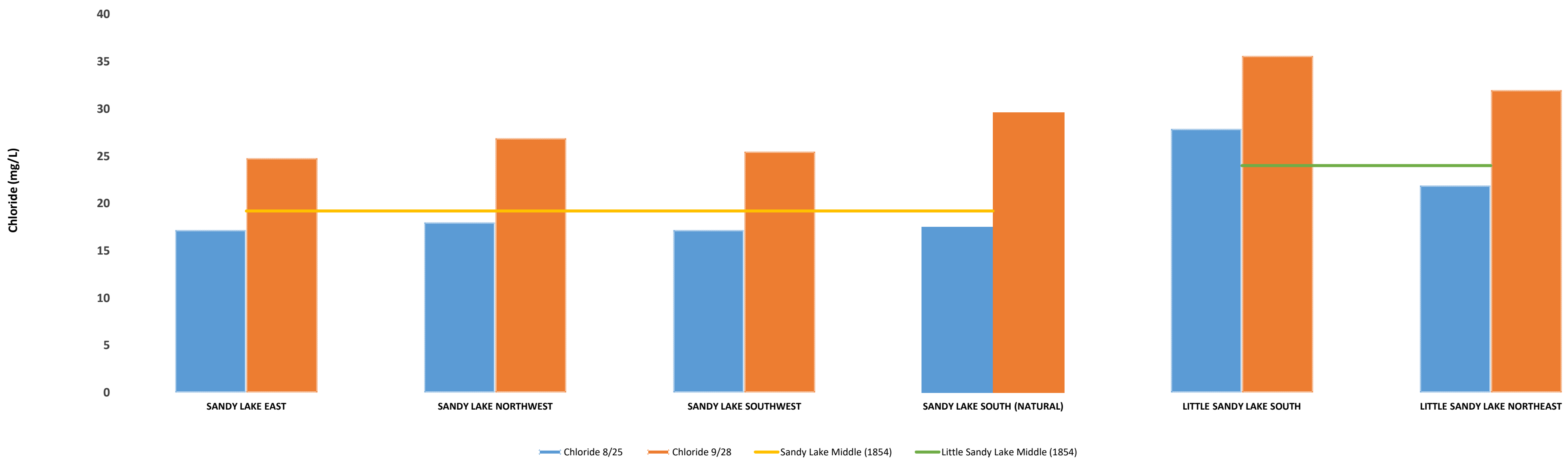


Figure 15
Wild Rice Plot Sulfate

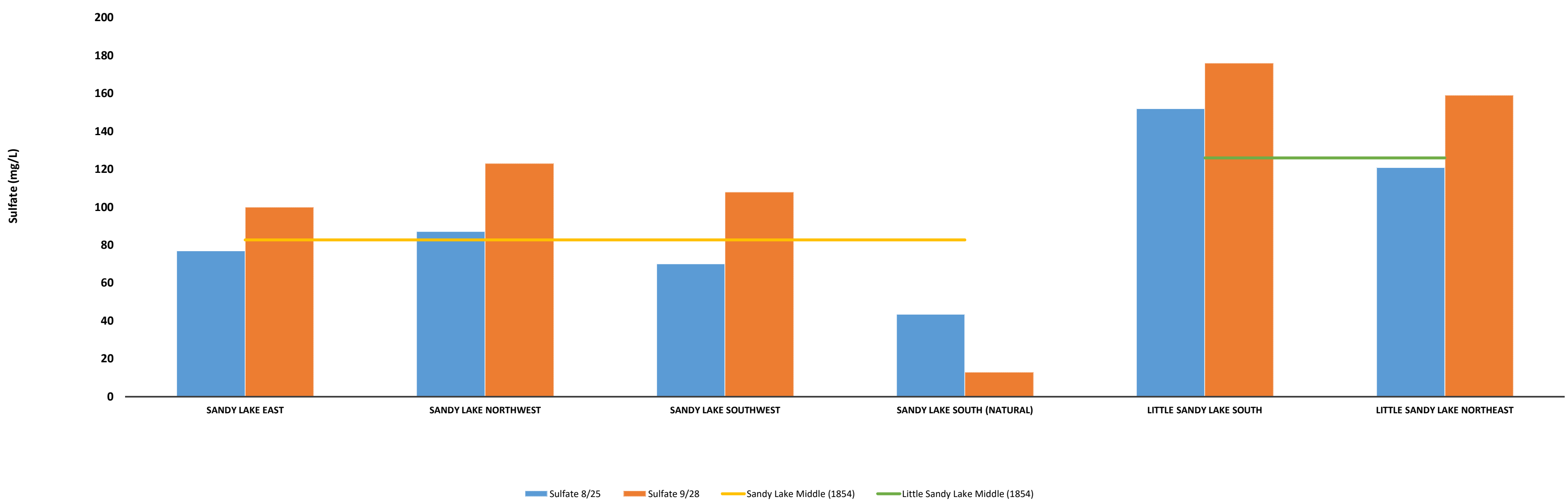


FIGURE 16
WILD RICE PLOT ALKALINITY

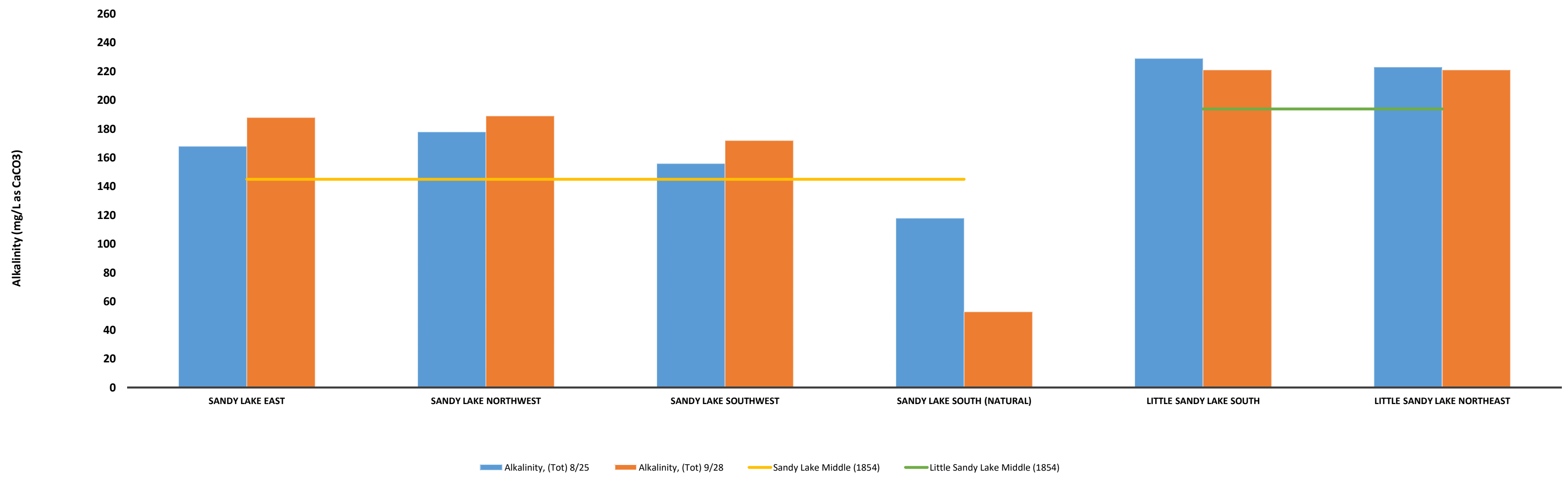


FIGURE 17
WILD RICE PLOT TOTAL DISSOLVED SOLIDS

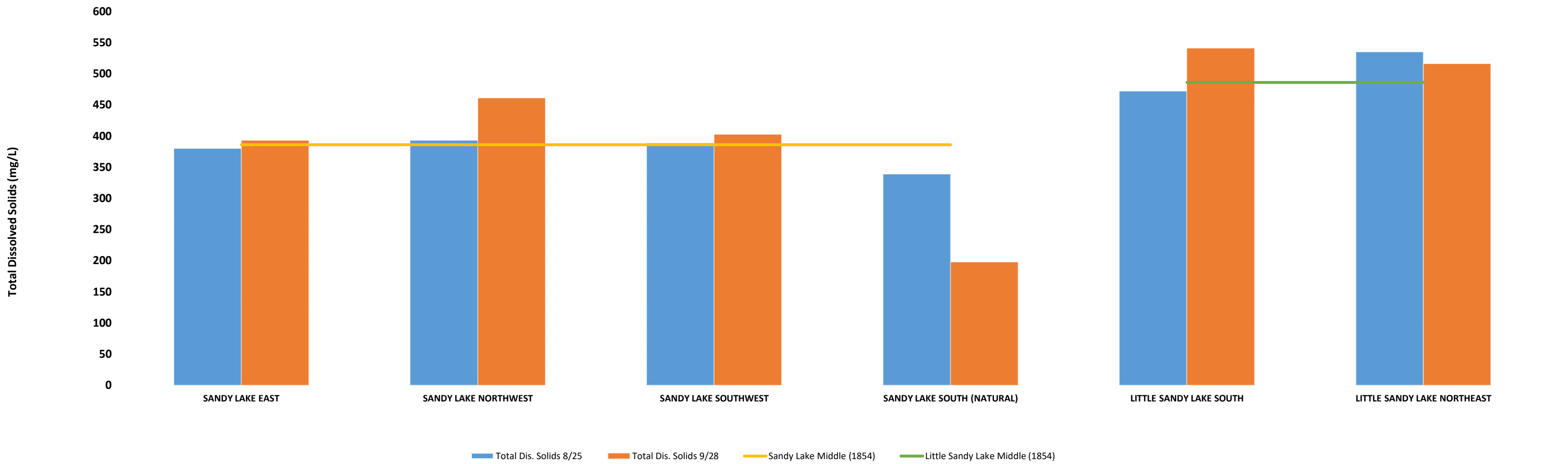


FIGURE 18
WILD RICE PLOT SPECIFIC CONDUCTANCE

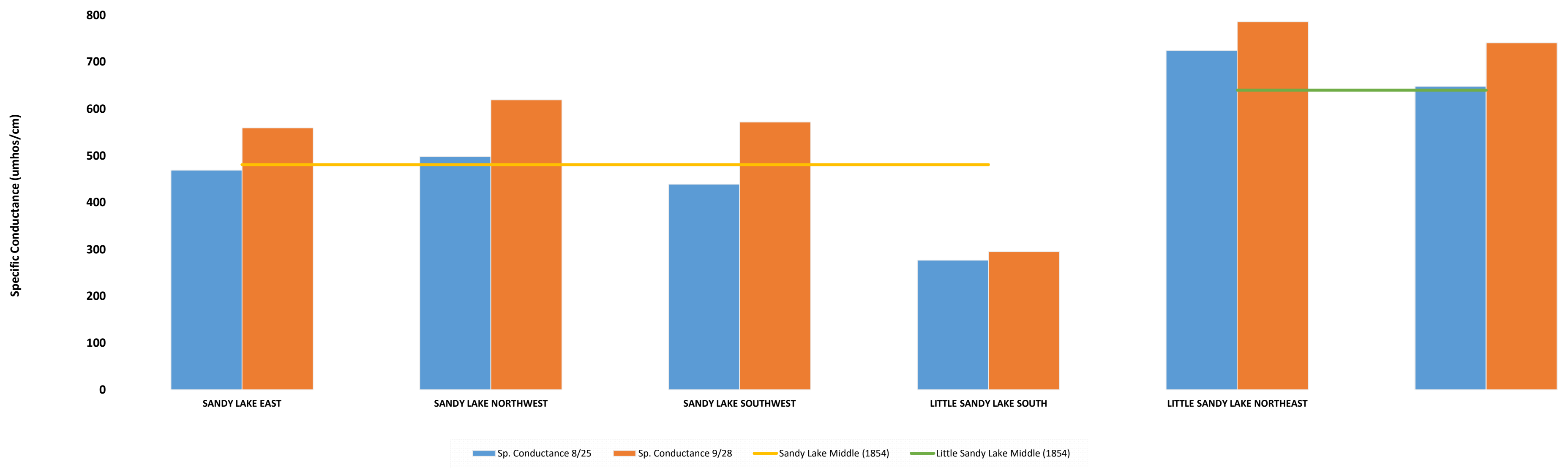


FIGURE 19
WILD RICE PLOT PH

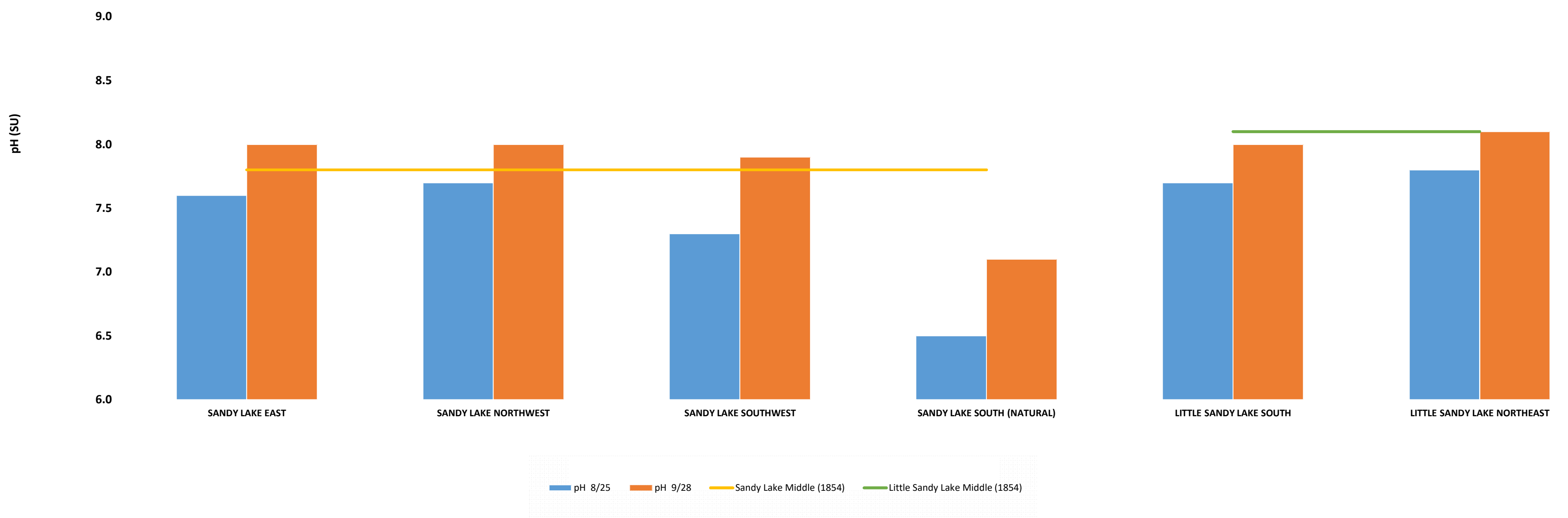


Figure 20
Wild Rice Plot Ammonia as Nitrogen

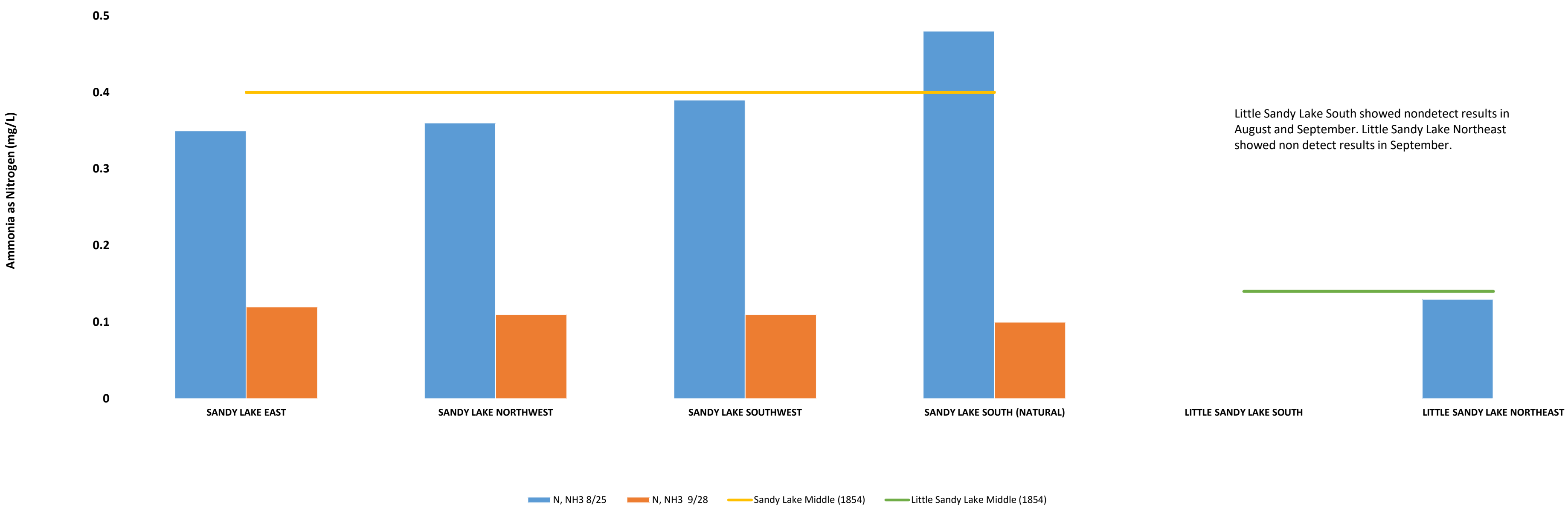
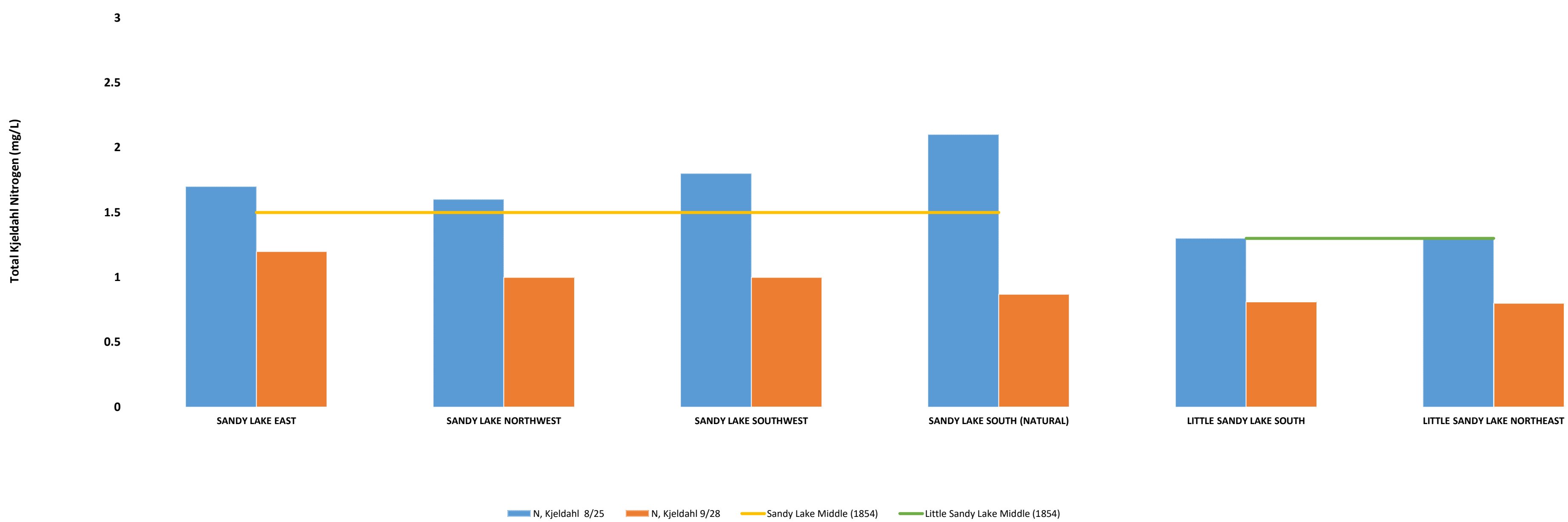


Figure 21
Wild Rice Plot Total Kjeldahl Nitrogen



2.7 TWIN LAKES WATER QUALITY – QUALITY ASSURANCE

It is well understood that all State of Minnesota certified laboratories are required to perform various tests to verify that their results are as reported. This is accomplished by running duplicates, method blanks, matrix spikes, etc. For this report, three additional checks were performed in order to verify the data as it has been compiled in this final report.

The first evaluation was to complete an ion balance of major cations and anions to ensure that no significant constituents were being missed. This ion balance, showing cations and anions in terms of milliequivalents per liter (meq/L), is included in the sample results found in Appendix A. Ideally, the cations and anions should balance when expressed as meq/L. As can be seen, this was not always the case for samples collected at Twin Lakes. To evaluate specific water quality results, correlation coefficients were calculated for each of the cation/anion balances (see Table 10 below). With the exception of Culvert Inflow, most of the locations showed a very good correlation between the cation and anion concentrations. The reason for the low correlation coefficient for the Culvert Inflow results is not completely clear, but is likely caused by the relatively low concentrations of dissolved ions and the possibility that certain constituents were not analyzed that could have had a relatively large contribution to the overall balance.

TABLE 10. CORRELATION COEFFICIENTS

	Cation vs Anion Totals	Calculated TDS vs Actual TDS	TDS vs Specific Conductance
Inflow 1	0.99	0.97	0.97
Inflow 2	0.90	0.92	0.86
Inflow 3	0.92	0.83	0.76
South Inflow	0.97	0.88	0.78
Twin Lakes Outflow	0.87	0.82	0.89
Culvert Inflow	0.57	0.36	0.27
LSL Middle	0.96	0.73	0.83
SL Middle	0.86	0.78	0.59

The second evaluations was to compare the relationship between the calculated TDS vs the actual laboratory TDS values. The calculated TDS was determined by summing the laboratory results for each individual analysis. This "Calculated Total Dissolved Solids" data is presented in Appendix A. The calculated TDS can be individually compared with the actual laboratory TDS and, ideally, these values would be the same. As was done with the cation vs. anion comparison above, the correlation coefficient between the two TDS results was tabulated for each location (see Table 10). The TDS correlation coefficients were not as high as the cation vs. anion relationship and as with the ion balance evaluation the Culvert Inflow had a poor result of 0.36.

The third evaluation was the comparison of Specific Conductance to the laboratory TDS. The purpose of this comparison was to determine the relationship during the five years between the laboratory procedure and field measurements. These data are also found in Appendix A. The correlation coefficient results comparing TDS to the field specific conductance values for each location can be found in Table 10.   As seen in this table, not only did the Culvert Inflow produce a low correlation coefficient (0.43), but the SL Middle was also fairly low (0.59).

Overall, the checks on precision of the analytical data indicate that the primary constituents that make up the ions in solution at the various sampling sources were being measured.

3.0 SEDIMENT QUALITY

During October 2013, sediment cores were obtained from ten locations within each lake (Sandy Lake and Little Sandy Lake). Each sediment core was frozen and cut into 5-centimeter sections for measurement of physical and chemical characteristics. Due to the differing lengths of sediment in each core, a variable number of sections were obtained between cores. Using specific sections from these sediment cores, Dr. Peter Lee compared and contrasted the characteristics of Sandy and Little Sandy Lakes, Whitefish Lake (a wild rice producing lake near Thunder Bay, Ontario), sediment characteristics observed by Jorgenson (2013), and sediment characteristics observed by Myrbo et al. (2012) (Table 11). Sediment characteristics from two additional wild rice producing aquatic systems in Ontario (Rat River Bay and Wild Potato Lake) are provided for comparison to Sandy and Little Sandy Lakes' sediment characteristics (Table 11).

Contrasting total values in the top 5-centimeter (cm) sediment layer for Sandy Lake versus Little Sandy Lake (Table 11), Little Sandy Lake sediment had noticeably higher values for Acid Volatile Sulfide (AVS), B, Fe, Mn, and S and lower values for SEM (Cd, Cu, Ni, Pb, Zn). Other characteristics were similar in concentrations. Measured concentrations of Fe, S, AVS, Mn, and Pb in both sediments decrease considerably from the top 5-cm layer to the 6-10 cm layer. This trend continued to the 21-25 cm layer with S levels lower by approximately 10x, and Fe by approximately 5x at these sediment depths. Concentrations of these elements deeper within the sediment column may be representative of background concentrations prior to industry influences.

The suggestion of concentrations of specific elements at the 20-25 cm sediment depths as representative of pre-industry influence may also be supported by measured concentrations of these elements in sediment sampled from Rat River Bay and Wild Potato Lake. Each of these two systems support yearly harvestable densities of wild rice, and are non-industry influenced systems.

A concern about the ability of wild rice seeds to germinate and grow into seedlings in sediment sampled from Sandy and Little Sandy lakes existed at the initiation of this study. Therefore, during 2013 and 2014, wild rice bioassays were completed using bulk sediment sampled from Sandy Lake. The 2013 bioassay used single-bubble ambient air to aerate the water column of exposure chambers. Bioassay treatments in 2014 included both ambient air- and nitrogen- bubbled replicates. Due to space and time constraints, sediment from Little Sandy Lake was not used for initial wild rice bioassay experiments. Wild rice seeds were obtained from Whitefish Lake near Thunder Bay, Ontario. Whitefish Lake routinely contains a harvestable density of wild rice, and has been used as a field site and wild rice seed source for previous wild rice experiments. The overall purpose of this bioassay was to expose wild rice seeds obtained from Whitefish Lake to Sandy Lake sediment under laboratory conditions, and measure final dry weight following a seven-day exposure duration.

Table 11. Total measured concentrations of characteristics from sediment samples obtained from Sandy Lake and Little Sandy Lake (Twin Lakes system; 2013 data); Jorgenson 2013; Myrbo 2012; and three wild rice producing systems in Ontario, Canada – Whitefish Lake, Rat River Bay, and Wild Potato Lake (Lakehead University Environmental Laboratory – LUEL – non-published data).

			Sandy Lake			Little Sandy Lake									
	Detection Limit	**Units**	**0-5 cm**	**6-10 cm**	**21-25 cm**	**0-5 cm**	**6-10 cm**	**21-25 cm**	**Jorgenson (2013)**	**Myrbo (mean)**	**Myrbo (min)**	**Myrbo (max)**	**Whitefish Lake**	**Rat River Bay**	**Wild Potato Lake**
% Moisture Content	n/a	%	86.87	82.26	85.41	86.7	85.34	83.26	-	76.5	20.1	96	-	-	-
Acid Volatile Sulfides	0.0001	%	0.034	0.024	0.005	0.192	0.083	0.0051	-	-	-	-	-	-	-
Acid Volatile Sulfides	0.003	umole/g	10.71	7.53	1.64	60	25.93	1.6	-	0.72	0	6.25	1.9	-	-
SEM [Cd,Cu,Ni,Pb,Zn]	0.002	umole/g	0.991	0.733	0.916	0.125	0.112	0.084	-	1.39	-	-	-	-	-
Bulk Density	0.05	g/cm^3	0.12	0.19	0.12	0.16	0.18	0.21	-		-	-	-	-	-
Total As	2	ug/g	9.63	6.99	5.01	9.6	8.79	4.02	-	2.64	0.44	11.92	1	0.1	0.18
Total B	2	ug/g	28.7	17.71	20.37	61.58	45.12	44.63	-		-	-	-	-	-
Total Cd	0.25	ug/g	0.8	1.014	0.93	0.35	0.83	0.53	-	0.37	0.02	0.88	1.66	0.0336	509
Total Co	0.2	ug/g	8.04	6.1	5.14	5.83	6.09	5.75	-	2.11	0.19	10.26	0.71	0.227	0.524
Total Cr	0.03	ug/g	19.62	19.76	21.07	17.76	21.76	24.3	-	7.07	-	-	-	0.058	0.15
Total C	0.05	ug/g	11.47	11.67	12.2	9.69	11.94	11.62	-	7.19	0.68	22.65	25.84	0.2129	0.3862
Total Fe	0.1	ug/g	59414.6	35683.6	15315.47	68833.9	39081.4	13125.7	1210	8328.4	1298.4	50389	7852.65	287.808	777.455
Total Mn	0.05	ug/g	436.62	298.25	259.38	624.39	267.45	181.91	134.25	608.6	45.52	3814.96	135.41	11.59	36.829
Total Mo	2	ug/g	< DL	< DL	< DL	< DL	< DL	< DL	-	-	-	-	-	<DL	<DL
Total Ni	0.2	ug/g	12.55	13.04	14.86	8.44	11.4	14.3	-	8.43	-	-	-	1.1032	1.3898
Total Pb	1	ug/g	30.18	22.2	6.3	33.36	23.36	4.95	-	11.11	0.6	76.64	13.42	0.2475	0.4016
Total S	1	ug/g	47,172.4	28,590.4	6,374.58	64,517.3	32,975.5	4,071.13	4,519	3116	55	12,515	247.19	1.36	1.91
Total Se	2	ug/g	< DL	< DL	< DL	< DL	< DL	< DL	-	-	-	-	-	<DL	<DL
Total Zn	0.03	ug/g	98.36	92.2	75.23	68.16	82.9	61.61	75.14	38.05	4.92	103.98	49.7	1.6394	2.9717
Total Carbon	0.01	%	20.63	18.71	24.5	17.31	16.76	18.23	-	-	-	-	-	-	-
N in Sediment	0.01	%	1.72	1.47	1.69	1.7	1.43	1.32	-	-	-	-	-	-	-

Results of the 2013 bioassay indicated that wild rice seedlings grown in Sandy Lake sediment had a significantly higher final dry weight than those grown in Whitefish lake sediment (Figure 22). However, results of the 2014 bioassay indicated that wild rice seedlings germinated and grown in Sandy Lake sediment with air as the single-bubble aeration source had a significantly lower dry weight biomass than those germinated and grown in Whitefish Lake sediment with either air or nitrogen gas (N2) as the bubble source (Figure 23). Regardless of the statistical conclusions regarding final dry weight (g), wild rice seeds germinated and grew into healthy seedlings in Sandy Lake sediment in all replicates of both years' bioassay trials.

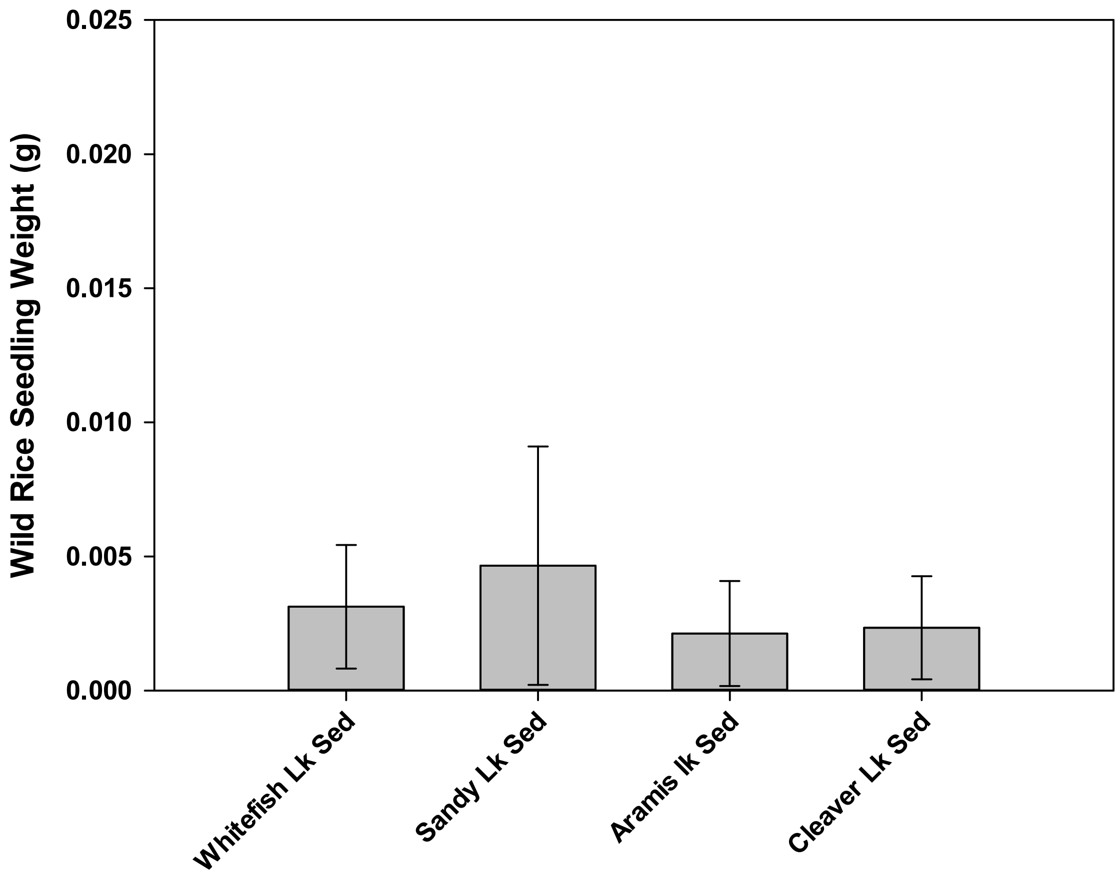


FIGURE 22. 2013 WILD RICE SEEDLING AVERAGE FINAL DRY WEIGHT RESULTS FOLLOWING THE SEVEN-DAY BIOASSAY EXPOSURE DURATION. Error bars represent one standard deviation.

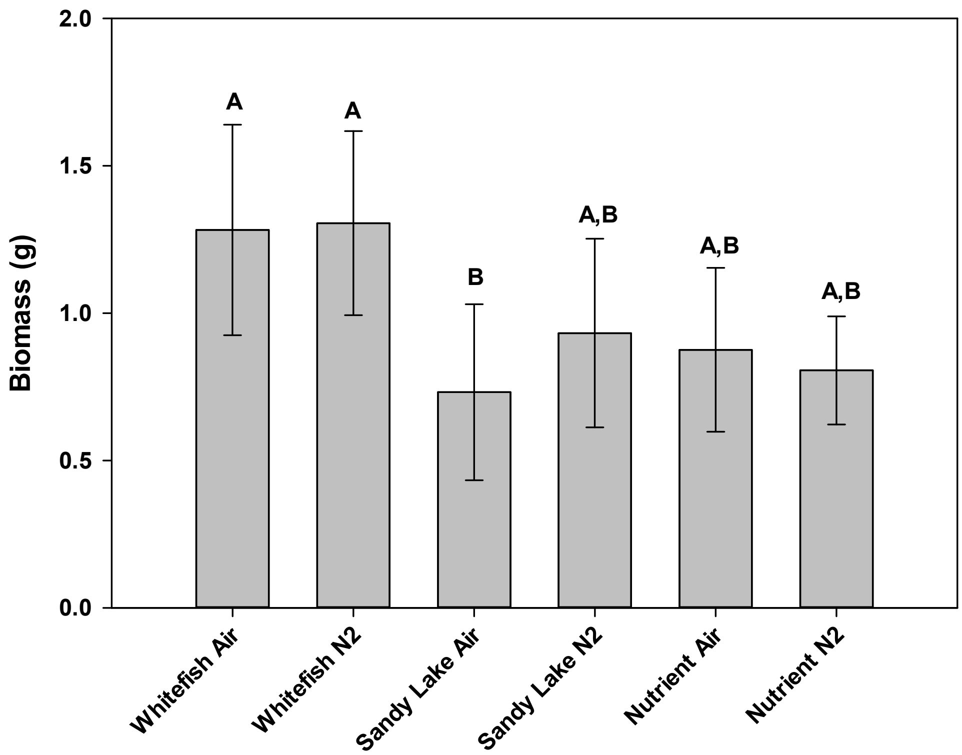


FIGURE 23. 2014 WILD RICE SEEDLING AVERAGE FINAL DRY WEIGHT RESULTS FOLLOWING THE SEVEN-DAY BIOASSAY EXPOSURE DURATION. Treatments labelled 'Nutrient' were used as controls during this initial wild rice bioassay. Error bars represent one standard deviation. Letters indicate statistical differences; columns sharing the same letter are not significantly different.

Separate studies related to wild rice restoration have been completed on two mining-influenced lakes in Ontario, Canada (see Appendix B). The subject Canadian lakes are significantly different from the Twin Lakes in that they are both meromictic (i.e., chemically stratified), with diverse and complex chemical characteristics below the chemocline, and receive significantly greater inputs of dissolved constituents. Similar to the studies described above, sediment from the two subject Canadian lakes were used to evaluate the growth potential of wild rice in contrast to sediment from a non-industry influenced aquatic system. Results of the evaluation indicated that there were no significant differences in wild rice seed germination between the three sediment sources. Subsequent mesocosm growth studies using sediment from the subject mining-influenced, as well as non-industry influenced, Canadian lakes resulted in the successful growth of wild rice seedlings into reproductively mature plants from all three sediment sources.

These observations, and observations of wild rice seedlings grown in Sandy Lake sediment in 2013 and 2014 bioassay tests, indicate that sediments from Sandy Lake, and likely Little Sandy Lake, will support germination, growth, and development of wild rice into mature seed producing plants under field conditions.

Based on the data collected and observations obtained during the Plan between 2013 and 2015, wild rice seeding events of select areas within each lake were developed and completed. Specifics of these wild rice seeding efforts are detailed in Section 8.0 of this report. However, in summary, over the course of two years of observations of wild rice seeded areas, wild rice plants in the aerial developmental stage were observed in all areas seeded within the Twin Lakes system. Therefore, in general, in areas of appropriate water depth and lack of competing vegetation, the sediment in both Little Sandy and Sandy lakes will support germination, growth, and development of wild rice into mature, seed producing plants. Overall, the quality of the sediment in both Little Sandy and Sandy lakes is more than sufficient to support germination, growth, and development of wild rice into reproductively mature, seed producing plants.

4.0 PORE WATER QUALITY

4.1 SEDIMENT PORE WATER QUALITY

In 2013, the general process for obtaining pore water from sediment cores was as follows: 1) obtain and freeze sediment core; 2) cut sediment core into multiple sections (typically 10 cm of sediment or more to obtain sufficient volume of pore water for analyses); 3) thaw sediment and centrifuge thawed sample to 'fractionate' sediment particulates and pore water; 4) decant pore water; 5) analyze pore water. More than one of these steps may allow for the potential of atmospheric exposure.

The ten sediment cores collected from each lake in October 2013 were considered representative of central and peripheral locations throughout each lake. Dr. Peter Lee from Lakehead University Environmental Laboratory provided an evaluation of the sediment pore water characteristics including a comparison between Little Sandy Lake and Sandy Lake, previous MPCA pore water data, and a Canadian wild rice producing lake (Whitefish Lake) (see Appendix C).

The measured physical and chemical characteristics of sediment pore water samples from these cores are detailed in Appendix D. The results of analysis showed that concentrations of pore water sulfide were below detection (< 10 µg/L) in all samples from Sandy Lake. Although there was no measureable sulfide in the Sandy Lake pore water samples, it may have been mitigated by dissolved iron in the pore water which ranged from 0.326 – 7.988 mg/L in Sandy Lake. Of the fourteen pore water samples from sediment cores obtained from Little Sandy Lake, nine showed sulfide concentrations at or below detection, while the remaining five contained sulfide at concentrations ranging from 0.13 – 0.57 mg/L. However, this sulfide may also be mitigated by dissolved iron measured in the pore water, which ranged from 0.18 – 3.65 mg/L.

Although this has been the preferred method for collecting sediment samples and obtaining measurements of physical and chemical sediment characteristics, this method is lacking with respect to sediment pore water collection and characterization. This was evidenced by the inability to retrieve sufficient volumes of pore water from some of the sediment cores sampled during 2013 and 2014. Loss of sulfide may have also occurred during transport, which was evidenced by a "rotten egg" smell permeating from the sample bottles during and after transport.

4.2 Peeper Pore Water Quality

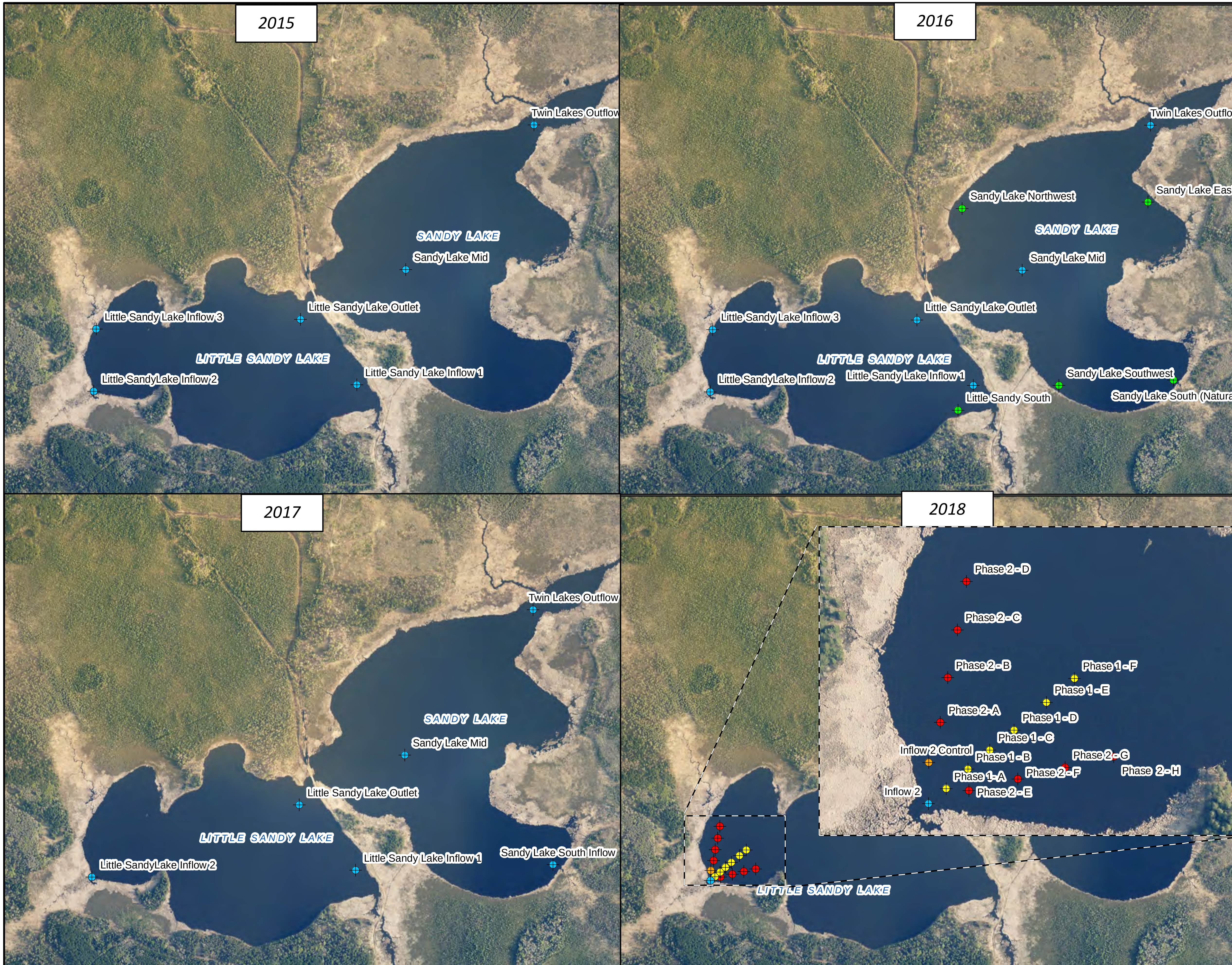
A more effective and defensible method of sediment pore water sampling and characterization is through the use of Rhizon type samplers and/or peepers. Generally, the use of peepers consists of a peeper assembly designed to hold four, 50-mL centrifuge tubes (see Figure 24) at the 0°, 120°, 240° and 360° locations around the peeper tube and within the top 10 cm of the sediment column when deployed. Each 50-mL centrifuge tube (see Figure 24) was completely filled (no headspace) with analytical standards-grade deionized water obtained from Pace Analytical Laboratories (Pace Analytical; Virginia, MN). Each tube contained a 0.45 µM pore size filter covering the tube surface, along with a polyethylene screen to protect the filter from damage. The screen and 0.45 µM filter covering the tube outlet were held in place by a plastic cap with the majority of the surface removed to allow for exchange of sediment pore water constituents into the deionized water to equilibrium via diffusion. Just prior to each deployment, four tubes were installed in the peeper assembly and then the peeper assembly was pushed into the lake bed sediment until the fixed 5-gallon bucket lid affixed just above the top centrifuge tube was in contact with the sediment surface. Following this procedure ensured that the inserted centrifuge tubes were located in the top 10 cm of sediment. Figure 25 shows an entire peeper assembly ready for deployment. Peepers were pulled from the sediment and samples collected from the sample vials for pore water analysis at roughly one-month intervals. Following sample collection, the sample vials pulled for analysis were replaced with freshly prepared vials and the peepers were placed back in the lake sediment.

Figure 24. Peeper sediment pore water sampling device

Figure 25. Example of a 50-mL centrifuge tube used for peeper sediment pore water quality measurements

During the 2015 sampling season, monthly peeper samples were obtained from Twin Lakes Outflow, Sandy Lake Middle, Little Sandy Lake Outlet (i.e., a location approximately 100 meters from the channel separating the Twin Lakes toward the center of Little Sandy Lake), Little Sandy Lake Inflow 2 and Little Sandy Lake Inflow 3. During 2016, sampling at these locations was repeated until August, when peepers were moved to wild rice growth locations. In 2017, the same locations as 2015 were again sampled, except that sampling at the Little Sandy Lake Inflow 3 location was discontinued, and sampling at the Sandy Lake South Inflow was established. In 2018, a two-phase delineation was established at the Inflow 2 location (see Figure 26 for all peeper locations from 2015-2018). Twin Lakes peeper data from 2015 through 2018 is shown in Appendix E.

The 2015 through 2017 measured concentrations of pore water sulfide and dissolved iron concentrations were inversely correlated (Figure 27) for all locations except Little Sandy Lake Inflow 2, i.e., pore water sulfide concentrations tended to decrease as pore water dissolved iron concentrations increased. The higher pore water sulfide concentrations seen at Little Sandy Lake Inflow 2 may have affected the available iron in the pore water in that location. Also, in general, it appears that the pore water sulfide concentrations increased throughout each season (Figure 28). This suggests that a seasonal influence may exist.

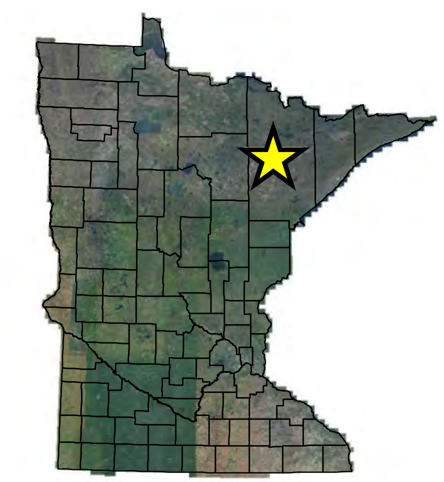


N

0 425,000 850,000 1,700,000

Feet

1 Inch = 906,440 Feet



Legend

- Wild Rice Peeper Deployment
- Peeper Deployment
- Inflow 2 Control
- Phase 1 Peeper Deployment
- Phase 2 Peeper Deployment

Figure 26
2015-2018 Twin Lakes Peeper Locations

Twin Lakes
US Steel Corporation - Minnesota Ore Operations
Mt. Iron, Minnesota (St. Louis County)

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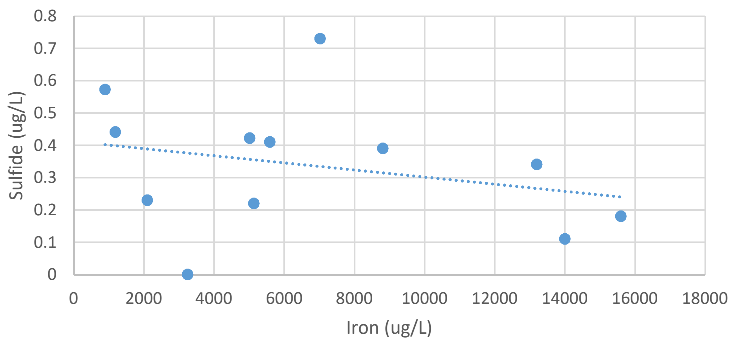
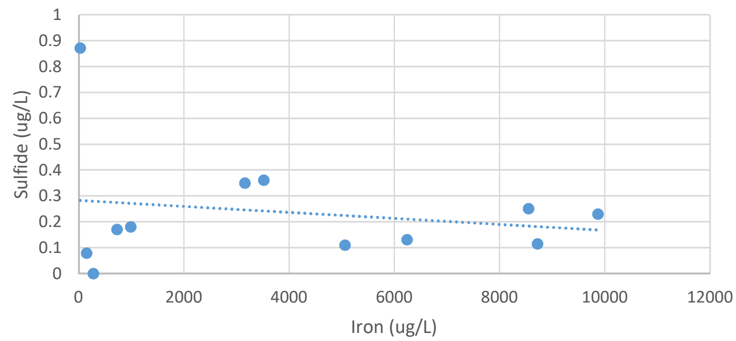
Figure 27
Sulfide Iron Relationship in Twin Lakes
Peeper Pore Water (2015-2017)

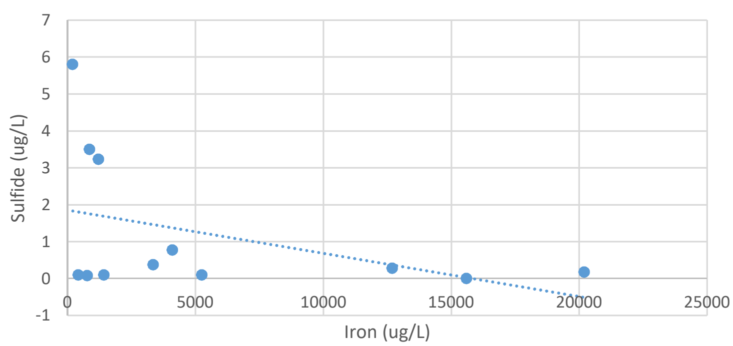
Twin Lakes Outflow



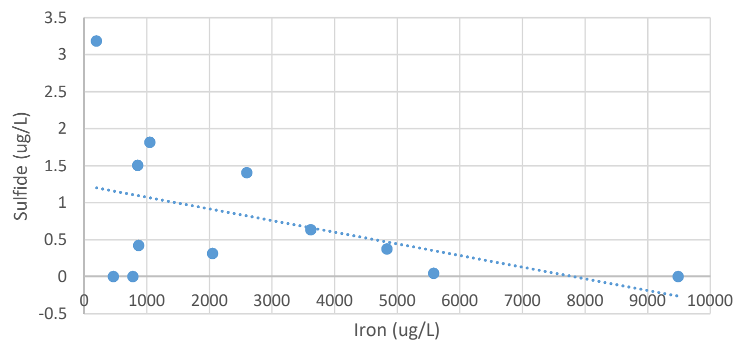
Sandy Lake Mid



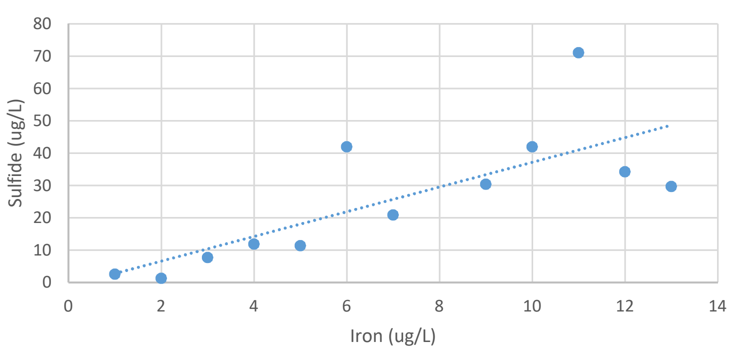
Little Sandy Lake Outlet



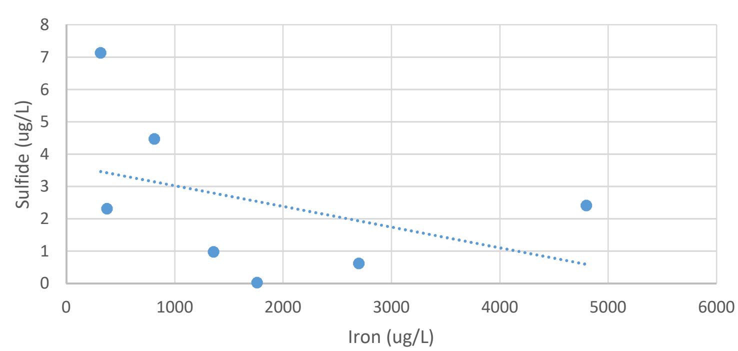
Little Sandy Lake Inflow 1



Little Sandy Lake Inflow 2



Little Sandy Lake Inflow 3



Sandy Lake South Inflow

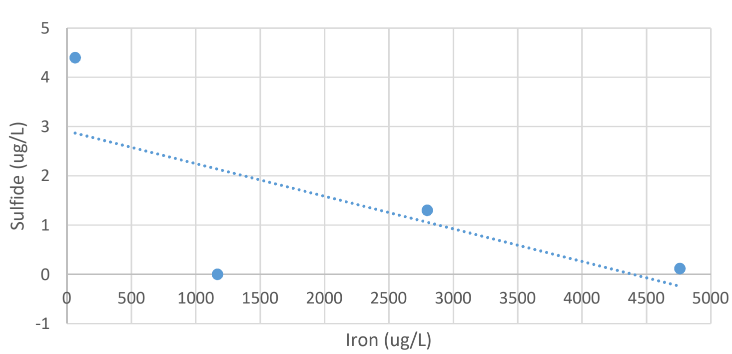
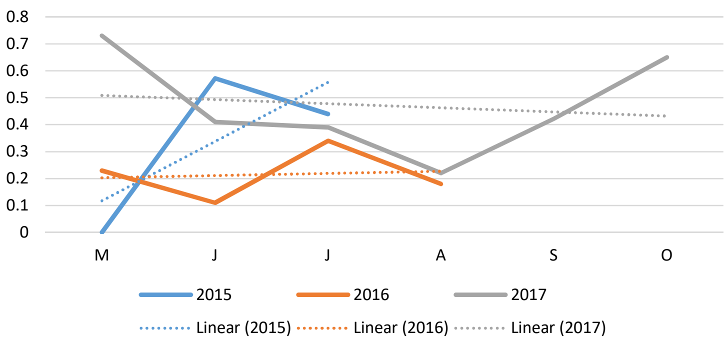
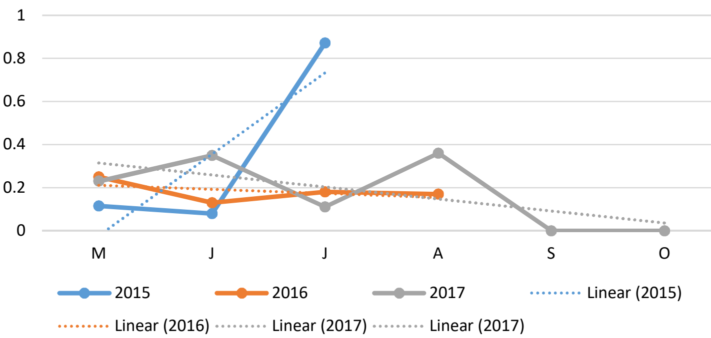


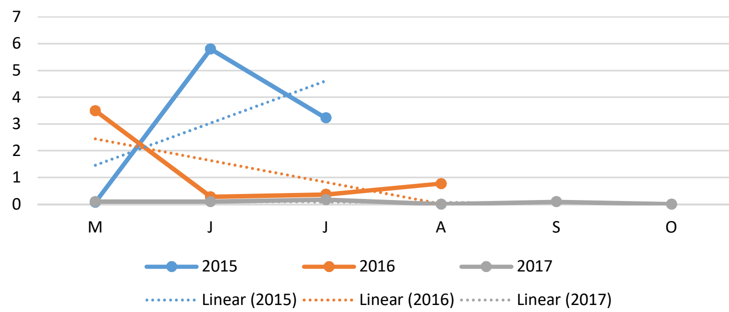
Figure 28
Sulfide Seasonal Influence in Twin Lakes
Peeper Pore Water (2015-2017)



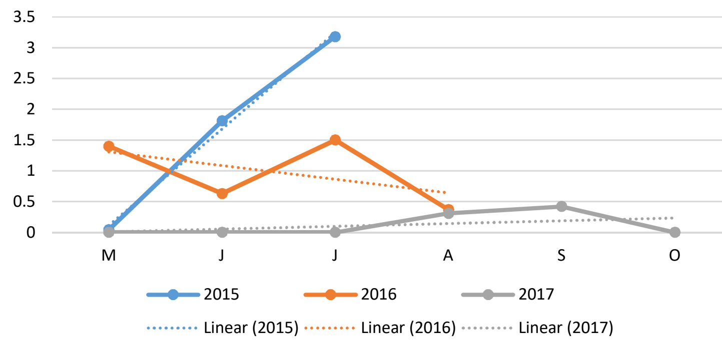
Twin Lake Outlet



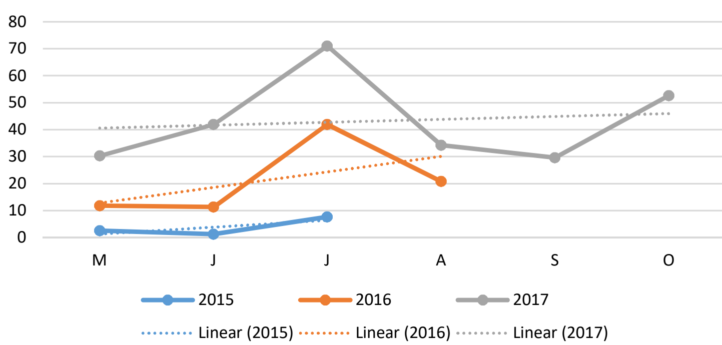
Sandy Lake Middle



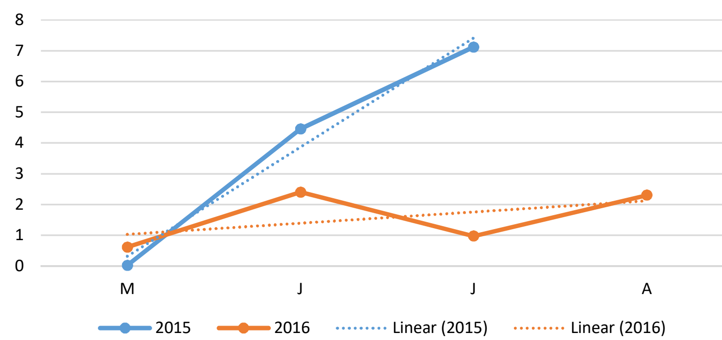
Little Sandy Lake Outlet



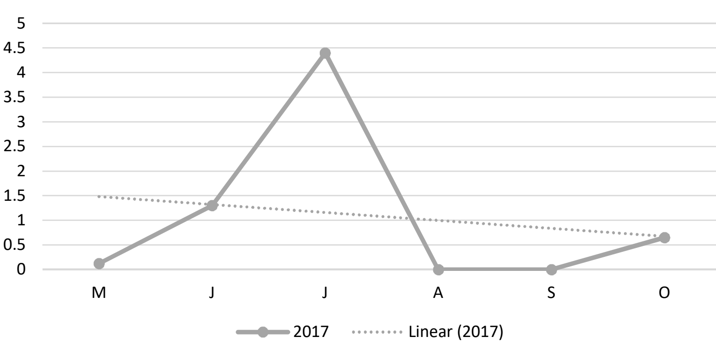
Little Sandy Lake Inflow 1



Little Sandy Lake Inflow 2



Little Sandy Lake Inflow 3



Sandy Lake Inflow South

To address comments received after the 2015 monitoring season regarding use of peepers for sediment pore water characterization, a procedure was implemented to deoxygenate the sampling materials used in peepers. Peeper materials deoxygenated prior to use were the DI water, 50-mL centrifuge tubes, caps, filter, and screen. Deoxygenation was completed under nitrogen atmosphere in an air-tight glovebox, and followed the method described by Teasdale et al. (1995). Deoxygenated and prepared vials were sealed with parafilm and kept in a nitrogen atmosphere in a sealed plastic bag prior to field deployment. This procedure was undertaken in 2017 and, although there didn't appear to be any significant difference in sample results, continued throughout the remainder of the Plan.

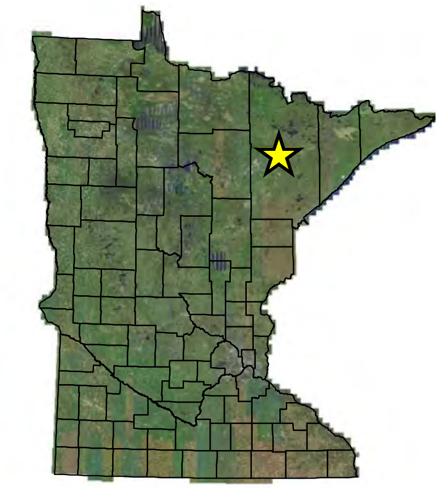
In 2017, an updated method of obtaining and preserving peeper samples for sulfide was developed. At the time of retrieval, water in the upper-most and lower-most 50-mL tubes from the 0°and 360° locations on each peeper assembly were immediately combined in the sample bottle containing sodium hydroxide/zinc acetate preservative for subsequent analysis of sulfide. This was done to 1) minimize the potential atmospheric exposure of the sample prior to preservation, and 2) obtain a more representative sample of pore water characteristics specifically for sulfide. The remaining two intermediate 50-mL peeper tubes (at the 120° and 240° locations) were placed in separate sample bottles for measurement of sulfate, iron and manganese.

During the 2015 through 2017 sampling seasons, the highest sediment pore water sulfide concentrations were measured from samples obtained at the Inflow 2 monitoring location. Concurrently, the lowest total iron concentrations were measured in samples also obtained at this monitoring location. These data tend to indicate that as sulfide is produced in the pore water, available iron is bound as iron sulfide, thus decreasing the pore water total iron available for reaction with sulfide.

To better understand this trend, two phases of peeper deployment were planned for Little Sandy Lake near Inflow 2 in 2018. The primary objective of the 2018 peeper deployment was to delineate the aerial extent of the elevated pore water sulfide that has consistently been observed in the Inflow 2 area. During Phase 1, seven peepers were deployed in May 2018. The first peeper was located at the spot where Inflow 2 peepers had previously been deployed. The remaining six peepers were installed in one transect perpendicular to the shoreline at 50-100 feet spacing increments towards the center of the lake (see Figure 29). The peepers were sampled and redeployed in the same locations in June. In July, all of the peepers were sampled and removed with the exception of the Inflow 2 peeper, which was redeployed for Phase 2 in the same location. The Phase 2 peepers were initially planned to be placed in a transect perpendicular to the Phase 1 locations, spanning the southwest bay of Little Sandy Lake. However, data analysis from the first round of sampling in June, showed that the sulfide concentrations in each peeper trended lower toward the middle of the lake, while the iron concentrations trended higher. It was theorized that the Inflow 2 location is a localized area of high sulfide/low iron and these concentrations decreased and increased, respectively, farther away from Inflow 2. To test this theory, eight Phase 2 peepers were deployed in July in two transects on either side of the previous location of the Phase 1 transect (see Figure 30). As with the Phase 1 peepers, the Phase 2 peepers were sampled and redeployed in the same location in August. In September, the Phase 2 peepers were sampled again and removed for the season. Data collected from the peepers showed high sulfide concentrations at the Inflow 2 location and trended lower toward the center of the lake (see Figure 31). Peeper data also showed lower iron concentrations at the Inflow 2 peeper location trending higher toward the center of the lake (see Figure 32).

N

0.015 0.0075 0 0.015 0.03
Miles



Legend

- Inflow 2
- Phase 1 Peeper Deployment

Figure 29
2018 Phase 1 Peeper Deployment Map

Twin Lakes - Little Sandy Lake
US Steel Corporation -
Minnesota Ore Operations
Mt. Iron, Minnesota (St. Louis County)

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Drawn By : Tracy Muck
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Background Imagery provided by Saint Louis County
Web Services. Date of Imagery: May, 2016

Figure 30
2018 Phase 2 Peeper Deployment Map

Twin Lakes - Little Sandy Lake
US Steel Corporation - Minnesota Ore Operations
Mt. Iron, Minnesota (St. Louis County)

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Background Imagery provided by Saint Louis County Web Services. Date of Imagery: May, 2016

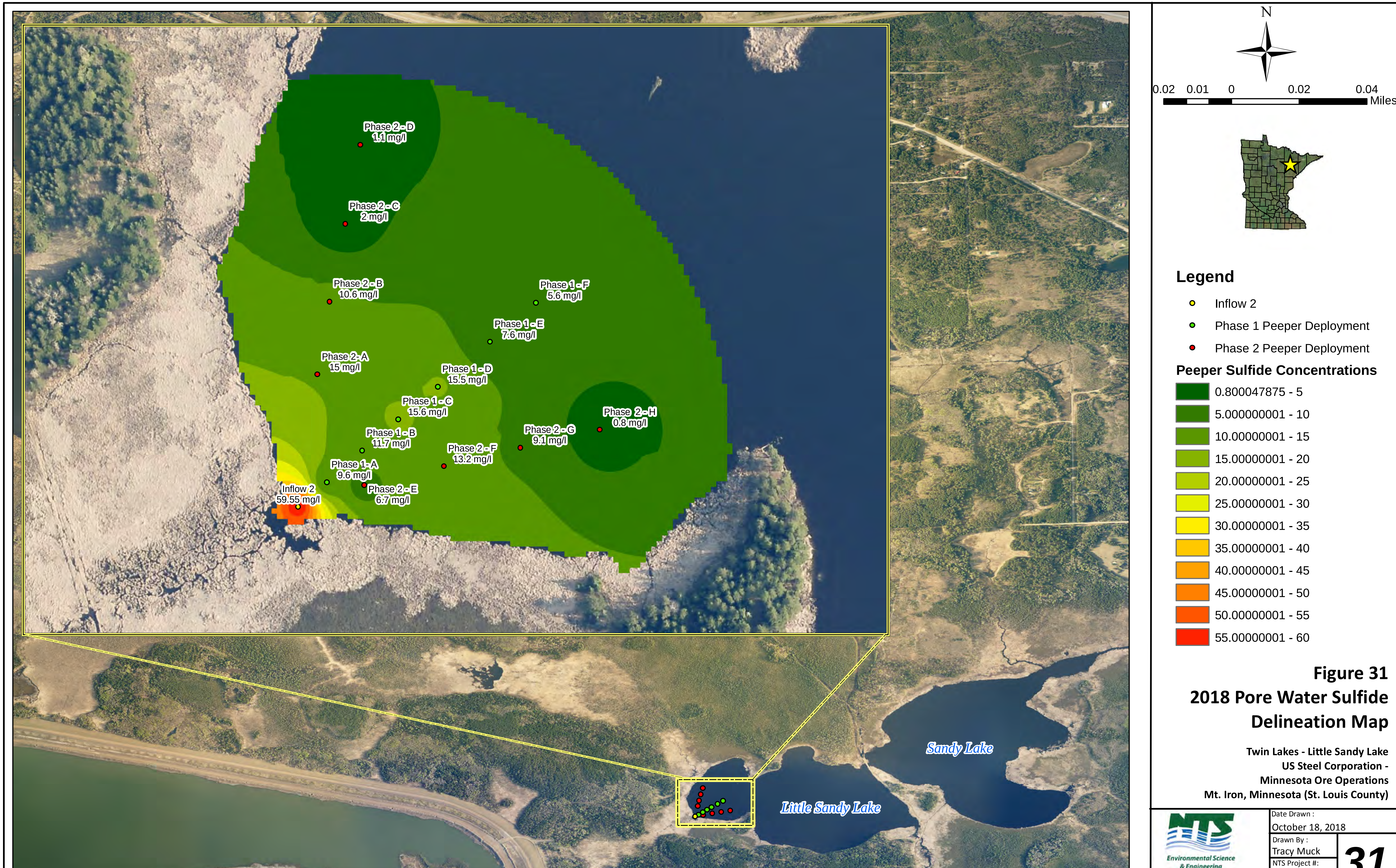

Figure 31
2018 Pore Water Sulfide Delineation Map

Twin Lakes - Little Sandy Lake
US Steel Corporation -
Minnesota Ore Operations
Mt. Iron, Minnesota (St. Louis County)

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Drawn By: Tracy Muck	31
NTS Project #: 10170E	

Background Imagery provided by Saint Louis County Web Services. Date of Imagery: May, 2016

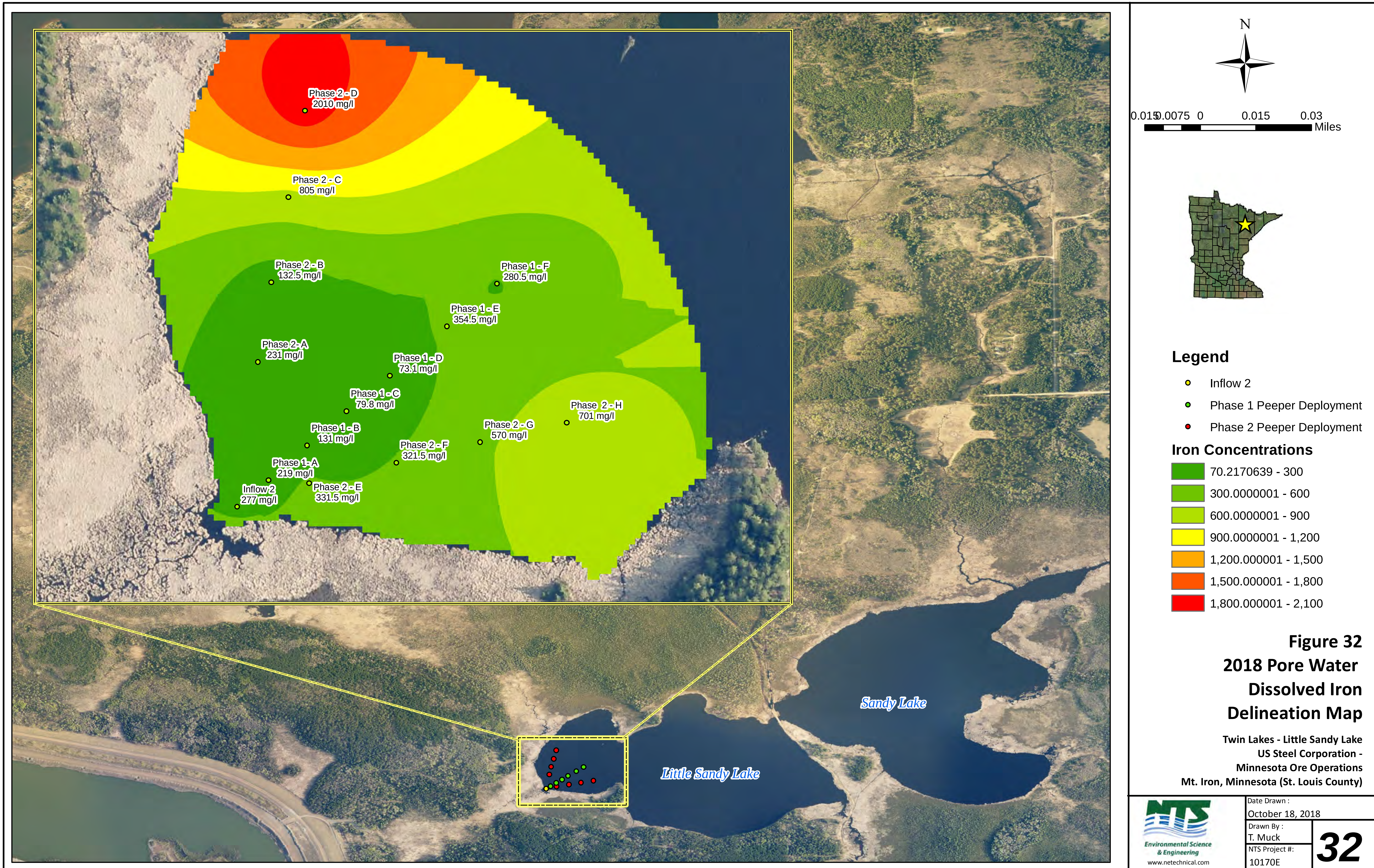

Figure 32
2018 Pore Water Dissolved Iron Delineation Map

Twin Lakes - Little Sandy Lake
US Steel Corporation - Minnesota Ore Operations
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Background Imagery provided by Saint Louis County Web Services. Date of Imagery: May, 2016

4.3 Rhizon Pore Water Quality

In July 2017, the Minnesota Pollution Control Agency (MPCA) released procedures for sampling pore water from sediment (MPCA July 2017), which involved the use of Rhizon filters to directly sample sediment pore water from cores. During 2017 this alternate method of pore water sampling was used in a 'side by side' comparison with specific peepers in September. In 2018, this side-by-side method of sediment pore water sampling was again used in June and August. This was accomplished by inserting the Rhizon filter with attached tubing (see Figure 33) approximately 10 cm into a sediment core, applying a vacuum supplied by an evacuated 125-mL serum bottle containing sodium hydroxide/zinc acetate preservative, into which a minimum volume of 50 mL of pore water is aspirated (Figure 34). Concurrent peeper samples were obtained and preserved in the field using the method described in Section 4.2. In the same manner as described above for peeper materials, Rhizon materials were also deoxygenated prior to use for sediment pore water sampling. In addition, the 125-mL sample container was purged with nitrogen prior to evacuation. The sodium hydroxide/zinc acetate preservative was added under nitrogen atmosphere in an air-tight glovebox.

Although the method for using Rhizons for sediment pore water sampling was completed following the established MPCA guidelines, substantial differences were found to exist between concentrations of sulfide from peeper samples and Rhizon samples (see Figure 35). Specifically, in 2017, pore water sulfide concentrations measured by the peeper sampling technique were approximately double those measured when using Rhizons. Further, in 2017, a nearly identical peeper:Rhizon sulfide concentration ratio was observed between all side-by-side samples obtained using peepers and Rhizons. Although this trend was not seen during the 2018 Rhizon versus peeper side-by-side comparisons the Rhizon sulfide concentrations were almost always consistently lower than the peeper sulfide concentrations for the same location.

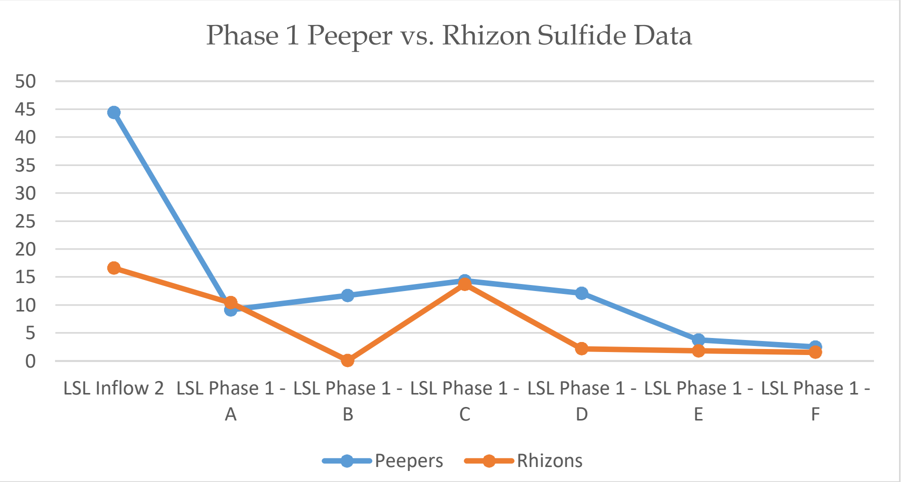
FIGURE 33. RHIZON FILTER APPARATUS USED FOR SEDIMENT PORE WATER SAMPLING. NOT PICTURED – 125-ML EVACUATED GLASS SAMPLE CONTAINER

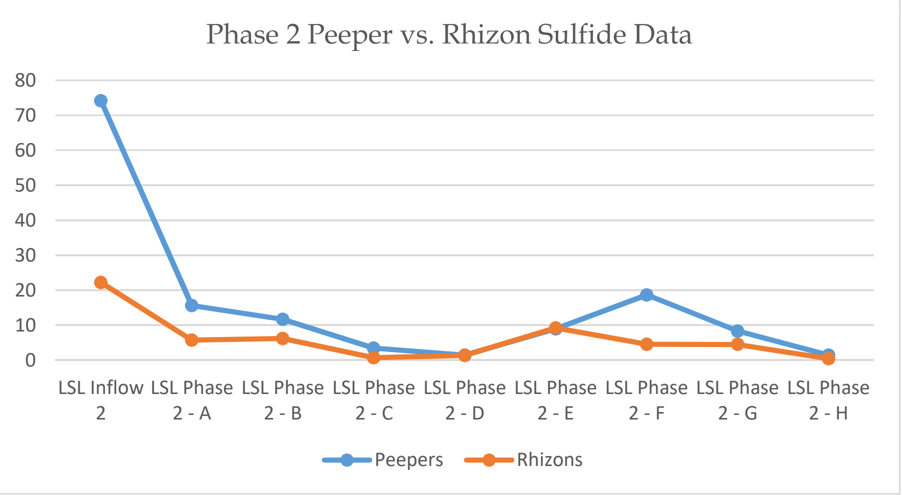
FIGURE 34. RHIZON FILTER APPARATUS IN USE FOR SAMPLING SEDIMENT PORE WATER

FIGURE 35
TWIN LAKES SULFIDE SAMPLE COLLECTION COMPARISON

	Peeper Sulfide mg/L	Rhizon Sulfide mg/L
	6/18/2018	6/15/2018
LSL Inflow 2	44.4	16.6
LSL Phase 1 - A	9.13	10.4
LSL Phase 1 - B	11.7	0.0786
LSL Phase 1 - C	14.3	13.7
LSL Phase 1 - D	12.1	2.16
LSL Phase 1 - E	3.75	1.78
LSL Phase 1 - F	2.49	1.53
	8/20/2018	8/20 & 8/21/2018
LSL Inflow 2	74.2	22.2
LSL Phase 2 - A	15.6	5.72
LSL Phase 2 - B	11.7	6.15
LSL Phase 2 - C	3.43	0.675
LSL Phase 2 - D	1.38	1.28
LSL Phase 2 - E	8.91	9.18
LSL Phase 2 - F	18.6	4.54
LSL Phase 2 - G	8.3	4.48
LSL Phase 2 - H	1.42	0.411

Note: The detection limit is <0.0779





In order to better understand what may be causing this divergence, a peeper assembly was planned for installation at a location near Inflow 2 (Inflow 2 Control) approximately 100 feet north of the Inflow 2 peeper. This peeper assembly was fitted with a Rhizon filter at 10 centimeters below the top of the sediment, with approximately 10 feet of attached tubing stored above the surface of the water at the top of the peeper assembly (see Figure 36). This peeper assembly was also fitted with peeper tubes and was deployed in July 2018. In August, this Rhizon was used to extract a sample "in-situ" for analysis of pore water sulfide. A sediment core was also collected and sampled "ex-situ" with a Rhizon, as was done at the other Phase 2 peeper locations. The peeper tubes from the peeper assembly were also sampled. All three samples were analyzed for sediment pore water sulfide. The results are shown in Table 12 below. It can be seen that the "ex-situ" Rhizon method produced the lowest results, while the "in-situ" method produced somewhat higher results. The peeper method shows pore water sulfide results higher than both of the Rhizon methods.

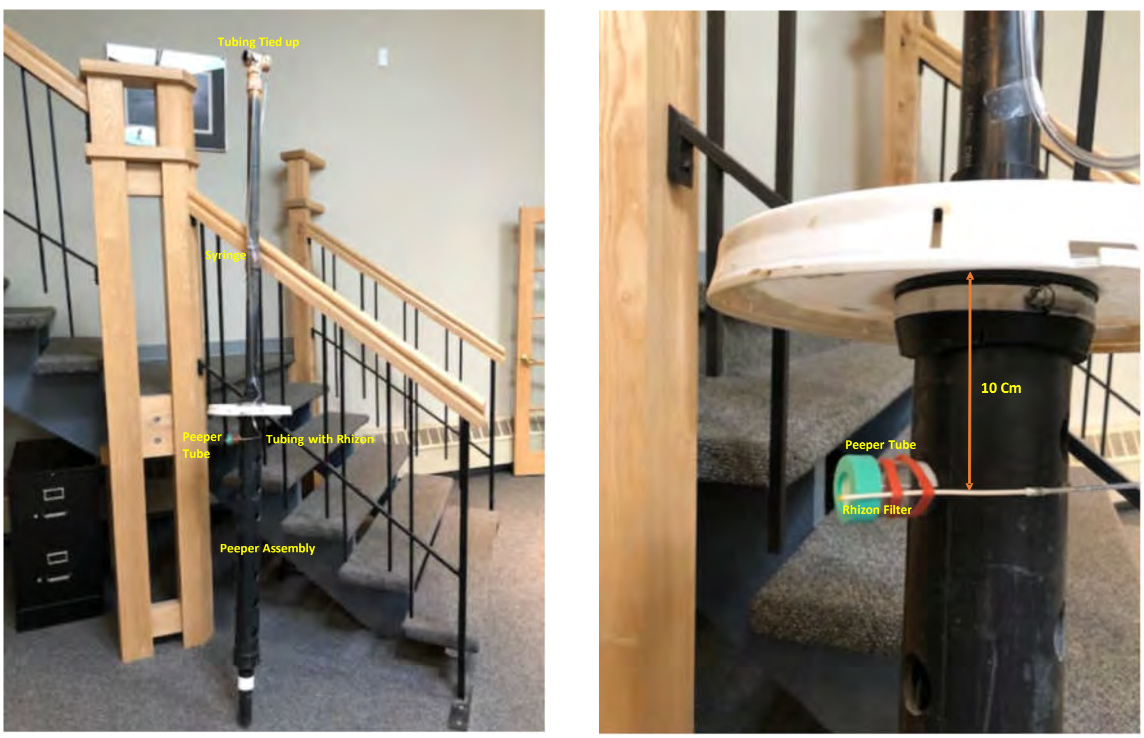


FIGURE 36. IN-SITU RHIZON ASSEMBLY ATTACHED TO PEEPER

TABLE 12: AUGUST 2018 SEDIMENT PORE WATER METHOD COMPARISON

Inflow 2 Control Location		
Ex-Situ Rhizon Method Sulfide (mg/L)	In-Situ Rhizon Method Sulfide (mg/L)	Peeper Method Sulfide (mg/L)
0.463	3.96	27.7

There are a number of possible explanations for these differences, including: disturbance caused by placement of the Rhizon filter into the sediment could have resulted in sulfide loss or transformation; the length of tubing required to satisfy the sampling protocol could be a source of oxygen for oxidation of sulfide to sulfate; and slightly different sampling techniques used by multiple personnel conducting sediment pore water sampling using Rhizons.

Additional side-by-side sediment pore water samples using peepers and Rhizons would be necessary to further elucidate and verify the differences in measured sulfide concentrations currently observed between these methods. Because consistent results were not obtained via the Rhizon method, it appears that this method is not representative of actual pore water sulfide concentrations. Therefore, it is recommended that future sediment pore water sampling techniques should utilize the peeper method.

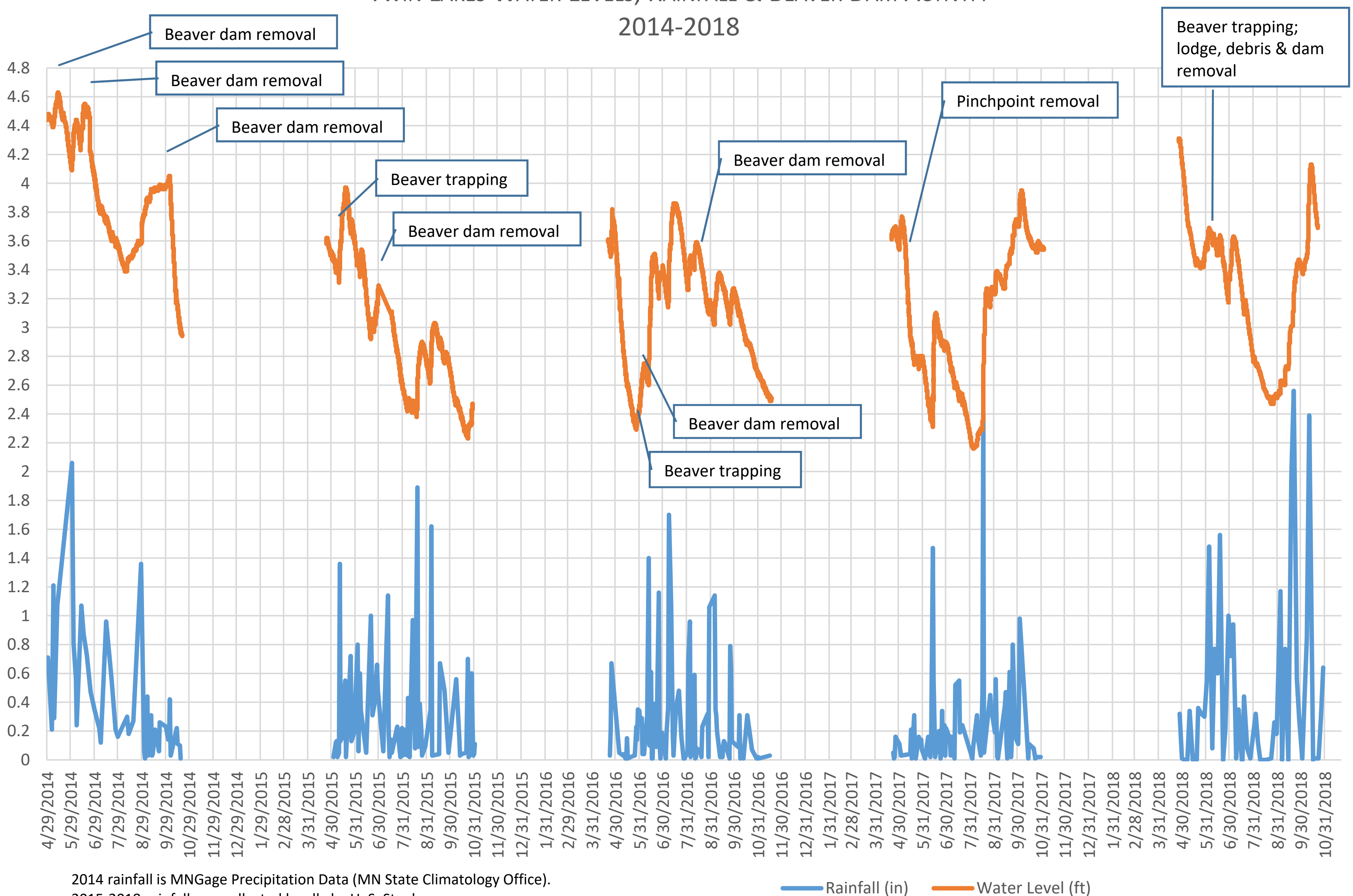
5.0 HYDROLOGY

5.1 TWIN LAKES WATER LEVELS

Water depth has been identified as one of the primary factors in the annual success, or failure, of wild rice growth. To provide a measure of the natural hydrologic inputs and outputs from the Twin Lakes system, and facilitate implementation of various aspects of the Plan, the depth of water at the steel bridge which connects the old county road between the two lakes has been recorded during the open water monitoring periods of 2014 – 2018. Continuous water level and water temperature measurements were collected via an OTT/Hach pressure transducer (PT). In general, the PT was deployed as soon as possible following ice-out during each of the Plan years and removed from service in mid- to late-October or early November prior to freeze-up. Typically, data from the PT was downloaded once each month during routine Plan sampling/monitoring events and calibrated against a manual water level/stream gauge mounted on the adjacent concrete bridge abutment. Daily precipitation totals were collected at a manual rain gauge located adjacent to the U. S. Steel Minntac Tailings Basin Return Pumphouse, approximately two miles south, southwest of the steel bridge and PT location. The results of 2014-2018 monitoring for rainfall and water depth are presented in Figure 37. For comparison purposes, gridded precipitation data was collected in 2018 from the High Spatial Density Precipitation Network (HIDEN) administered by Minnesota Department of Natural Resources (MNDNR) State Climatology Office. The rainfall data comparison for 2018 is presented in Figure 38. The majority of the data appears to align. However, one fairly large precipitation event in September was captured at the Minntac rain gauge that was not seen in the HIDEN data. This discrepancy demonstrates the potential for localized rain events that may affect the Twin Lakes water levels, but may not be captured by nearby weather stations.

The data in Figure 37 indicate that the Twin Lakes water depth is greatly influenced by rainfall, and the inability of inflows to efficiently move out of the Twin Lakes system. Water level data for each of the five Plan years is presented in Figure 39. There is ample documentation that water depth for optimum wild rice growth is in the range of 1.0 – 3.0 feet.

Figure 37
Twin Lakes Water Levels, Rainfall & Beaver Dam Activity
2014-2018



2014 rainfall is MNGage Precipitation Data (MN State Climatology Office).
2015-2018 rainfall was collected locally by U. S. Steel.

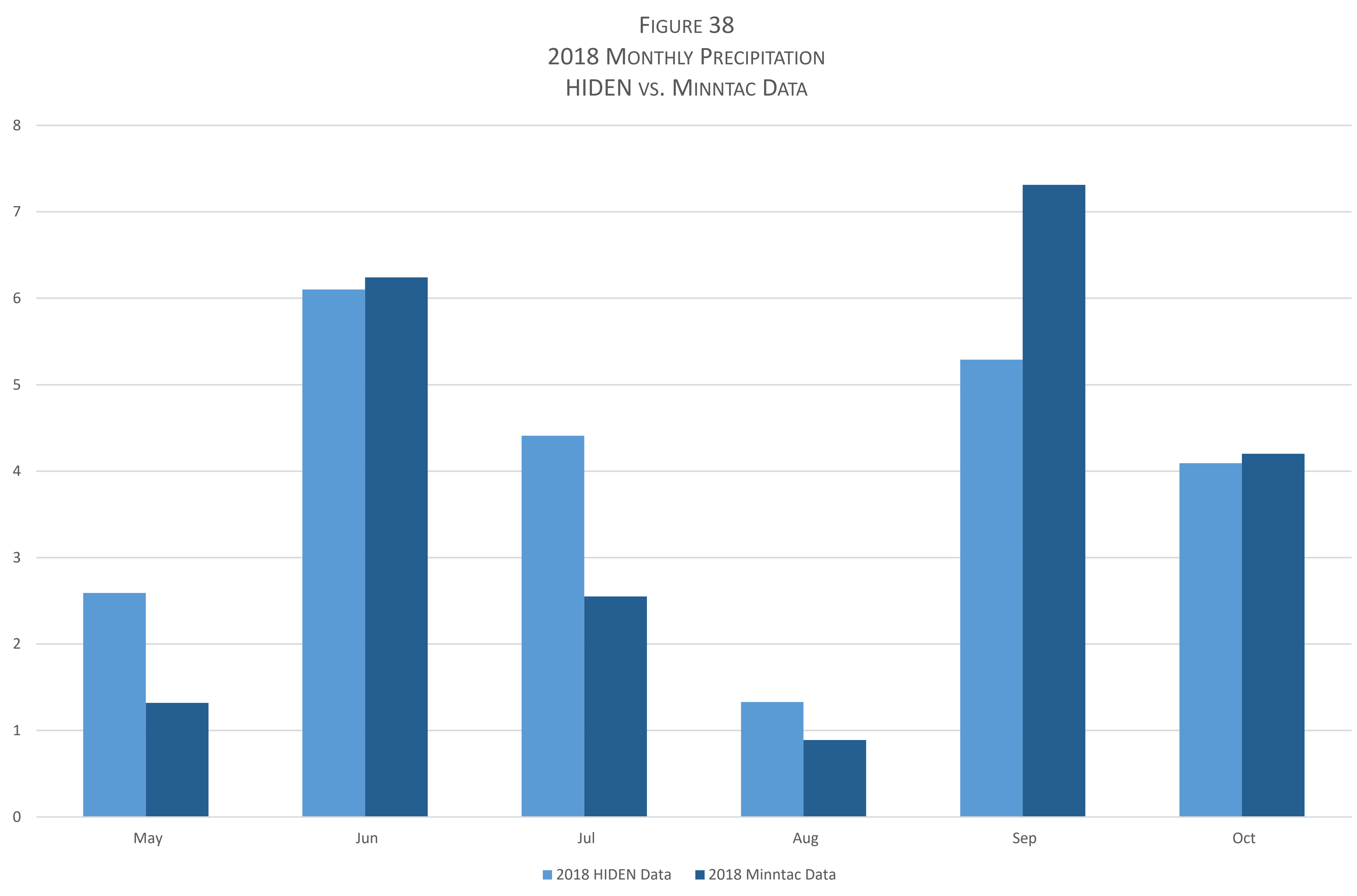
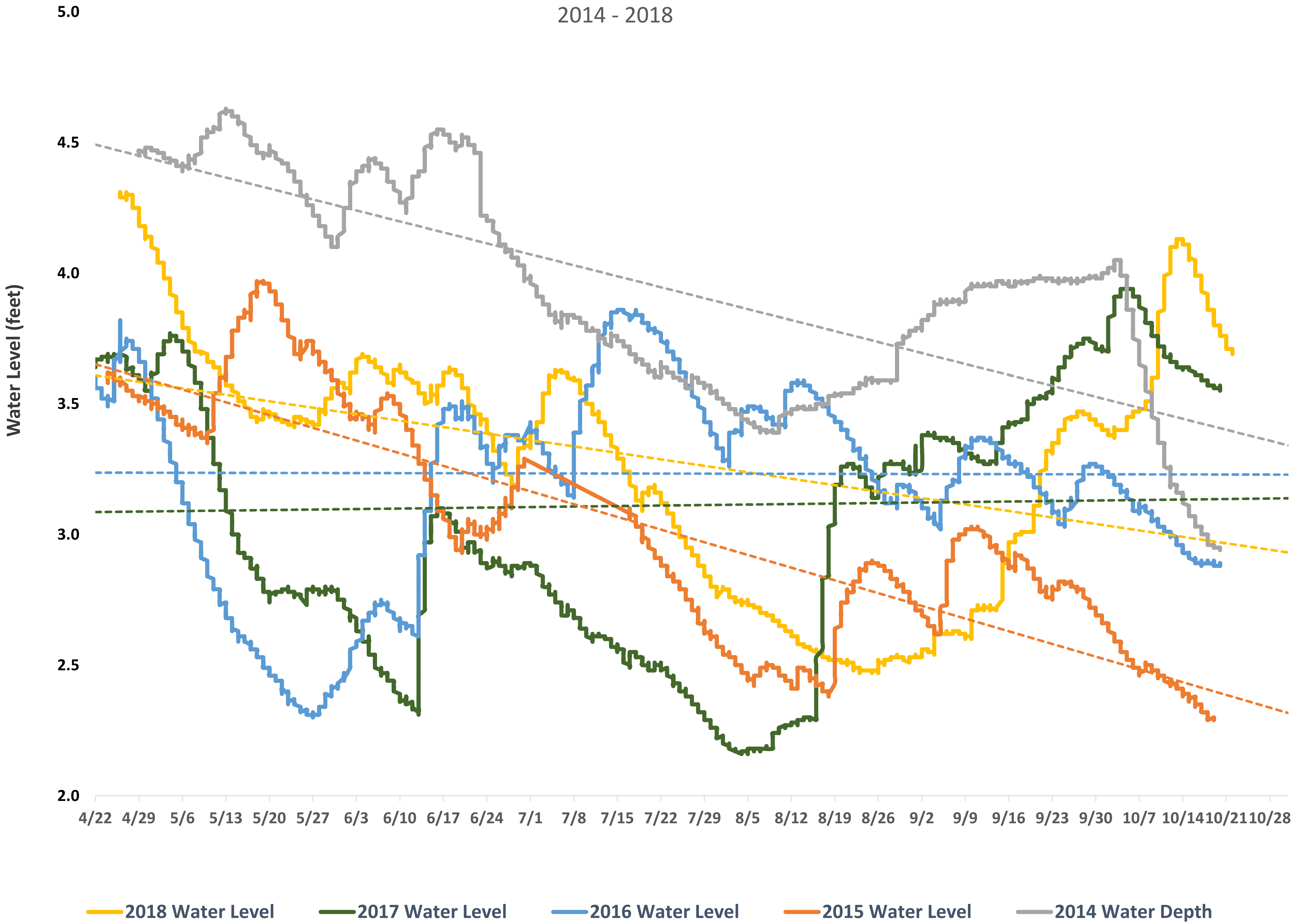


FIGURE 38
2018 MONTHLY PRECIPITATION
HIDEN VS. MINNTAC DATA
8
7
6
5
4
3
2
1
0
May
Jun
Jul
Aug
Sep
Oct
2018 HIDEN Data
2018 Minntac Data

FIGURE 39
TWIN LAKES YEARLY WATER LEVELS
2014 - 2018



Based on estimated bathymetry of Little Sandy and Sandy lakes, the depth of water measured by the PT at the steel bridge should be no more than 0.5 feet, which would correspond with the maximum optimum depth for wild rice growth (~2.5 – 3.0 feet) across the majority of both lakes. As can be seen in Figure 3, at no time during the entire five-year Plan did the depth at the steel bridge decrease to optimum (~ 0.5 feet) for successful wild rice growth and development throughout this system. With the exception of a few short instances during abnormally dry periods, the depth of water at the steel bridge was consistently above 2.5 feet, which corresponds to water depths exceeding 4.5 – 5.0 feet within each lake. More importantly, measured water depth at the steel bridge within the critical April – May early seedling life-stage timeframe typically exceeds 3.0 – 3.5 feet, which corresponds to water depths of approximately 5.0 – 5.5 feet within each lake. These depths exceed the upper-end of optimal by over 2.0 feet.

5.2 GROUNDWATER FLOW MODEL

U. S. Steel investigated the hydrology of the Twin Lakes via two separate modeling exercises to evaluate the influences that various factors may have on the relatively high overall water levels observed during execution of the Plan. The first modeling exercise was completed by GHD (formerly CRA) and built upon a 2013 groundwater flow model developed for the Sand River Watershed (GHD 2013). The model results showed that a significant portion of water seeping from the east side of the tailings basin is collected by the seep collection and return system, while the remainder migrates further downgradient through the subsurface in groundwater and discharges to surface water, primarily along the northeastern corner of the tailings basin. The Twin Lakes receive water from subsurface groundwater discharge and inflow from surface water courses. Surface water inflow is the primary contributor to the Twin Lakes, while groundwater discharge is a relatively small contributor.

This modeling exercise confirmed that most of the water inputs to the Twin Lakes from the tailings basin are via surface water inputs, with relatively minor inputs from groundwater. It also confirmed a flow path to the Twin Lakes at the northeast corner of the tailings basin.

5.3 HYDROLOGIC FLOOD-ROUTING MODEL

The second modeling exercise evaluated the overall impact of the tailings basin on precipitation runoff and its effect on Twin Lakes water levels. A flood routing model was developed by Barr Engineering (Barr 2019) to evaluate relative differences in Twin Lakes water levels under a number of different scenarios, including:

1. Current Conditions
2. Pre-mining (i.e., pre-tailings basin) Conditions
3. Current Conditions with Beaver Dams
4. Current Conditions with Sand River Shortened

The Current Conditions model evaluated the effects of a 100-year, 24-hour rainfall event and the resulting precipitation runoff from the Upper Sand River Watershed through the Twin Lakes under the current condition of the Minntac tailings basin in place. The Pre-mining Conditions model evaluated the same rainfall event but with changes made to the upstream end of the model to represent the area as it was prior to construction of the tailings basin. The Current Conditions with Beaver Dams model was developed by adding weirs to the model to simulate beaver dams in two locations on the Sand River downstream of Sandy Lake, equivalent to the locations of chronic pinchpoints discussed in Section 6.0 below. The Current Conditions with Sand River Shortened model was developed to evaluate whether the Sand River channel was restricting outflow from the Twin Lakes. It should be noted that groundwater seepage from the Minntac tailings basin at a rate of 1000 gpm was added to the Current Conditions model and removed from the Pre-mining Conditions model to simulate tailings basin seepage inputs to Little Sandy Lake in addition to the design storm runoff volume.

Water levels for Little Sandy and Sandy lakes from the Current Conditions, Pre-mining Conditions, and Current Conditions with Beaver Dams models are shown on Figures 40 and 41 below. As shown on these figures, the Pre-mining Conditions lake level peak is higher than the Current Conditions lake level peak.

Additionally, the water levels take slightly longer to draw down after the storm event in the Pre-mining Conditions model when compared to the Current Conditions. Current Conditions with Beaver Dams shows that the lake level response to the rainfall event is similar, but the water level in the lake does not draw down as low due to the dams holding back water upstream in the Sand River and Little Sandy and Sandy lakes. Water levels for Little Sandy and Sandy lakes from the Current Conditions and Current Conditions with Shortened Sand River models are shown on Figures 42 and 43. These figures show that the model predicts essentially no differences in water level responses in Little Sandy and Sandy lakes as a result of the storm event when changing the length of the Sand River below Twin Lakes. This indicates that the unobstructed river is capable of conveying water out of the Twin Lakes and allowing water levels to recede.

These model results show that overall the Twin Lakes are receiving less water now than under pre-mining conditions. The model also indicates that if the Sand River is clear of obstructions and maintained as an open channel, water will move out of the system more efficiently and the water level in the Twin Lakes has the potential to drop to lower levels than what is currently observed.

FIGURE 40

LITTLE SANDY LAKE HYDROLOGIC MODELING RESULTS

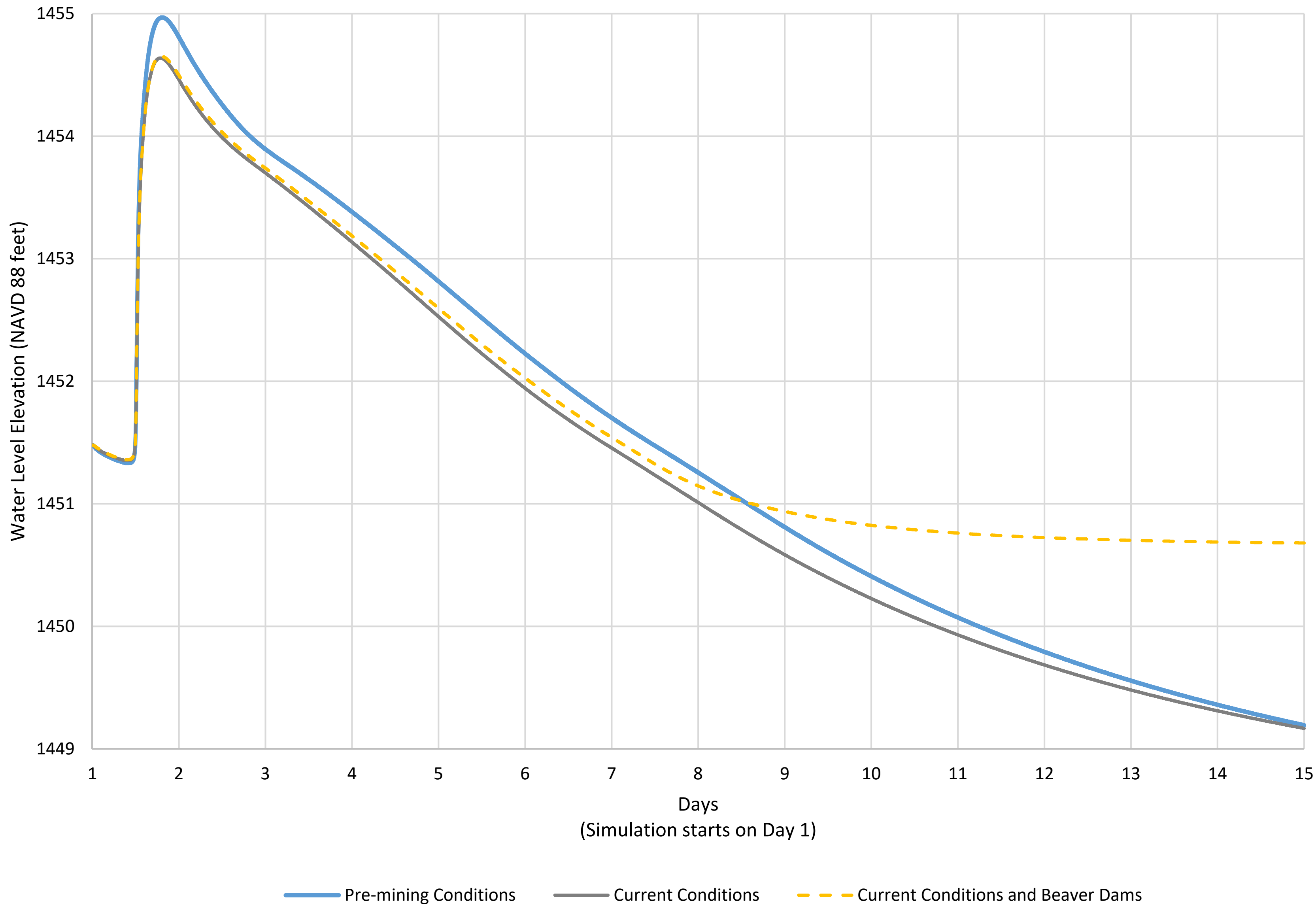


FIGURE 41
SANDY LAKE HYDROLOGIC MODELING RESULTS

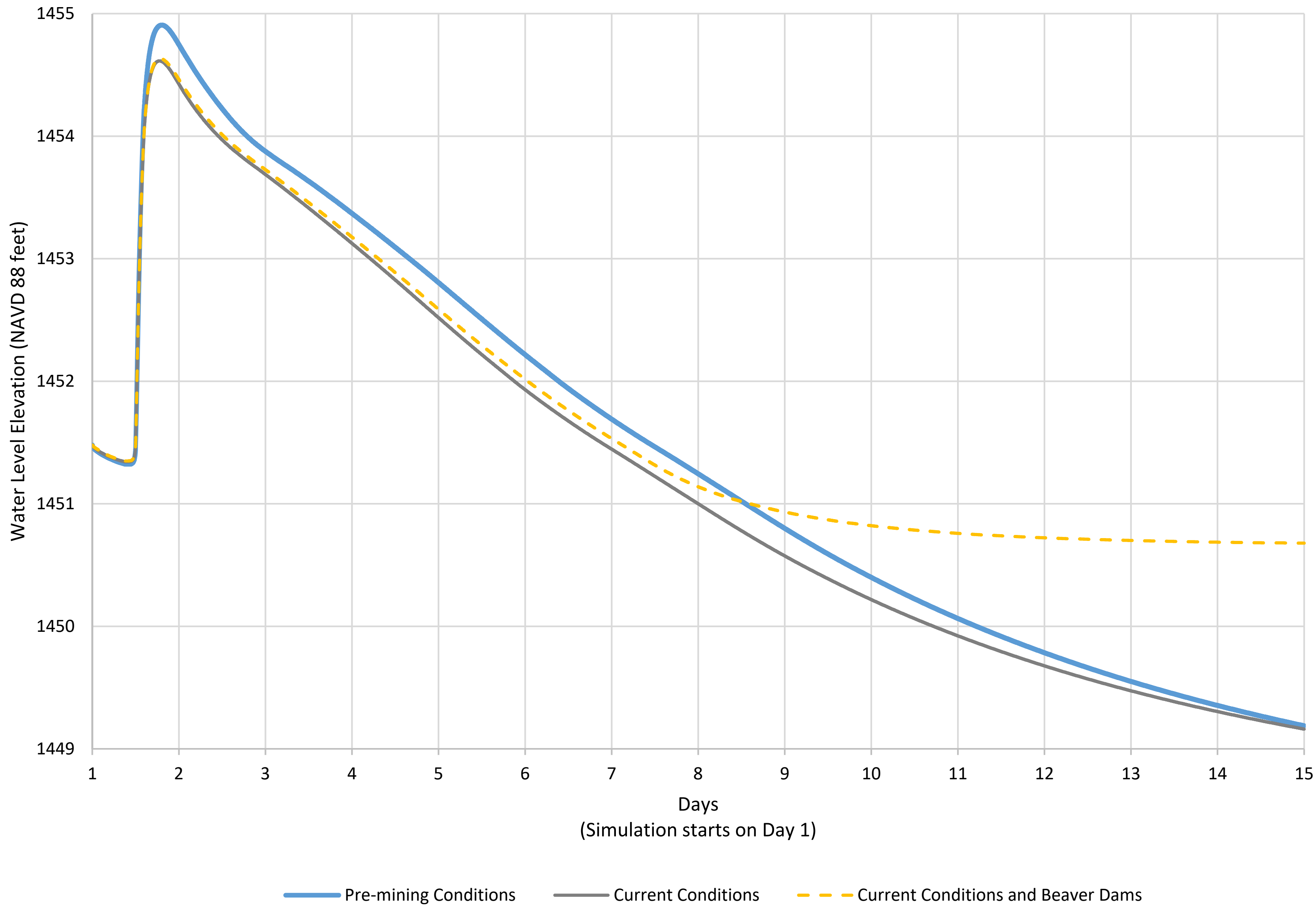


FIGURE 42
LITTLE SANDY LAKE SHORTENED SAND RIVER
MODELING RESULTS

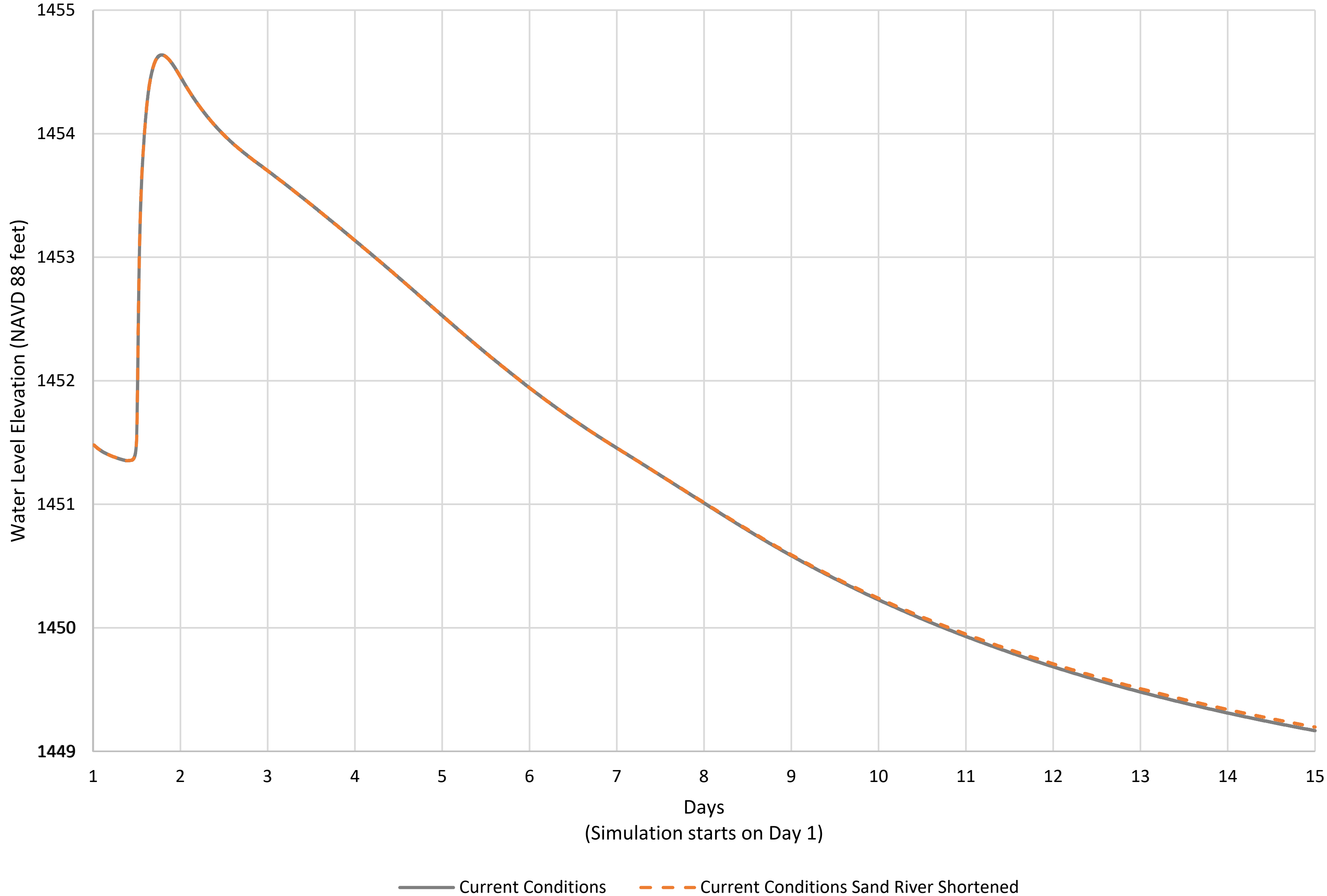
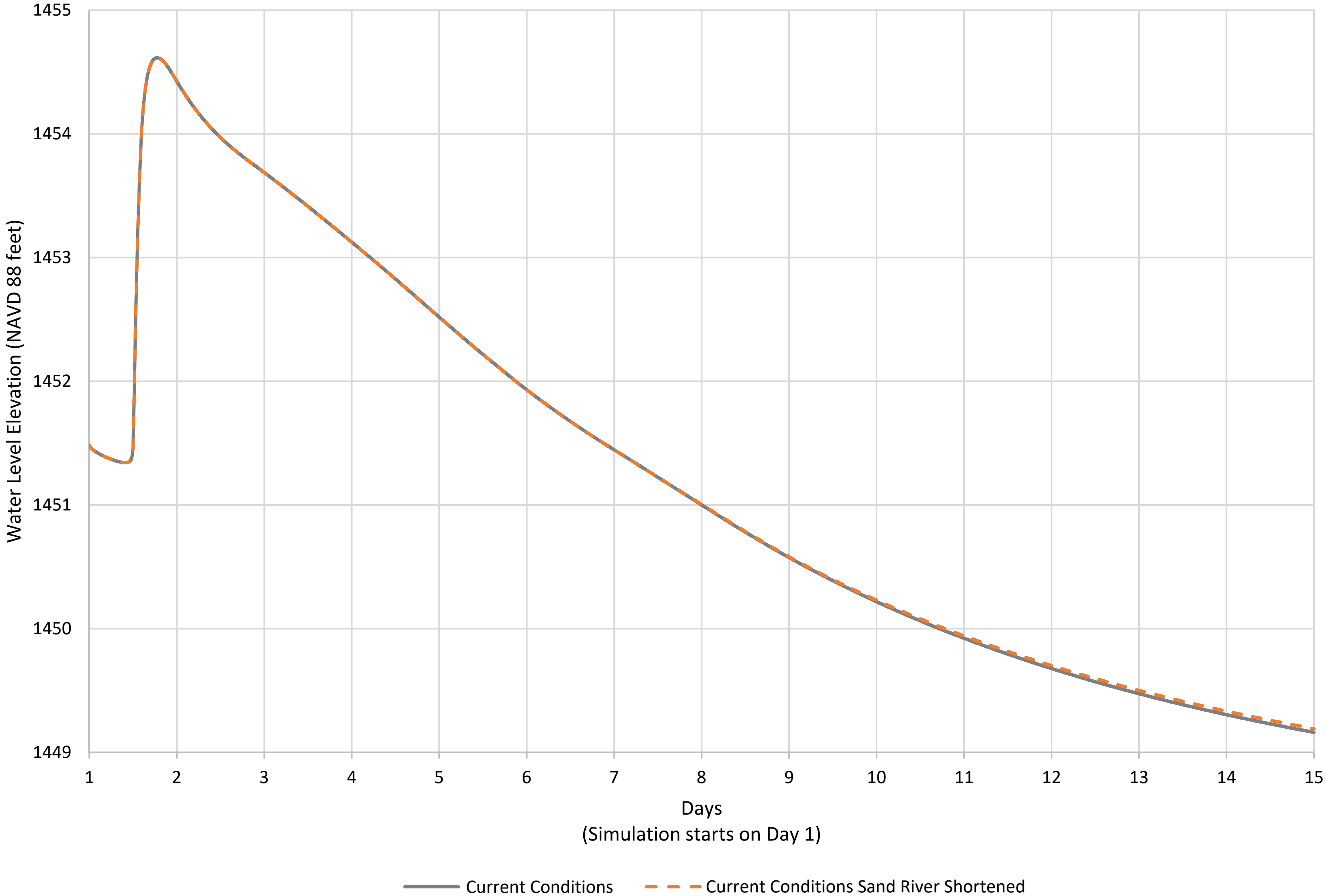


FIGURE 43
SANDY LAKE SHORTENED SAND RIVER
MODELING RESULTS



6.0 BEAVER AND ANIMAL EFFECTS

Due to the critical nature of water depth for wild rice success, beaver trapping and dam removal from the Sand River downstream of the Twin Lakes was pursued each year of Plan execution. During 2014, a private animal control contractor was hired to, in general, "remove beaver from the Twin Lakes area, including the Sand River from the outlet of Twin Lakes to U.S. Hwy 53". The contractor was also charged with removing any observed beaver dams influencing flows into and out of the Twin Lakes. An unspecified number of animals were removed from the system and dams located in the Sand River downstream of the Twin Lakes outlet were pulled by hand on three separate occasions. However, in each case, beavers returned and, at least partially, rebuilt the dams.

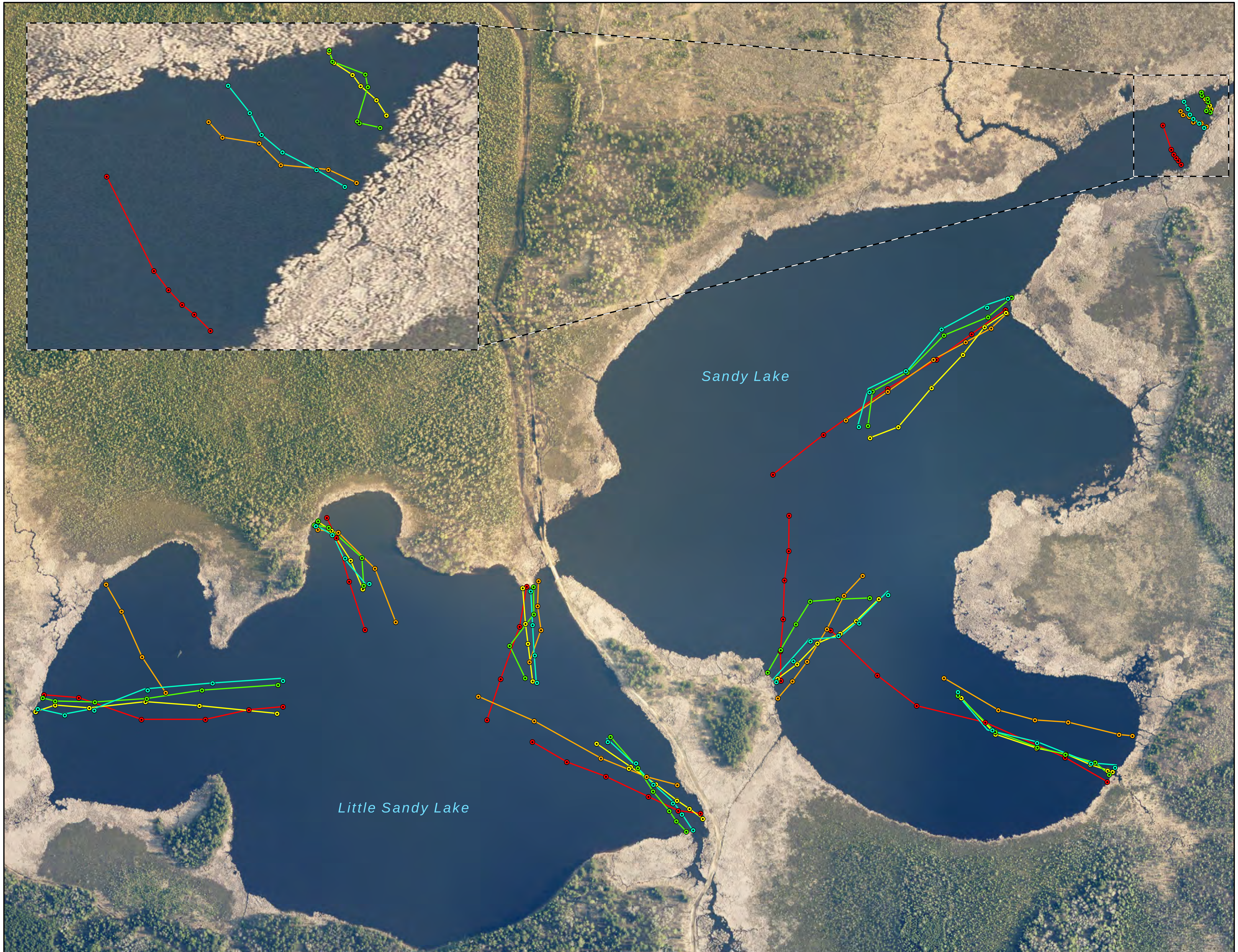
Beginning with the 2015 Plan year, and continuing through the final year of study, U. S. Steel contracted with the United States Department of Agriculture (USDA) Animal and Plant Health Inspection Service (APHIS) to conduct an intensive beaver and dam removal program. The removal activities of APHIS crew was much more effective than that realized during 2014. In 2015, a total of approximately 60 beavers were reported to have been removed from Admiral Lake, from near the head of the Sand River system down to County Road 303 (Rice River Road). The APHIS crew also noted the presence of a large number of beaver damps along the Sand River downstream of Sandy Lake, with on large dam downstream of U.S. Hwy 53 holding back 4 – 5 feet of water. In total, the APHIS crew removed 36 dams in early 2015, 29 by hand and 7 by blasting. Reports from the APHIS crew in late July 2015 indicated that there were no fresh beaver signs. A separate survey of the Sand River downstream of the Twin Lakes was completed by U. S. Steel and NTS personnel on June 21, 2015 to evaluate the presence of beaver dams and pinch points. The majority of observed channel obstructions were responsible for only small increases in water level immediately upstream. However, in aggregate, the old beaver dams and associated channel debris are causing water levels to be held up in the system, especially after significant rainfall events, as evidenced by pressure transducer data from the steel bridge.

The APHIS crew returned each of the following Plan years to ensure that any beaver that had returned, and any newly build dams, were removed. In spite of these continual animal control and beaver dam removal efforts, Twin Lakes water depths could not be controlled to the levels most conducive for optimum wild rice growth.

7.0 AQUATIC PLANT OBSERVATIONS

Between 2014 and 2018, aquatic plant surveys were completed in roughly the same locations each year (see Figure 44). Throughout the Plan, each transect in the Twin Lakes showed an increasing trend in number of aquatic taxa, with the exception of Sandy Lake Transect 4 and Little Sandy Lake Transect 4, each of which showed slightly decreasing trends (see Figure 45). Average percent rake coverage at each transect in Twin Lakes also showed an increasing trend between 2014 and 2018 (see Figure 46).

By comparison, transects in Sandy Lake showed more aquatic plant varieties than transects in Little Sandy Lake. Total aquatic plant types per transect in Sandy Lake ranged from 10 to 14, while the types

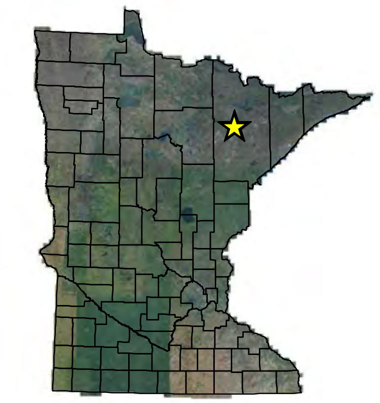


N

0 215 430 860

Feet

1 Inch = 433 Feet



Legend

- 2018 Vegetation Survey Points
- 2017 Vegetation Survey Points
- 2016 Vegetation Survey Points
- 2015 Vegetation Survey Points
- 2014 Vegetation Survey Points
- 2018 Vegetation Survey Transects
- 2017 Vegetation Survey Transects
- 2016 Vegetation Survey Transects
- 2015 Vegetation Survey Transects
- 2014 Vegetation Survey Transects

Figure 44
Twin Lakes
Aquatic Plant Survey
Transect Locations
(2014-2018)

Twin Lakes Survey
US Steel Corporation-
Minnesota Ore Operations
Mt. Iron, Minnesota (St. Louis County)

NTS Environmental Science & Engineering
www.netechnical.com

Date Drawn : October 25, 2018

Drawn By : T. Muck

NTS Project #: 10170E

44

Figure 45
Aquatic Plant Taxa Trends in Twin Lakes

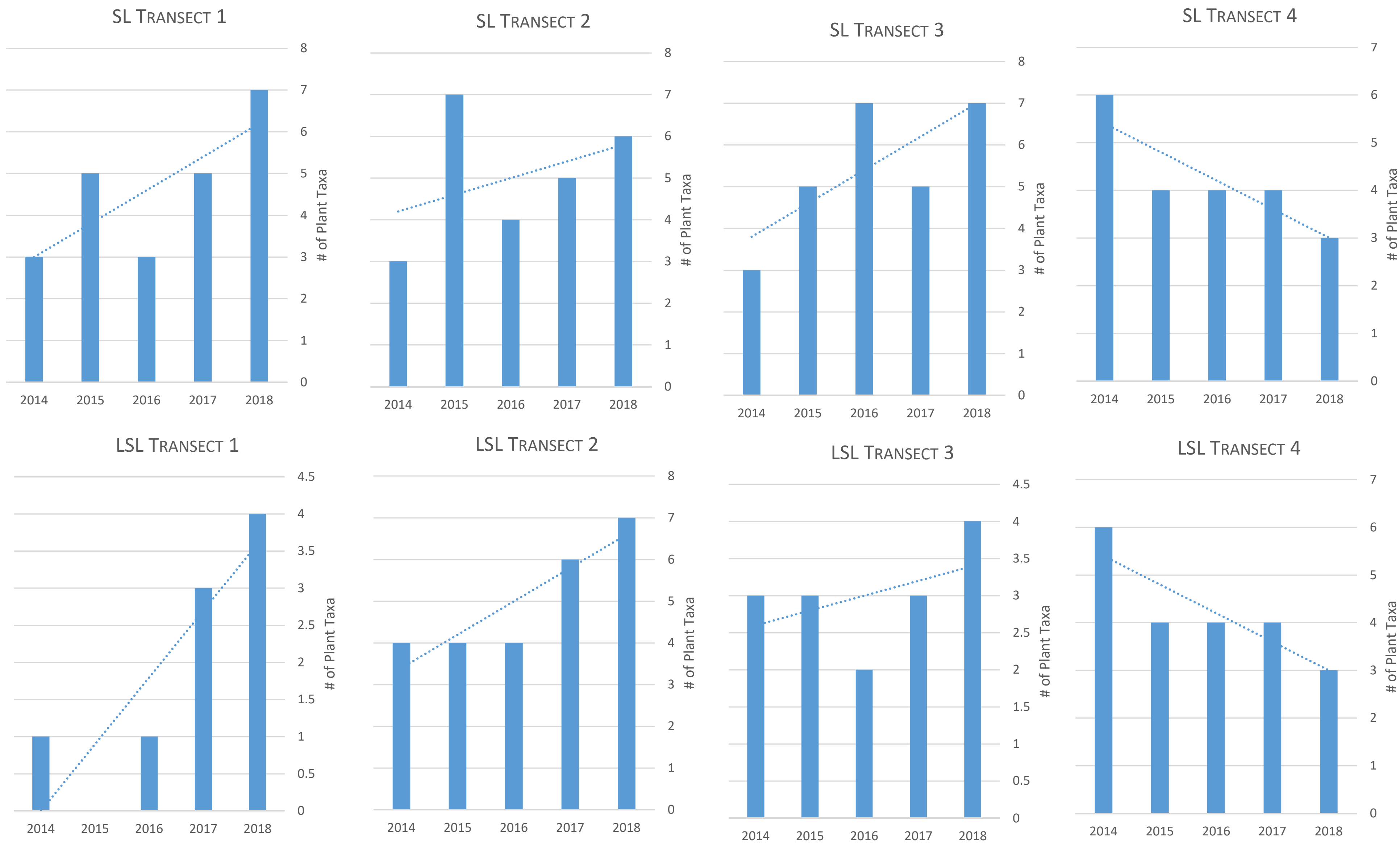
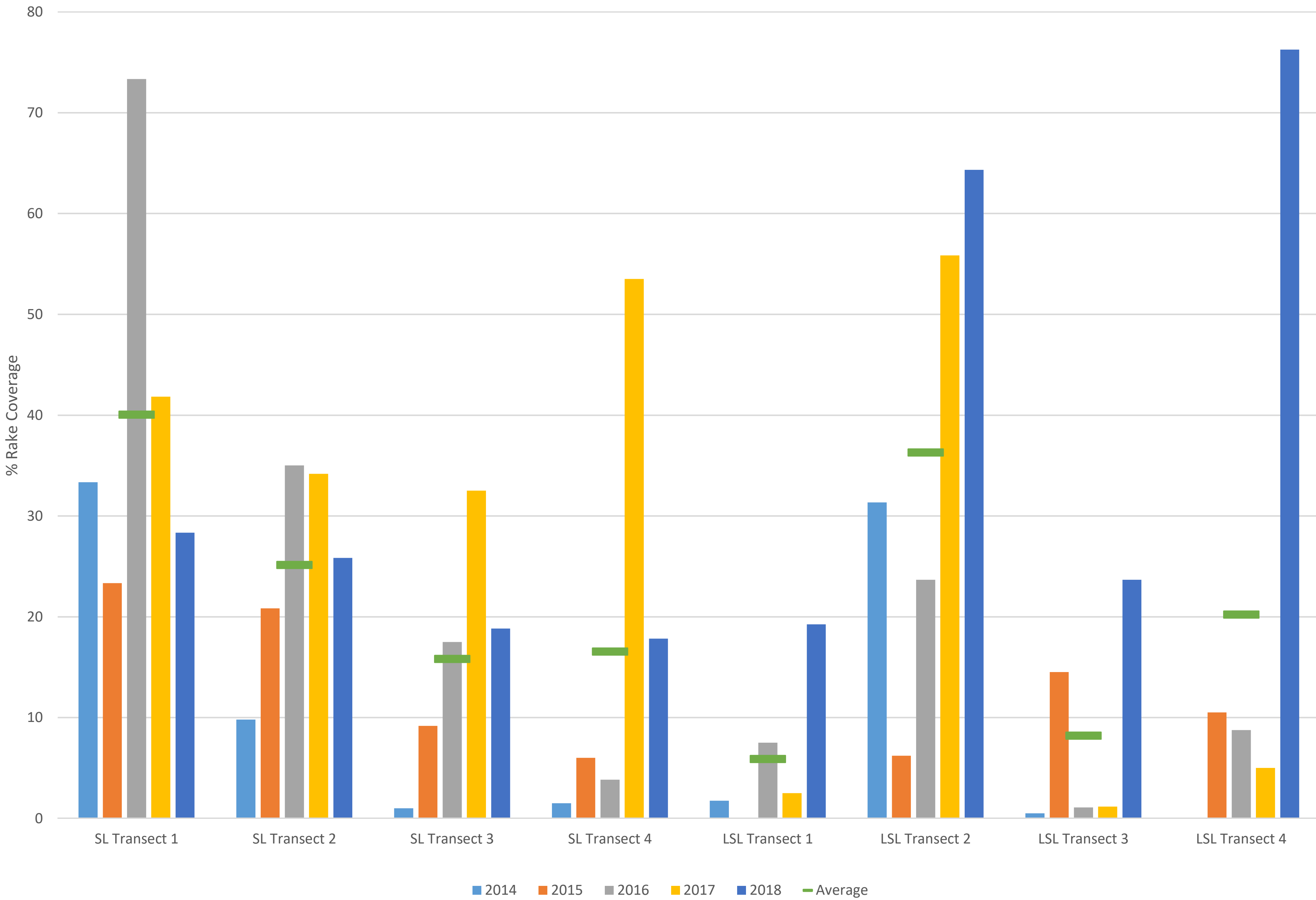


Figure 46
Aquatic Plant Survey
% Rake Coverage in Twin Lakes (2014-2018)



in Little Sandy Lake ranged between 5 and 7 per transect. Although there were more aquatic plant taxa in Sandy Lake than in Little Sandy Lake, it should be noted that Little Sandy Lake showed more consistent plant growth in each transect over the five-year Plan, with Northern Watermilfoil most commonly found in every transect. It was also noted that average percent rake coverage collected from transects in Sandy Lake was slightly greater than those collected in Little Sandy. Average percent rake coverage in Sandy Lake ranged from 15.8 to 40% per transect over the course of the five-year Plan, while average percent rake coverage ranged between 5.8 and 36.3%.

The types of aquatic vegetation found in each lake were similar. The majority in both lakes consisted of Northern Watermilfoil and Northern Bladderwort. Chara was also prominent in Sandy Lake, but not so much in Little Sandy Lake.

Cattails were present around the entire perimeter of each lake during each year of the Plan. In comments responding to the 2018 Sandy Lake and Little Sandy Lake Monitoring Report prepared by 1854 Treaty Authority, Mike Madden, local property owner near the Twin Lakes, noted that in the 1970's, no cattails existed in either lake (see Appendix F). The areas where cattails now grow were spruce bog, or cranberry bog as it was known by the locals. The cattails became more prevalent at approximately the same time wild rice began to decline, which is also when the Twin Lakes water levels started to rise. Mr. Madden also noted in his comments that even the creek to Admiral Lake (Sand River) was completely open in the 1970's and passable by small boat. Currently the Sand River upstream of Little Sandy Lake is choked with cattails and other aquatic vegetation and is essentially impassable. It is possible that allelopathy and competition with other aquatic plants may have been another factor in the decline of wild rice plants in the Twin Lakes.

8.0 WILD RICE SEEDING

Following successfully decreasing water depths during 2015, a decision was made to pursue limited "pilot-scale" wild rice seeding efforts in six locations in the Twin Lakes system. A conference call was held on August 21, 2015, to ensure that interested stakeholders were provided an opportunity to participate in the planning process for the proposed seeding. Representatives of the regional Native American communities (Bois Forte, Fond du Lac and the 1854 Treaty Authority), as well as the USACE, participated in the call and provided valuable input and advice. The primary topics of discussion during the conference call are provided below, along with details associated with each of the topics encountered throughout the process.

8.1 SOURCE AND AMOUNT OF WILD RICE FOR SEEDING

Abundant stands of wild rice had been observed in the Sand River downstream of Sandy Lake, between Rice River Road (County Road 303) and MN Hwy 169, during the preceding several years. Therefore, it was proposed that wild rice harvested during 2015 from that section of the Sand River be used as the seed source for any 2015 seeding activities. The primary reason for using Sand River seed was that it is likely most genetically similar to wild rice historically present in the Twin Lakes. There was general consensus among the conference call participants that this was an appropriate seed source. Darren Vogt, 1854 Treaty Authority, recommended that wild rice seed be distributed at a rate of 50 – 100 lbs. per acre.

In an effort to obtain wild rice seed, notices were placed in two locations along the Sand River on or about August 22, 2015, in areas that would be conspicuous to ricers, advertising the desire to obtain recently harvested wild rice. An advertisement was also placed on the 1854 Treaty Authority Wild Rice Web page. One call was received from a ricer on the Sand River. However, the ricer ultimately decided to keep the rice for personal use. Since no sources of Sand River wild rice were secured by the middle of the second week of September, plans were made to harvest rice from Sand River using project personnel.

8.2 SEED HARVEST AND STORAGE

Two individuals from U. S. Steel obtained the required DNR permits and collected wild rice from stands within the Sand River upstream of MN Hwy 169 on September 14, 2015. The wild rice plant density was fair to good, but the amount of seed remaining on the heads was sparse. Approximately 40 lbs. of raw wild rice was collected and immediately transported to Northeast Technical Services' Soils Lab in Virginia, MN. At that time, the wild rice was weighed, split into six equal amounts of about 2850 grams, and placed into woven poly bags. Each of the six bags of raw rice were then placed into separate five-gallon plastic buckets and filled with water collected from the Sand River at MN Hwy 169 the previous week. The buckets containing the raw wild rice and Sand River water were sealed and placed into a climate-controlled room where the air temperature was held at 56°F for the duration of storage.

8.3 PERMITTING REQUIREMENTS

During the August 21, 2015, conference call, it was mentioned that seeding activities could not proceed without a permit from the DNR. U. S. Steel worked with the DNR and U.S. Forest Service to obtain the required permits. It should be noted that U. S. Steel could not get a permit for restoration of aquatic vegetation directly. Rather, as per DNR policy, only the landowner can be permitted for this type of activity. The majority of the Twin Lakes shoreline is owned by the federal government as part of the Superior National Forest. As such, U. S. Steel worked with U.S. Forest Service personnel from their Laurentian District Aurora, MN, office to secure the required permits.

DNR also specified that approval be sought from all minority riparian landowners on the Twin Lakes prior to proceeding with any seeding effort. A search of the St. Louis County tax records revealed that, besides the federally-owned land surrounding the majority of the two lakes, there were two privately-held parcels abutting the Twin Lakes, both on Sandy Lake. Letters were subsequently sent to each of the two minority riparian landowners seeking approval for the pilot-scale wild rice seeding effort. No response was received from one of the landowners, while the second expressed opposition to the proposed seeding because of the potential for damage to the resident fishery from decreased water depth(s). However, DNR allowed the permit to stay in effect since Sandy and Little Sandy lakes are primarily managed for waterfowl.

8.4 SPIRITUAL CEREMONY

Arrangements for a spiritual ceremony to be conducted as part of the seeding activities were made with members of the Bois Forte Band of Chippewa. Through the efforts of Bill Latady and Linda Tibbets-Barto, the spiritual ceremony was scheduled for, and held on, the morning of October 23, 2015, on a hill overlooking the canoe landing on the north side of Sandy Lake. Vernon Adams conducted the ceremony in the presence of representatives from Bois Forte, the 1854 Treaty Authority, U.S. Army Corps of Engineers, U. S. Steel, Northeast Technical Services, and members of the public.

8.5 WILD RICE SEEDING PROCEDURES AND RESULTS

Following the spiritual ceremony, pilot-scale seeding activities were initiated. Three separate areas in each of the Twin Lakes were identified for seeding based on previous known wild rice areas, and appropriate existing water depths and sediment type (i.e., organic substrate). A couple of the seeding plots were subsequently moved from the original plan based on input from area residents familiar with the lakes.

8.6 2016 WILD RICE SEEDED AREA OBSERVATIONS

Four of the six seeded plots produced variable amounts of emergent wild rice, with two of the six demonstrating fairly good growth (see **Appendix** G for photos of the wild rice seed plots and **Appendix** H for estimates of wild rice densities). The seeding efforts in the two plots on the north side of Little Sandy Lake resulted in no observed or very sparse growth. Interestingly, the seeding effort in the plot on the south side of Little Sandy Lake, close to the Inflow 1 location, resulted in fairly strong wild rice growth. In general, there is more aquatic vegetation competing with wild rice in Sandy Lake than in Little Sandy Lake, and there are areas of Little Sandy Lake in which more competing aquatic vegetation occurs than in other areas, possibly due to characteristics of the lakebed. There is historical documentation indicating areas of the Twin Lakes consistently produced good stands of wild rice, while other areas of the Twin Lakes produced poorly or not at all. Therefore, it is possible, if not probable, that portions of the Twin Lakes are not suitable for, and will not support, wild rice growth due to site specific conditions unrelated to water quality or water depth.

During the 2016 field season, wild rice test seeding plots were inspected for growth of wild rice plants. Floating leaf stage wild rice plants were observed during July 2016 and were confirmed during August 2016. Wild rice plants in at least the floating leaf stage were observed in all three seeded plots in Sandy Lake. Mature, aerial, seed-producing wild rice plants were observed in the Sandy Lake East (SLE) and Sandy Lake Southwest (SLSW) locations with ≥ 200 plants per plot area. Wild rice plants in the floating leaf stage were observed in the Sandy Lake Northwest location but with a density of only about 30 – 40 plants in the entire plot. Wild rice plants in the SLE and SLSW locations produced a sufficient number of seeds to have the capability of limited 'self-seeding' in those areas. Also within Sandy Lake during 2016, the presence of wild rice plants was observed near the Sandy Lake Inflow South location. These plants were not a result of the 2015 wild rice seeding effort, and were classified as natural wild rice growth. These plants were also mature, seed producing plants capable of limited self-seeding in that area. It was estimated that a total of 15 – 20 natural wild rice plants emerged into aerial phase near the mouth of the Sandy Lake Inflow South tributary.

Three plots were also seeded with wild rice in Little Sandy Lake. The test plot near Inflow 1 contained ≥ 100 mature, seed producing wild rice plants. Similar to seed producing plants in two plots in Sandy Lake, seed producing plants in Little Sandy Lake had the capability for limited self-seeding in that plot. Sparse floating leaf wild rice plants were observed in the Little Sandy Northeast test seeding plot, with 7 – 10 plants observed in the entire area. No wild rice plants were observed in the Little Sandy Lake test seeding plot near Inflow 3 (i.e., Little Sandy Lake Northwest).

Regardless of the lake in which they were observed, mature seed-producing wild rice plants appeared healthy. No indications of nutrient deficiencies such as chlorosis, or leaf discoloration associated with potential nitrogen or phosphorus deficiencies, were observed; and no evidence of diseased plants was observed (i.e., fungal brown spot disease).

Minnesota DNR surveys from 1966 indicate that only isolated areas of Little Sandy Lake contained areas of wild rice growth. Sandy Lake is documented to have had wild rice throughout the entire lake, with some areas of denser wild rice growth than others. One criterion of these lakes that has measurably changed since the 1966 survey is water depth throughout the entirety of each lake. A review of the 1966 survey results suggests that water depth throughout the Twin Lakes system did not extend past three feet. Over the course of the Twin Lakes Wild Rice Restoration Opportunities Plan study, water depths within each lake routinely exceeded four feet, and surpass five feet in the most central areas in each lake. During the time period from the 1966 survey and current, wild rice density has decreased to the point of very sparse 'natural' growth to complete absence from both lakes in some years. It is possible that as water depths throughout the Twin Lakes system increased, the ability of wild rice to compete for light during the seedling phenological stage has been adversely influenced resulting in a near complete lack of germination potential. However, given the success of the 2015 seeding studies, other areas of the twin Lakes with similar depth and sediment characteristics should be able to support wild rice growth given a viable seed source/seed bank. Another possibility is that although wild rice seeds historically may have germinated, increasing water depths in early spring could have resulted in decreased success of adult plant development and depletion of the viable wild rice seed bank throughout the Twin Lakes system. Overall, current physical conditions, such as increased water depth and fluctuations, and the presence of competing perennial aquatic vegetation may be preventing significant wild rice growth and development throughout the majority of the Twin Lakes system.

8.7 2017 Wild Rice Seeded Area Observations

All of the areas seeded during October 2015 were revisited during July and August of 2017 to observe follow-on wild rice growth. This follow-on wild rice growth could have resulted from seeds that remained dormant throughout 2016 or from seeds that originated from seed-producing plants observed in 2016. During the 2017 field season, wild rice growth was observed in all previously seeded areas, including the plot near Inflow 3. Wild rice growth/regrowth at the SLE plot was much less than the fairly strong growth observed in 2016, while the growth at the SLSW and SLN plots were relatively unchanged (moderate and sparse, respectively). The LSLS plot once again showed strong wild rice growth, similar to what was observed in 2016, with an observation of approximately 50 seed-producing plants present. One surprising observation was that while the Little Sandy Lake Northeast plot showed little growth in 2016, a large number of plants were observed in 2017, with a visual estimate of approximately 60 seed-producing plants. This wild rice growth likely resulted from seeds that remained dormant throughout 2016. These observations of wild rice growth in areas seeded during 2015 suggest that wild rice seeds can remain viable for multiple years in Little Sandy Lake sediment. Furthermore, due to the observed herbivory of reproductively viable plants during 2016, self-seeding as a source of the growth observed during 2017 in seeded areas is less likely than seeds broadcast during 2015 remaining viable for growth during 2017. Regardless of the source of seed for wild rice plants observed during 2017, in the absence of reproductively viable and successful plants, and self-seeding that exceeds the number of reproductively successful plants, a self-sustaining population of wild rice in these lakes will not develop.

Observations of wild rice plants achieving reproductive maturity in seeded areas suggests that a viable source of wild rice seed no longer exists in the sediment throughout the majority of this system.

9.0 CONCLUSIONS

9.1 SURFACE WATER QUALITY

- Concentrations of certain water quality constituents (e.g., hardness, sulfate, alkalinity and chloride) are elevated with respect to background levels.
- Mining-influenced inputs to the Twin Lakes are primarily in two locations: the Sand River at the inlet to Little Sandy Lake (Inflow 1) and the wetland channel at Inflow 2.
- Implementation of a seep collection and return system on the east side of the Minntac tailings basin resulted in a significant reduction in constituent loading to the Twin Lakes.
- In general, there were no significant differences in surface water quality between areas that supported wild rice growth and other areas of the lakes.

9.2 SEDIMENT QUALITY

- The majority of the sediment within the Twin Lakes is characteristic of that preferred by wild rice (i.e., organic-rich), and contains no identifiable characteristics directly detrimental to wild rice growth, development, or distribution.
- Over the course of two complete growing seasons, mature wild rice plants were observed in all six test seeding plots within the Twin Lakes, demonstrating that the sediment in multiple areas of the Twin Lakes is suitable for wild rice growth.
- The pilot seeding trials demonstrated that wild rice seeds are capable of maintaining viability through multiple winters in the sediment of both Sandy Lake and Little Sandy Lake.
- Certain areas of the Twin Lakes, in particular Little Sandy Lake, appear to have natural sediment characteristics that do not support wild rice growth.
- A review of other wild rice restoration projects indicates that sediment from other lakes with even greater mining industry influences than those measured in the Twin Lakes have been used to successfully grow wild rice plants to reproductive maturity.

9.3 SEDIMENT PORE WATER QUALITY

- Twin Lakes surface water quality did not correlate well with sediment pore water quality. The quality of sediment pore water in the majority of the Twin Lakes is relatively low in sulfide and relatively high in iron.
- The sediment pore water in all six Twin Lakes pilot seeding areas did not appear to adversely impact germination or growth. Over the course of two full wild rice growing seasons, all six seeded areas within the Twin Lakes supported growth of wild rice plants to maturity following a single seeding event.
- Sediment pore water at Inflow 2 is relatively high in sulfide and low in iron, suggesting the influence of anoxic conditions on inflow from the adjacent wetland channel.

- More detailed sediment pore water testing in the vicinity of Inflow 2 indicated that it is a localized condition confined to the extreme western portion of Little Sandy Lake.

9.4 Beaver and Animal Effects

- Beaver influences on the Twin Lakes are evident within the Sand River outflow channel downstream of Sandy Lake. Over the course of the Plan dozens of beavers and a large number of beaver dams were removed from the Sand River outflow channel.
- Beaver dams have an adverse effect on water depths within the Twin Lakes, resulting in deeper lake levels during spring melt (the more critical time for wild rice seedlings), and generally greater water depths in the Twin Lakes throughout the year.
- Continued management of beaver populations and removal of beaver dams within the Sand River outflow channel is imperative for maintenance of water depths conducive to wild rice growth and distribution within the Twin Lakes.

9.5 Aquatic Plant Observations

- Dense cattail growths have taken over large areas of the periphery of the Twin Lakes that contains sediment types and water depths preferable to wild rice growth and distribution.
- Dense growths of cattails in particular can cause depletion of sediment nitrogen, resulting in less preferred sediment and pore water conditions for wild rice growth and distribution. Nutrient limitation can also result in wild rice plants sensitized to known diseases such as fungal brown spot disease.
- Cattails and water lilies/lily pads may also have allelopathic influences on wild rice plants; generally excluding wild rice from areas in which cattails or lily pads are dominant.
- Perennial aquatic plants such as Coontail and pondweed, which can survive under ice and snow during winter, were observed throughout the Twin Lakes. These plants directly compete with wild rice seedlings for resources, specifically light, thus resulting in added stress to, if not mortality of, the seedling.
- Proper management, including removal, of perennial aquatic plants from areas with sediment and water depth characteristics preferred by wild rice is critical to successful restoration and maintenance of a self-sustaining wild rice population in the Twin Lakes.
- Observations indicate that rafts of cattail plants can become dislodged from the edge of typical growth areas, float downstream and accumulate in pinch points in the Sand River, contributing to the obstruction of flow out of the Twin Lakes system.

9.6 Hydrology

- Current Twin Lake water levels are significantly higher than what was reported from the mid-1960s and much greater than optimum for successful wild rice growth and propagation.
- The majority of seepage from the Minntac tailings basin enters the Twin Lakes as surface flow, primarily from the Sand River but also via wetland channels emanating from the northeast portion of the perimeter dike.
- Hydraulic modeling indicates that the Twin Lakes receives less overall inflow from precipitation runoff under current conditions than it did prior to tailings basin construction.

- Hydraulic modeling also indicates that the Sand River channel downstream of the Twin Lakes is capable of effectively moving precipitation runoff out of the system, but that dams and channel debris from cattails and decades of beaver activity is restricting outflow.

10.0 TWIN LAKES WILD RICE RESTORATION OPPORTUNITIES

The overall objective of the Twin Lakes Wild Rice Restoration Opportunities Plan was to evaluate the factors that have or are influencing wild rice growth in the Twin Lakes and identify opportunities to restore wild rice to both Little Sandy and Sandy lakes. Multiple adverse influences on wild rice growth and development have been identified, combined mitigation of which could result in an ultimate opportunity for restoration of wild rice to the Twin Lakes system. These influences are: 1) general lack of a viable wild rice seed bank in the sediment of Little Sandy and Sandy lakes; 2) water depth and fluctuations throughout the Twin Lakes system is not conducive to wild rice growth and development; and 3) competing aquatic vegetation has become established in large areas of the Twin Lakes system. A fourth likely adverse influence on wild rice growth and development in the Twin Lakes system are natural site-specific sediment conditions unrelated to surface water or sediment pore water characteristics. It is very likely that portions of the Twin Lakes, in particular Little Sandy Lake, have sediment characteristics that do not and will not support wild rice growth.

One mitigation tactic for the lack of a viable wild rice seed bank in the Twin Lakes system is to initiate an intensive, multi-year wild rice seeding effort focused initially in those areas with appropriate water depth, sediment type, and general lack of competing vegetation. Any areas seeded as a part of this initiative would likely require protection from herbivorous wildlife. During wild rice restoration efforts undertaken in other areas, protective netting has been placed around the seeded areas to prevent access by water fowl. In addition to aerial netting, underwater fencing such as chicken wire has been used to prevent herbivory from wildlife accessing wild rice plants from aquatic pathways. Successful protection of wild rice plants from herbivory in seeded plots is critical to development of wild rice plants into the final reproductive (seed producing) phenological stage. Since wild rice is an annual plant, self-seeding is required for the following year's growth to ensure a self-sustaining wild rice population. Wild rice seeding efforts have been successfully used in previous studies to restore wild rice to areas from which it had been removed; and currently, wild rice seeding efforts are being used by Native American groups to restore wild rice to lakes under their respective management control.

Maintaining a more optimal water depth with minimal fluctuations throughout the growing season for wild rice growth and development within the Twin Lakes system is equally critical to successful wild rice restoration. Ideally, water depth during the late-spring would not be in excess of 2.0 feet in which wild rice had been seeded, or areas intended for wild rice restoration efforts. This is due to the need for light during the sensitive seedling phenological stage, the more typical limiting resource for wild rice seedlings. Subsequently, water depth in areas of desired wild rice growth and development would be managed to not exceed 2.0 feet during the floating leaf phenological stage; and no more than 3.0 feet following development of wild rice plants into the aerial phenological stage. Ideally, water depth would be managed to not exceed 2.0 – 2.5 feet throughout the wild rice growing season. Typically, the shallower the water depth in wild rice areas, the more successful individual plants will be with respect to growth and development; and overall individual plants will produce more seeds. This is due to more complete development of the primary stem, and the increased likelihood of ‘tillering’ (production of additional seed-producing stems) by individual plants.

Finally, another primary adverse influence observed in the Twin Lakes and related to the growth and propagation of wild rice is the presence of aquatic vegetation competing for limited resources. Removal of competing aquatic vegetation in areas intended for wild rice restoration would be critical. Some types of aquatic vegetation such as cattails, lily pads, and Coontail may become more widely and densely established than wild rice in areas of appropriate water depth and sediment type conducive for wild rice growth and development. This can substantially decrease the available area, light, and nutrient resources available, and needed, for successful wild rice restoration. Competing aquatic plants can adversely affect wild rice in several ways. Cattails and lily pads are adversely allelopathic to wild rice – in areas where dense growths of cattails and lily pads exist, wild rice plants tend to be excluded. Longer-term adverse influences on successful wild rice restoration may be associated with nutrient depletion, specifically nitrogen, in areas of dense aquatic plant growth (i.e., cattails). Therefore, removal and long-term (multi-year) management of competing aquatic vegetation is critical to successful restoration of wild rice.

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APPENDIX A

TWIN LAKES INFLOW / OUTFLOW WATER SAMPLING DATA

Twin Lakes
Inflow / Outflow Sampling Event

5/28/2014

Analytes - Cations	**Little Sandy Inflow 1**	**Little Sandy Inflow 2**	**Little Sandy Inflow 3**	**Sand River Outflow Trib 1**	**Sand River Outflow 2**	**Reporting Limits**	**Reporting Units**
Aluminum	<20.0	<20.0	<20.0	**41.9**	**32.9**	20.0	ug/L
Arsenic	<0.65	<0.65	<0.65	**1.2**	<0.65	0.65	ug/L
Barium	**24.9**	**19.4**	**22.3**	**28.2**	**18.9**	10.0	ug/L
Cadmium	<0.2	<0.2	<0.2	<0.2	<0.2	0.2	ug/L
Calcium	**39.1**	**26.0**	**24.6**	**10.7**	**19.1**	0.5	mg/L
Chromium	<5.0	<5.0	<5.0	<5.0	<5.0	5.0	ug/L
Cobalt	<5.0	<5.0	<5.0	<5.0	<5.0	5.0	ug/L
Copper	<5.0	<5.0	<5.0	<5.0	<5.0	5.0	ug/L
Gallium	<1.0	<1.0	<1.0	<1.0	<1.0	1.0	ug/L
Iron	**1030**	**475**	**224**	**3590**	**857**	50.0	ug/L
Lead	<0.5	<0.5	<0.5	<0.5	<0.5	0.5	ug/L
Magnesium	**47.6**	**34.4**	**36.1**	**3.7**	**23.7**	0.5	mg/L
Manganese	**95.2**	**23.9**	**25.5**	**258**	**67.6**	10.0	ug/L
Molybdenum	<10.0	<10.0	<10.0	<10.0	<10.0	10.0	ug/L
Nickel	<5.0	<5.0	<5.0	<5.0	<5.0	5.0	ug/L
Phosphorus	<0.10	<0.10	<0.10	<0.10	<0.10	0.10	mg/L
Potassium	**6.5**	**4.0**	**3.3**	**2.1**	**3.2**	0.25	mg/L
Rubidium	**2.8**	**2.5**	**3.0**	**1.8**	**2.4**	1.0	ug/L
Silver	<0.20	<0.20	<0.20	<0.20	<0.20	0.20	ug/L
Sodium	**19.5**	**12.0**	**9.3**	**3.2**	**9.3**	0.50	mg/L
Strontium	**135**	**85.5**	**78.2**	**44.2**	**66.5**	5.0	ug/L
Zinc	<10.0	<10.0	<10.0	<10.0	<10.0	10.0	ug/L
Analytes - Anions							
Chloride	**9.5**	**15.8**	**27.9**	**6.3**	**13.3**	1.0	mg/l
Nitrate as N	<0.20	<0.20	<0.20	<0.20	<0.20	0.20	mg/L
Nitrogen	<1.0	<1.0	<1.0	<1.0	<1.0	1.0	mg/L
Nitrogen, Kjeldahl, Total	<0.50	**0.68**	**0.59**	**0.56**	**0.52**	0.50	mg/L
Nitrogen, NO2 plus NO3	<0.10	<0.10	<0.10	<0.10	<0.10	0.10	mg/L
Ammonia as Nitrogen	<0.050	<0.050	<0.050	<0.050	<0.050	0.050	mg/L
Unionized Ammonia as N2	<6.9	<0.4	<4.6	<2.0	<8.2	varies	ug/L
Sulfate	**107**	**123**	**9.9**	<2.0	**84.3**	2.0	mg/L
Analytes - Other							
Total Dissolved Solids	**484**	**333**	**318**	**138**	**267**	10.0	mg/L
Alkalinity, Total as HCO3	**117**	**84.2**	**110**	**41.2**	**65.1**	12.2	mg/L
Alkalinity, Total as CaCO3	**95.7**	**69.0**	**90.2**	**33.8**	**53.4**	10.0	mg/L
Dissolved Organic Carbon	**13.5**	**15.6**	**20.2**	**20.9**	**16.7**	1.0	mg/L
Total Hardness by 2340B	**294**	**207**	**210**	**41.8**	**145**	10.0	mg/L
UV Absorbance @ 254 nm	**0.499**	**0.561**	**0.781**	**0.992**	**0.570**	0.009	cm^{-1}
SUVA	**3.7**	**3.6**	**3.9**	**4.7**	**4.0**	0.1	L/mg*m
YSI Data							
pH	**8.6**	**7.6**	**8.5**	**8.1**	**8.6**	± 0.2	Units
Temperature	**18.1**	**9.4**	**15.9**	**16.8**	**20.5**	± 0.1	ºC
Specific Conductance	**569**	**261**	**364**	**84**	**314**	± 1%	uS/cm
Dissolved Oxygen	**3.9**	**2.0**	**4.9**	**4.7**	**8.5**	± 0.01	mg/L
Calculations							
Total Cations	**6.9**	4.8	4.7	NM	3.4	-	meq
Total Anions	**4.4**	4.4	2.8	NM	3.2	-	meq
Calculated TDS	**348**	301	222	NM	219	-	mg/L
Actual TDS - Calc. (diff)	**136.4**	32.4	96.0	NM	47.5	-	mg/L
% Na to Tot. Cations	**10.9**	10.9	8.6	NM	11.8	-	%

Bold Print indicates the sample is above the detection limit
"<" indicates value below reporting limit
NM indicates that the analyte was not measured
[blue shading] Exceeds MN WQ Standard

Twin Lakes
Inflow / Outflow Sampling Event

6/23/2014

	Little Sandy Inflow 1	Little Sandy Inflow 2	Little Sandy Inflow 3	Sand River Outflow Trib 1	Trib from Culvert	Sand River Outflow 2	Little Sandy Lake	Sandy Lake	Reporting Limits	Reporting Units
Analytes - Cations										
Aluminum	**52.0**	**27.7**	<20.0	**56.0**	**83.3**	**35.1**	**30.6**	**37.7**	20.0	ug/L
Arsenic	<0.50	<0.50	<0.50	**1.0**	**1.0**	**0.51**	<0.50	<0.50	0.50	ug/L
Barium	**23.1**	**23.8**	**26.1**	**27.7**	**27.8**	**22.6**	**23.3**	**21.4**	10.0	ug/L
Cadmium	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	<0.2	0.20	ug/L
Calcium	**37.5**	**30.2**	**30.0**	**11.6**	**11.8**	**24.0**	**29.5**	**25.3**	0.50	mg/L
Chromium	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	5.0	ug/L
Cobalt	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	5.0	ug/L
Copper	<5.0	<5.0	<5.0	<5.0	**11.4**	<5.0	<5.0	<5.0	5.0	ug/L
Gallium	<1.0	<1.0	<1.0	<1.0	NM	<1.0	<1.0	<1.0	1.0	ug/L
Iron	**772**	**672**	**219**	**4590**	**4930**	**1050**	**717**	**800**	50.0	ug/l
Lead	<0.5	<0.5	<0.5	<0.5	**12.8**	<0.5	<0.5	<0.5	0.50	ug/L
Magnesium	**44.3**	**37.7**	**41.0**	**3.9**	**3.9**	**28.4**	**36.5**	**30.5**	0.50	mg/L
Manganese	**70.8**	**32.0**	ND	**160**	**195**	**41.8**	**42.7**	**42.5**	10.0	ug/L
Molybdenum	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0	<10.0	10.0	ug/L
Nickel	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	5.0	ug/L
Phosphorus	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	0.10	mg/L
Potassium	**4.09**	**3.68**	**2.22**	**1.21**	**1.25**	**3.24**	**3.67**	**3.51**	0.25	mg/L
Rubidium	**2.0**	**2.5**	**2.5**	**1.2**	NM	**2.5**	**2.6**	**2.5**	1.0	ug/L
Silver	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	0.20	ug/L
Sodium	**18.4**	**13.1**	**10.3**	**3.1**	**3.2**	**11.0**	**12.9**	**11.8**	0.50	mg/L
Strontium	**133**	**101**	**95.9**	**48.7**	**50.2**	**82.5**	**98.5**	**86.3**	5.0	ug/L
Zinc	<10.0	<10.0	<10.0	<10.0	**172**	<10.0	<10.0	<10.0	10.0	ug/L
Analytes - Anions										
Chloride	**25.5**	**16.5**	**8.0**	**6.1**	**6.4**	**15.3**	**17.1**	**15.7**	1.0	mg/L
Nitrate as N	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	<0.20	0.20	mg/L
Nitrogen (Total)	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	1.0	mg/L
Nitrogen, Kjeldahl, Total	**0.55**	**0.66**	**0.70**	**0.74**	**0.92**	**0.61**	**0.72**	**0.74**	0.50	mg/L
Nitrogen, NO2 plus NO3	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	0.10	mg/L
Ammonia as Nitrogen	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	<0.050	0.050	mg/L
Unionized Ammonia as N2	<.020	<0.13	<0.48	<0.07	<0.11	<0.47	<.094	<1.1	varies	ug/L
Sulfate	**159**	**119**	**91.3**	<2.0	<2.0	**93.6**	**121**	**98.6**	2.0	mg/L
Analytes - Other										
Total Dissolved Solids	**431**	**374**	**368**	**147**	**190**	**324**	**366**	**315**	20.0	mg/L
Alkalinity, Total as HCO3	**127**	**111**	**161**	**42.0**	**40.9**	**88.6**	**116**	**90.4**	12.2	mg/L
Alkalinity, Total as CaCO3	**104**	**90.6**	**132**	**34.4**	**33.5**	**72.6**	**95.3**	**74.1**	10.0	mg/l
Dissolved Organic Carbon	**20.4**	**22.3**	**28.6**	**27.8**	**28.0**	**21.8**	**22.0**	**22.0**	1.0	mg/L
Total Hardness by 2340B	**276**	**231**	**244**	**44.8**	**45.3**	**177**	**224**	**189**	10.0	mg/L
UV Absorbance @ 254 nm	**0.846**	**0.990**	**1.4**	**1.7**	NM	**1.1**	**0.958**	**0.938**	0.009	cm^{-1}
SUVA	**4.1**	**4.4**	**4.7**	**6.0**	NM	**5**	**4.4**	**4.3**	0.1	L/mg*m
YSI Data										
pH	**7.0**	**6.8**	**7.3**	**6.5**	**6.7**	**7.3**	**7.6**	**7.7**	± 0.2	Units
Temperature	**20.9**	**20.7**	**21.6**	**20.0**	**22.8**	**21.6**	**23.6**	**22.6**	± 0.1	ºC
Specific Conductance	**612**	**500**	**471**	**98**	**96**	**380**	**504**	**387**	± 1%	uS/cm
Dissolved Oxygen	NM	NM	NM	NM	NM	NM	NM	NM		
Calculations										
Total Cations	6.5	5.3	5.4	NM	1.3	4.1	NM	NM	-	meq
Total Anions	6.1	4.8	4.8	NM	0.8	3.9	NM	NM	-	meq
Calculated TDS	417	332	345	NM	69	266	NM	NM	-	mg/L
Actual TDS - Calc. (diff)	13.9	41.9	23.2	NM	120.7	58.2	NM	NM	-	mg/L
% Na to Tot. Cations	12.4	10.8	8.3	NM	11.0	11.6	NM	NM	-	%

Bold Print indicates the sample is above the detection limit
"<" indicates value below reporting limit
NM indicates that the analyte was not measured
Exceeds MN WQ Standard

Twin Lakes
Inflow / Outflow Sampling Event

7/21/2014

Analytes - Cations	**Little Sandy Inflow 1**	**Little Sandy Inflow 2**	**Little Sandy Inflow 3**	**Sand River Outflow Trib 1**	**Trib from Culvert**	**Sand River Outflow 2**	**Reporting Limits**	**Reporting Units**
Aluminum	**35.5**	**25.4**	<20.0	**65.5**	**72.8**	**30.3**	20.0	ug/L
Arsenic	<0.50	**0.98**	**0**	**1.3**	**1.1**	**0.62**	0.5	ug/L
Barium	**40.4**	**29.0**	**30.4**	**40.2**	**37.9**	**25.6**	10.0	ug/L
Cadmium	NM	NM	NM	NM	<0.2	NM	0.20	ug/L
Calcium	**59.2**	**33.0**	**33.9**	**15.5**	**14.9**	**23.9**	0.50	mg/L
Chromium	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	5.0	ug/L
Cobalt	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	5.0	ug/L
Copper	<5.0	<5.0	<5.0	<5.0	<5.0	<5.0	5.0	ug/L
Gallium	NM	NM	NM	NM	NM	NM	1.0	ug/L
Iron	**904**	**612**	**459**	**7290**	**7520**	**1470**	50.0	ug/L
Lead	NM	NM	NM	NM	<0.5	NM	0.50	ug/L
Magnesium	**78.1**	**42.4**	**43.8**	**5.1**	**4.8**	**26.5**	0.50	mg/L
Manganese	**218**	**63.8**	113	**337**	**300**	**27.6**	10.0	ug/L
Molybdenum	NM	NM	NM	NM	NM	NM	10.0	ug/L
Nickel	NM	NM	NM	NM	NM	NM	5.0	ug/L
Phosphorus	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	0.10	mg/L
Potassium	**2.5**	**3.3**	**3.5**	**0.91**	**0.93**	**2.8**	0.25	mg/L
Rubidium	**2.3**	**2.5**	**2.5**	**1.4**	ND	**2.3**	1.0	ug/L
Silver	NM	NM	NM	NM	NM	NM	0.20	ug/L
Sodium	**32.3**	**14.7**	**14.9**	**3.7**	**3.7**	**10.2**	0.50	mg/L
Strontium	**222**	**116**	**120**	**67.0**	**63.4**	**87.9**	5.0	ug/L
Zinc	NM	NM	NM	NM	<10.0	NM	10.0	ug/L
Analytes - Anions								
Chloride	**43.8**	**17.8**	**18.5**	**7.8**	**8.3**	**15.6**	1.0	mg/l
Nitrate as N	NM	NM	NM	NM	NM	NM	0.20	mg/L
Nitrogen	NM	NM	NM	NM	NM	NM	1.0	mg/L
Nitrogen, Kjeldahl, Total	<0.50	**1.2**	**1.3**	**1.5**	**1.2**	**0.99**	0.50	mg/L
Nitrogen, NO2 plus NO3	NM	NM	NM	NM	NM	NM	0.10	mg/L
Ammonia as Nitrogen	NM	NM	NM	NM	NM	NM	0.050	mg/L
Unionized Ammonia as N2	NM	NM	NM	NM	NM	NM	varies	ug/L
Sulfate	**277**	**113**	**119**	<2.0	<2.0	**87.0**	2.0	mg/L
Analytes - Other								
Total Dissolved Solids	**776**	**440**	**425**	**145**	**192**	**352**	10.0	mg/L
Alkalinity, Total as HCO3	**218**	**159**	**159**	**55.8**	**51.0**	**111**	12.2	mg/L
Alkalinity, Total as CaCO3	**179**	**130**	**130**	**45.7**	**41.8**	**91.2**	10.0	mg/L
Dissolved Organic Carbon	**19.8**	**26.5**	**24.8**	**28.9**	**30.4**	**26.2**	1.0	mg/L
Total Hardness by 2340B	**469**	**257**	**265**	**59.6**	**57.0**	**169**	10.0	mg/L
UV Absorbance @ 254 nm	**0.885**	**1.2**	**1.1**	**1.8**	**1.9**	**1.1**	0.009	cm^{-1}
SUVA	**4.5**	**4.6**	**4.4**	**6.2**	**1.3**	**4.4**	0.1	L/mg*m
YSI Data								
pH	**7.0**	**6.6**	**7.3**	**6.7**	**6.6**	**7.6**	± 0.2	Units
Temperature	**21.7**	**23.4**	**25.2**	**21.3**	**23.9**	**23.1**	± 0.1	ºC
Specific Conductance	**963**	**512**	**558**	**132**	**118**	**414**	± 1%	uS/cm
Dissolved Oxygen	NM	NM	NM	NM	NM	NM		
Calculations								
Total Cations	10.9	5.9	6.1	NM	1.6	3.9	-	meq
Total Anions	10.6	5.5	5.7	NM	1.0	4.1	-	meq
Calculated TDS	713	385	394	NM	86	280	-	mg/L
Actual TDS - Calc. (diff)	63.1	55.3	30.9	NM	105.7	72.2	-	mg/L
% Na to Tot. Cations	12.9	10.9	10.7	NM	10.0	11.3	-	%

Bold Print indicates the sample is above the detection limit
"<" indicates value below reporting limit
NM indicates that the analyte was not measured
[blue shading] Exceeds MN WQ Standard

Twin Lakes
Inflow / Outflow Sampling Event

8/22/2014

Analytes - Cations	**Little Sandy Inflow 1**	**Little Sandy Inflow 2**	**Little Sandy Inflow 3**	**Sand River Outflow Trib 1**	**Trib from Culvert**	**Sand River Outflow 2**	**Reporting Limits**	**Reporting Units**
Aluminum	**28.9**	<20.0	<20.0	**28.6**	**39.1**	<20.0	20.0	ug/L
Arsenic	<0.50	<0.50	<0.50	**1.2**	**0.85**	**0.71**	0.5	ug/L
Barium	**58.9**	**35.4**	**35.5**	**35.9**	**38.2**	**31.2**	10.0	ug/L
Cadmium	NM	NM	NM	NM	<0.2	NM	0.2	ug/L
Calcium	**85.9**	**40.5**	**40.0**	**15.2**	**15.5**	**22.3**	0.5	mg/L
Chromium	NM	NM	NM	NM	<5.0	NM	5.0	ug/L
Cobalt	NM	NM	NM	NM	<5.0	NM	5.0	ug/L
Copper	NM	NM	NM	NM	<5.0	NM	5.0	ug/L
Gallium	**1.0**	<1.0	<1.0	<1.0	<1.0	<1.0	1.0	ug/L
Iron	**1980**	**232**	**217**	**5450**	**5530**	1260	50.0	ug/L
Lead	NM	NM	NM	NM	<0.5	NM	0.5	ug/L
Magnesium	**121**	**51.7**	**51.2**	**5.0**	**5.2**	21.3	0.5	mg/L
Manganese	**347**	**92.2**	**110**	**297**	**229**	138	10.0	ug/L
Molybdenum	NM	NM	NM	NM	NM	NM	10.0	ug/L
Nickel	NM	NM	NM	NM	NM	NM	5.0	ug/L
Phosphorus	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	0.10	mg/L
Potassium	**4.6**	**3.8**	**3.7**	**1.2**	**1.3**	2.4	0.25	mg/L
Rubidium	**2.9**	**2.6**	**2.6**	**1.0**	**1.1**	1.7	1.0	ug/L
Silver	NM	NM	NM	NM	NM	NM	0.20	ug/L
Sodium	**50.3**	**18.6**	**18.4**	**4.4**	**4.5**	**8.8**	0.50	mg/L
Strontium	**307**	**137**	**137**	**61.5**	**62.7**	**79.1**	5.0	ug/L
Zinc	NM	NM	NM	NM	<10.0	NM	10.0	ug/L
Analytes - Anions								
Chloride	**75.6**	**24.5**	**24.4**	**12.6**	**12.2**	**14.6**	1.0	mg/l
Nitrate as N	NM	NM	NM	NM	NM	NM	0.20	mg/L
Nitrogen	NM	NM	NM	NM	NM	NM	1.0	mg/L
Nitrogen, Kjeldahl, Total	**0.64**	**0.95**	**1.8**	<0.50	<0.50	<0.50	0.50	mg/L
Nitrogen, NO2 plus NO3	NM	NM	NM	NM	NM	NM	0.10	mg/L
Ammonia as Nitrogen	NM	NM	NM	NM	NM	NM	0.050	mg/L
Unionized Ammonia as N2	NM	NM	NM	NM	NM	NM	varies	ug/L
Sulfate	**419**	**143**	**142**	<2.0	<2.0	**44.6**	2.0	mg/L
Analytes - Other								
Total Dissolved Solids	**1030**	**438**	**447**	**130**	**125**	**221**	10.0	mg/L
Alkalinity, Total as HCO3	**312**	**185**	**185**	**55.3**	**56.0**	**107**	12.2	mg/L
Alkalinity, Total as CaCO3	**256**	**152**	**152**	**45.3**	**45.9**	**88.0**	10.0	mg/L
Dissolved Organic Carbon	**20.5**	**25.7**	**25.4**	**17.1**	**19.6**	**23.6**	1.0	mg/L
Total Hardness by 2340B	**712**	**314**	**311**	**58.6**	**60.0**	**143**	10.0	mg/L
UV Absorbance @ 254 nm	**0.930**	**0.945**	**0.912**	**1.0**	**1.0**	**0.958**	0.009	cm^{-1}
SUVA	**4.5**	**3.7**	**3.6**	**5.8**	**5.2**	**4.1**	0.1	L/mg*m
YSI Data								
pH	**7.2**	**8.4**	**8.2**	**6.6**	**6.6**	**7.0**	± 0.2	Units
Temperature	**18.4**	**22.7**	**22.1**	**18.5**	**17.4**	**19.9**	± 0.1	ºC
Specific Conductance	**1347**	**632**	**641**	**138**	**137**	**307**	± 1%	uS/cm
Dissolved Oxygen	NM	NM	NM	NM	NM	NM		
Calculations								
Total Cations	16.6	7.2	7.1	NM	**1.6**	**3.4**	-	meq
Total Anions	16.0	6.8	6.8	NM	**1.0**	**3.1**	-	meq
Calculated TDS	1072	469	467	NM	**91**	**223**	-	mg/L
Actual TDS - Calc. (diff)	-41.7	-30.8	-20.3	NM	**34.2**	**-2.3**	-	mg/L
% Na to Tot. Cations	13.2	11.2	11.2	NM	**12.0**	**11.4**	-	%

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(blue shading) Exceeds MN WQ Standard

Twin Lakes
Inflow / Outflow Sampling Event

9/11/2014

Analytes - Cations	Little Sandy Inflow 1	Little Sandy Inflow 2	Little Sandy Inflow 3	Sand River Outflow Trib 1	Trib from Culvert	Sand River Outflow 2	Reporting Limits	Reporting Units
Aluminum	**21.2**	<20.0	<20.0	**31.5**	**42.3**	<20.0	20.0	ug/L
Arsenic	**0.75**	**1.1**	**0.57**	**0.68**	<0.50	**0.92**	0.50	ug/L
Barium	**43**	**31.9**	**31.5**	**24.3**	**28.2**	**26.4**	10.0	ug/L
Cadmium	NM	NM	NM	NM	<0.2	NM	0.2	ug/L
Calcium	**84.4**	**39.9**	**38.7**	**11.4**	**12.3**	**20.3**	0.5	mg/L
Chromium	NM	NM	NM	NM	<5.0	NM	5.0	ug/L
Cobalt	NM	NM	NM	NM	<5.0	NM	5.0	ug/L
Copper	NM	NM	NM	NM	<5.0	NM	5.0	ug/L
Gallium	**<1.0**	<1.0	<1.0	<1.0	<1.0	<1.0	1.0	ug/L
Iron	**229**	**169**	**173**	**2830**	**3380**	**803**	50.0	ug/L
Lead	NM	NM	NM	NM	<0.5	NM	0.5	ug/L
Magnesium	**124**	**52.8**	**51.2**	3.8	**4.2**	**19.7**	0.5	mg/L
Manganese	**66.3**	**62.7**	**77.0**	**113**	**111**	**66.6**	10.0	ug/L
Molybdenum	NM	NM	NM	NM	NM	NM	10.0	ug/L
Nickel	NM	NM	NM	NM	NM	NM	5.0	ug/L
Phosphorus	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	0.10	mg/L
Potassium	**7.4**	**3.6**	**3.4**	**1.3**	**1.5**	**2.2**	0.25	mg/L
Rubidium	**3.2**	**2.4**	**2.3**	**1.1**	**1.1**	**1.6**	1.0	ug/L
Silver	NM	NM	NM	NM	NM	NM	0.20	ug/L
Sodium	**50.9**	**19.5**	**18.8**	**3.8**	**4.1**	**8.3**	0.50	mg/L
Strontium	**302**	**142**	**138**	**47.3**	**52.7**	**76.0**	5.0	ug/L
Zinc	NM	NM	NM	NM	<10.0	NM	10.0	ug/L
Analytes - Anions								
Chloride	**86.3**	**28.5**	**27.7**	**11.1**	**11.7**	**15.1**	1.0	mg/l
Nitrate as N	NM	NM	NM	NM	NM	NM	0.20	mg/L
Nitrogen	NM	NM	NM	NM	NM	NM	1.0	mg/L
Nitrogen, Kjeldahl, Total	**0.75**	**0.85**	**0.82**	**0.53**	<0.50	**0.90**	0.50	mg/L
Nitrogen, NO2 plus NO3	NM	NM	NM	NM	NM	NM	0.10	mg/L
Ammonia as Nitrogen	NM	NM	NM	NM	NM	NM	0.050	mg/L
Unionized Ammonia as N2	NM	NM	NM	NM	NM	NM	varies	ug/L
Sulfide	<5.0	<5.0	<5.0	<5.0	<5.0	NM	5.0	mg/L
Sulfate	**465**	**162**	**156**	<2.0	<2.0	**48.4**	2.0	mg/L
Analytes - Other								
Total Dissolved Solids	**1080**	**465**	**476**	**132**	**134**	**255**	10.0	mg/L
Alkalinity, Total as HCO3	**316**	**194**	**193**	**41.6**	**46.2**	**99.1**	12.2	mg/L
Alkalinity, Total as CaCO3	**259**	**159**	**158**	**34.1**	**37.9**	**81.2**	10.0	mg/L
Dissolved Organic Carbon	**14.8**	**22.5**	**22.6**	**16.8**	**16.2**	**20.8**	1.0	mg/L
Total Hardness by 2340B	**721**	**317**	**307**	**44.1**	**48.0**	**132**	10.0	mg/L
UV Absorbance @ 254 nm	**0.550**	**0.818**	**0.838**	**0.812**	**0.814**	**0.826**	0.009	cm^{-1}
SUVA	**3.7**	**3.6**	**2.3**	**4.8**	**5.0**	4.0	0.1	L/mg*m
YSI Data								
pH	**7.3**	**7.9**	**7.6**	**6.6**	**6.6**	**7.1**	± 0.2	Units
Temperature	**11.4**	**13.7**	**13.8**	**9.8**	**11.8**	**12.2**	± 0.1	ºC
Specific Conductance	**1479**	**689**	**678**	**99**	**120**	**308**	± 1%	uS/cm
Dissolved Oxygen	NM	NM	NM	NM	NM	NM		
Calculations								
Total Cations	16.8	7.3	7.1	NM	1.3	3.1	-	meq
Total Anions	17.3	7.4	7.2	NM	0.8	3.1	-	meq
Calculated TDS	1135	501	490	NM	74	215	-	mg/L
Actual TDS - Calc. (diff)	-55.0	-36.4	-13.6	NM	59.7	40.2	-	mg/L
% Na to Tot. Cations	13.2	11.6	11.6	NM	13.7	11.7	-	%

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NM indicates that the analyte was not measured
[blue shading] Exceeds MN WQ Standard

Shaded (exceeds MN WQ Standard): Sulfate – Inflow 1, Inflow 2, Inflow 3, Sand River Outflow 2; Total Dissolved Solids – Inflow 1; Alkalinity, Total as HCO3 – Inflow 1; Total Hardness by 2340B – Inflow 1; Specific Conductance – Inflow 1.

Twin Lakes
Inflow / Outflow Sampling Event

10/13/2014

	Little Sandy Inflow 1	Little Sandy Inflow 2	Little Sandy Inflow 3	Sand River Outflow Trib 1	Trib from Culvert	Sand River Outflow 2	Reporting Limits	Reporting Units
Analytes - Cations								
Aluminum	**24.5**	**41.7**	**23.3**	**28.8**	**23.3**	**22.8**	20.0	ug/L
Arsenic	<0.50	<0.50	**0.53**	**0.86**	**0.63**	**0.81**	0.50	ug/L
Barium	**37.7**	**20.3**	**29.0**	**22.9**	**23.9**	**28.1**	10.0	ug/L
Cadmium	NM	NM	NM	NM	<0.2	NM	0.2	ug/L
Calcium	**95.0**	**25.4**	**44.4**	**10.6**	**11.0**	**34.8**	0.5	mg/L
Chromium	NM	NM	NM	NM	<5.0	NM	5.0	ug/L
Cobalt	NM	NM	NM	NM	<5.0	NM	5.0	ug/L
Copper	NM	NM	NM	NM	<5.0	NM	5.0	ug/L
Gallium	<1.0	<1.0	<1.0	<1.0	<1.0	<1.0	1.0	ug/L
Iron	**245**	**1100**	**399**	**2430**	**1870**	**409**	50.0	ug/L
Lead	NM	NM	NM	NM	<0.5	NM	0.5	ug/L
Magnesium	**140**	**37.5**	**62.3**	**3.9**	**4.0**	**44.9**	0.5	mg/L
Manganese	**54.4**	**64.3**	**127**	**119**	**82.3**	**47.1**	10.0	ug/L
Molybdenum	NM	NM	NM	NM	NM	NM	10.0	ug/L
Nickel	NM	NM	NM	NM	NM	NM	5.0	ug/L
Phosphorus	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	0.10	mg/L
Potassium	**11.4**	**1.7**	**3.7**	**1.7**	**1.9**	**3.4**	0.25	mg/L
Rubidium	**4.0**	**1.5**	**2.4**	**1.1**	**1.4**	**2.3**	1.0	ug/L
Silver	NM	NM	NM	NM	NM	NM	0.20	ug/L
Sodium	**58.2**	**15.2**	**23.1**	**4.2**	**4.5**	**17.8**	0.50	mg/L
Strontium	**327**	**87.5**	**154**	**42.7**	**44.2**	**123**	5.0	ug/L
Zinc	NM	NM	NM	NM	<10.0	NM	10.0	ug/L
Analytes - Anions								
Chloride	**103**	**24.9**	**30.1**	**12.2**	**13.1**	**25.8**	1.0	mg/l
Nitrate as N	NM	NM	NM	NM	NM	NM	0.20	mg/L
Nitrogen	NM	NM	NM	NM	NM	NM	1.0	mg/L
Nitrogen, Kjeldahl, Total	**0.64**	**1.2**	**1.2**	**0.72**	<0.50	**1.2**	0.50	mg/L
Nitrogen, NO2 plus NO3	NM	NM	NM	NM	NM	NM	0.10	mg/L
Ammonia as Nitrogen	NM	NM	NM	NM	NM	NM	0.050	mg/L
Unionized Ammonia as N2	NM	NM	NM	NM	NM	NM	varies	ug/L
Sulfate	**540**	**89.3**	**154**	<2.0	**3.1**	**124**	2.0	mg/L
Analytes - Other								
Total Dissolved Solids	**1170**	**369**	**489**	**98.0**	**114**	**375**	10.0	mg/L
Alkalinity, Total as HCO3	**309**	**309**	**229**	**40.1**	**39.2**	**157**	12.2	mg/L
Alkalinity, Total as CaCO3	**253**	**253**	**188**	**32.9**	**32.1**	**129**	10.0	mg/L
Dissolved Organic Carbon	**10.3**	**23.6**	**25.0**	**8.0**	**8.5**	**21.8**	1.0	mg/L
Total Hardness by 2340B	**814**	**218**	**368**	**42.4**	**43.7**	**272**	10.0	mg/L
UV Absorbance @ 254 nm	**0.320**	**0.864**	**0.896**	**0.346**	**0.360**	**0.786**	0.009	cm^{-1}
SUVA	**3.1**	**3.7**	**4.2**	**4.3**	**4.2**	**3.6**	0.1	L/mg*m
YSI Data								
pH	**7.5**	**7.4**	**6.9**	**6.8**	**6.8**	**7.8**	± 0.2	Units
Temperature	**7.2**	**7.7**	**7.3**	**7.4**	**7.3**	**7.9**	± 0.1	ºC
Specific Conductance	**1620**	**679**	**403**	**117**	**116**	**561**	± 1%	uS/cm
Dissolved Oxygen	NM	NM	NM	NM	NM	NM		
Calculations								
Total Cations	19.1	5.1	8.5	NM	1.2	6.3	-	meq
Total Anions	19.3	7.7	7.9	NM	0.7	6.0	-	meq
Calculated TDS	1257	505	549	NM	66	410	-	mg/L
Actual TDS - Calc. (diff)	-87.2	-136.0	-59.7	NM	47.9	-34.7	-	mg/L
% Na to Tot. Cations	13.3	13.0	11.9	NM	16.4	12.3	-	%

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(shaded) Exceeds MN WQ Standard

Twin Lakes
Inflow / Outflow Sampling Event

5/22/2015

	Little Sandy Inflow 1	Little Sandy Inflow 2	Little Sandy Inflow 3	Little Sandy Middle	Sandy Middle	Twin Lakes Outflow	Culvert Inflow	Reporting Limits	Reporting Units
Analytes - Cations									
Aluminum	**29.7**	**15.2**	<10.0	NM	NM	**16.4**	**28.4**	10.0	ug / L
Arsenic	<0.50	<0.50	<0.50	NM	NM	<0.50	<0.50	0.50	ug / L
Barium	**19.0**	**23.7**	**26.5**	NM	NM	**24.4**	**17.5**	10.0	ug / L
Calcium	**38.4**	**42.6**	**34.0**	**45.2**	**40.7**	**41.6**	**9.0**	0.50	mg / L
Iron	**407**	**238**	**80**	NM	NM	**287**	**1180**	50.0	ug / L
Magnesium	**53**	**62.6**	**55.3**	**64.9**	**57.4**	**58**	**3.2**	0.50	mg / L
Manganese	**31.3**	**32.8**	**14.8**	NM	NM	**32.6**	**46.1**	10.0	ug / L
Phosphorus	<0.10	<0.10	<0.10	NM	NM	<0.10	<0.10	0.10	mg / L
Potassium	**6.27**	**5.73**	**3.38**	NM	NM	**6.03**	**1.88**	0.25	mg / L
Rubidium	**2.8**	**3.0**	**2.6**	NM	NM	**2.8**	**1.4**	1.0	ug / L
Sodium	**21.3**	**20.8**	**13.9**	**23**	**22.2**	**22.2**	**3.7**	0.50	mg / L
Strontium	**129**	**133**	**101**	NM	NM	**136**	**34.3**	10.0	ug / L
Analytes - Anions									
Chloride	**31.4**	**29.6**	**15.8**	**33.9**	**33.4**	**33.4**	**8.2**	1.0	mg / l
Nitrogen, Kjeldahl, Total	**0.62**	**0.73**	**0.59**	NM	NM	**0.57**	<0.50	0.50	mg / L
Ammonia as Nitrogen	NM	NM	NM	NM	NM	NM	NM	0.050	mg / L
Unionized Ammonia as N2	NM	NM	NM	NM	NM	NM	NM	varies	ug/L
Sulfate	**191**	**216**	**182**	**223**	**196**	**200**	**2.5**	2.0	mg / L
Analytes - Other									
Total Dissolved Solids	**457**	**506**	**418**	**530**	**466**	**473**	**97**	10.0	mg / L
Alkalinity, Total as HCO3	**114**	**128**	**113**	**134**	**117**	**119**	**30.0**	12.2	mg / L
Alkalinity, Total as CaCO3	**93.1**	**105**	**92.6**	**110**	**96.1**	**97.3**	**24.6**	10.0	mg / L
Dissolved Organic Carbon	**12.5**	**12.9**	**14.7**	NM	NM	**10.8**	**11.3**	1.0	mg / L
Total Hardness by 2340B	**314**	**364**	**313**	**380**	**338**	**343**	**35.7**	10.0	mg / L
UV Absorbance @ 254 nm	**0.429**	**0.408**	**0.468**	NM	NM	**0.36**	**0.478**	0.009	cm^{-1}
SUVA	**3.5**	**3.3**	**3.3**	NM	NM	**3.5**	**4.4**	0.1	L / mg*m
YSI Data									
pH	**7.1**	**7.7**	**7.3**	**8.1**	**8.0**	**7.8**	**6.7**	± 0.2	Units
Temperature	**9.8**	**14.2**	**8.5**	**15**	**14.9**	**13.6**	**14.5**	± 0.1	ºC
Specific Conductance	**632**	**735**	**601**	**775**	**668**	**698**	**85**	± 1%	uS / cm
Dissolved Oxygen	NM	NM	NM	NM	NM	NM	NM	± 0.01	mg / L
Calculations									
Total Cations	7.4	8.3	6.9	8.6	7.7	8.0	1.0	-	meq
Total Anions	6.8	7.5	6.1	7.8	6.9	7.1	0.8	-	meq
Calculated TDS	456	506	418	524	467	481	60	-	mg/L
Actual TDS - Calc. (diff)	1.0	-0.4	0.0	5.8	-0.9	-7.8	36.8	-	mg/L
% Na to Tot. Cations	12.6	10.9	8.7	11.6	12.5	12.1	16.7	-	%

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NM indicates that the analyte was not measured
[blue shading] Exceeds MN WQ Standard

Twin Lakes
Inflow / Outflow Sampling Event

6/12/2015

	Little Sandy Inflow 1	Little Sandy Inflow 2	Little Sandy Inflow 3	Little Sandy Middle	Sandy Middle	Twin Lakes Outflow	Culvert Inflow	Reporting Limits	Reporting Units
Analytes - Cations									
Aluminum	**38.2**	**12.8**	<10.0	NM	NM	**12.4**	**32.0**	10.0	ug / L
Arsenic	<0.50	<0.50	<0.50	NM	NM	<0.50	**0.76**	0.50	ug / L
Barium	NM	NM	NM	NM	NM	NM	NM	10.0	ug / L
Calcium	**50.7**	**39.7**	**32.6**	**40.7**	**33.4**	**31.6**	**11.8**	0.50	mg / L
Iron	**582**	**259**	**106**	NM	NM	**350**	**2210**	50.0	ug / L
Magnesium	**69.3**	**57.7**	**49.9**	**57.7**	**47.2**	**43.6**	**4**	0.50	mg / L
Manganese	**126**	**97.9**	**24.8**	NM	NM	**61.8**	**139**	10.0	ug / L
Phosphorus	NM	NM	NM	NM	NM	NM	NM	0.10	mg / L
Potassium	**7.2**	**5.12**	**2.12**	NM	NM	**4.81**	**1.49**	0.10	mg / L
Rubidium	**2.9**	**3**	**2.4**	NM	NM	**2.8**	**1.2**	1.0	ug / L
Sodium	**28.1**	**19.2**	**12.6**	**20.2**	**17.9**	**16.8**	**3.8**	0.50	mg / L
Strontium	**175**	**128**	**102**	NM	NM	**107**	**45.1**	10.0	ug / L
Analytes - Anions									
Chloride	**42.8**	**28**	**13.7**	**31.4**	**28.5**	**27.4**	**8.5**	5.0	mg / l
Nitrogen, Kjeldahl, Total	**0.62**	**1.4**	**1.2**	**0.85**	**0.67**	**0.58**	**0.5**	0.50	mg / L
Ammonia as Nitrogen	<0.10	<0.10	**0.15**	<0.10	<0.10	<0.10	<0.10	0.10	mg / L
Unionized Ammonia as N2	<0.02	<0.18	**0.33**	<0.36	<0.48	<0.13	<0.02	varies	ug/L
Sulfate	**271**	**205**	**169**	**219**	**174**	**163**	**2.1**	10.0	mg / L
Analytes - Other									
Total Dissolved Solids	**594**	**486**	**400**	**475**	**399**	**375**	**121**	10.0	mg / L
Total Suspended Solids	**1.6**	NM	NM	<1.2	<1.2	**1.6**	NM	1.2	mg / L
Alkalinity, Total as HCO3	**167**	**140**	**140**	**142**	**114**	**111**	**44.8**	12.2	mg / L
Alkalinity, Total as CaCO3	**137**	**115**	**115**	**116**	**93.7**	**91.1**	**36.7**	5.0	mg / L
Dissolved Organic Carbon	**14.8**	**16.5**	**19.9**	NM	NM	**14.8**	**12.4**	1.0	mg / L
Total Hardness by 2340B	**412**	**337**	**287**	**339**	**278**	**259**	**45.9**	10.0	mg / L
UV Absorbance @ 254 nm	**0.502**	**0.544**	**0.679**	NM	NM	**0.484**	**0.572**	0.009	cm^{-1}
SUVA	**3.4**	**3.3**	**3.4**	NM	NM	**3.3**	**4.6**	0.1	L / mg*m
YSI Data									
pH	**6.9**	**7.6**	**6.9**	**7.9**	**8.0**	**7.5**	**6.7**	± 0.2	Units
Temperature	**16.4**	**22.1**	**16.5**	**21.9**	**21.3**	**19.9**	**18.8**	± 0.1	ºC
Specific Conductance	**892**	**707**	**583**	**730**	**610**	**590**	**106**	± 1%	uS / cm
Dissolved Oxygen	**3.4**	**8.5**	**5.1**	**9.1**	**8.98**	**7.68**	**8.23**	± 0.01	mg / L
Calculations									
Total Cations	9.7	7.7	6.3	7.7	6.3	6.0	1.2	-	meq
Total Anions	9.6	7.5	6.3	7.8	6.3	6.0	1.1	-	meq
Calculated TDS	638	497	422	511	416	399	79	-	mg/L
Actual TDS - Calc. (diff)	-43.6	-10.8	-21.6	-36.4	-17.0	-24.3	41.7	-	mg/L
% Na to Tot. Cations	12.6	10.8	8.6	11.5	12.3	12.1	13.7	-	%

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(shaded) Exceeds MN WQ Standard

Twin Lakes
Inflow / Outflow Sampling Event

7/10/2015

	Little Sandy Inflow 1	Little Sandy Inflow 2	Little Sandy Inflow 3	Little Sandy Core	Little Sandy Middle	Sandy Middle	Twin Lakes Outflow	Culvert Inflow	Reporting Limits	Reporting Units
Analytes - Cations										
Aluminum	**54.2**	<50.0	<50.0	NM	NM	<50.0	<50.0	<50.0	50.0	ug / L
Arsenic	NM	NM	NM	NM	NM	NM	NM	NM	0.50	ug / L
Barium	NM	NM	NM	NM	NM	NM	NM	NM	10.0	ug / L
Calcium	**60.9**	**39.3**	**44.3**	**47.5**	**47.7**	**38.4**	**35.3**	**15.4**	0.50	mg / L
Iron	**459**	**836**	**249**	NM	NM	**285**	**371**	**3150**	50.0	ug / L
Magnesium	**84.3**	**56.5**	**63.5**	**67.2**	**67.7**	**53.3**	**48.3**	**5.3**	0.50	mg / L
Manganese	**28.5**	**128**	**143**	NM	NM	**129**	**42.5**	**180**	10.0	ug / L
Phosphorus	NM	NM	NM	NM	NM	NM	NM	NM	0.10	mg / L
Potassium	**5.6**	**4.1**	**4.4**	NM	NM	**4.8**	**4.6**	**1.2**	0.50	mg / L
Rubidium	NM	NM	NM	NM	NM	NM	NM	NM	1.0	ug / L
Sodium	**39.3**	**20**	**22.3**	**25**	**25**	**20.8**	**19.1**	**4.4**	0.50	mg / L
Strontium	NM	NM	NM	NM	NM	NM	NM	NM	10.0	ug / L
Analytes - Anions										
Chloride	**45.9**	**23.6**	**29.1**	**33.2**	**32.6**	**29.3**	**25.7**	**9.8**	2.0	mg / l
Nitrogen, Kjeldahl, Total	**0.64**	**0.85**	**0.66**	**0.7**	**0.79**	**0.65**	**0.72**	**0.51**	0.50	mg / L
Ammonia as Nitrogen	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	0.10	mg / L
Unionized Ammonia as N2	<0.11	<0.17	<.025	<0.61	<0.66	<0.54	<0.60	<0.03	varies	ug/L
Sulfate	**294**	**168**	**204**	**217**	**219**	**171**	**140**	<2.0	4.0	mg / L
Analytes - Other										
Total Dissolved Solids	**752**	**516**	**575**	**589**	**581**	**509**	**462**	**166**	10.0	mg / L
Total Suspended Solids	**1.6**	**3.5**	**1.6**	**2**	1.6	**2**	**1.6**	**3.2**	1.0	mg / L
Alkalinity, Total as HCO3	**173**	**149**	**153**	**155**	**154**	**133**	**122**	**56.4**	12.2	mg / L
Alkalinity, Total as CaCO3	**142**	**122**	**125**	**127**	**126**	**109**	**99.9**	**46.2**	5.0	mg / L
Dissolved Organic Carbon	**18.4**	**22**	**17.5**	NM	NM	**17**	**17.1**	**12.8**	1.0	mg / L
Total Hardness by 2340B	**499**	**331**	**372**	**395**	**398**	**315**	**287**	**60.6**	3.3	mg / L
UV Absorbance @ 254 nm	NM	NM	NM	NM	NM	NM	NM	NM	0.009	cm^{-1}
SUVA	NM	NM	NM	NM	NM	NM	NM	NM	0.1	L / mg*m
YSI Data										
pH	**7.5**	**7.6**	**7.8**	**8.1**	**8.2**	**8.1**	**8.1**	**7.1**	± 0.2	Units
Temperature	**19.7**	**21.6**	**21.6**	**22.7**	**22.3**	**22.7**	**23.1**	**14.0**	± 0.1	ºC
Specific Conductance	**969**	**703**	**719**	**644**	**765**	**644**	**581**	**129.6**	± 1%	uS / cm
Dissolved Oxygen	**8.2**	**8.2**	**10.1**	**9.1**	**10**	**9.1**	**9.7**	**7.96**	± 0.01	mg / L
Calculations										
Total Cations	11.8	7.6	8.5	NM	9.0	7.3	6.7	1.5	-	meq
Total Anions	10.3	6.7	7.6	NM	8.1	6.6	5.7	1.3	-	meq
Calculated TDS	704	462	521	NM	547	452	396	98	-	mg/L
Actual TDS - Calc. (diff)	47.6	53.8	53.8	NM	34.5	57.4	66.0	67.7	-	mg/L
% Na to Tot. Cations	14.4	11.4	11.4	NM	12.0	12.3	12.4	12.4	-	%

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[blue shading] Exceeds MN WQ Standard

Twin Lakes
Inflow / Outflow Sampling Event

8/21/2015

	Little Sandy Inflow 1	Little Sandy Inflow 2	Little Sandy Inflow 3	Little Sandy Middle	Sandy Middle	Twin Lakes Outflow	Culvert Inflow	Reporting Limits	Reporting Units
Analytes - Cations									
Aluminum	**84.8**	**10.1**	<10.0	<10.0	**18.1**	**21.2**	**53**	10.0	ug / L
Arsenic	NM	NM	NM	NM	NM	NM	NM	0.50	ug / L
Barium	NM	NM	NM	NM	NM	NM	NM	10.0	ug / L
Calcium	**68.7**	**56.6**	**53.1**	**52.8**	**35.3**	**15.6**	**13.4**	0.50	mg / L
Iron	**1170**	**249**	**179**	**121**	**171**	**1200**	**3800**	50.0	ug / L
Magnesium	**94.3**	**82.3**	**79.8**	**80.8**	**54.6**	**14.3**	**4.8**	0.50	mg / L
Manganese	**193**	**77.8**	**91**	**98.7**	**40.1**	**53.9**	**210**	10.0	ug / L
Phosphorus	NM	NM	NM	NM	NM	NM	NM	0.10	mg / L
Potassium	**5.8**	**3.81**	**4.17**	**5.11**	**4.14**	**1.79**	**1.35**	0.10	mg / L
Rubidium	NM	NM	NM	NM	NM	NM	NM	1.0	ug / L
Sodium	**34.6**	**25.5**	**25.5**	**28.9**	**20.3**	**6.9**	**4.3**	0.50	mg / L
Strontium	NM	NM	NM	NM	NM	NM	NM	10.0	ug / L
Analytes - Anions									
Chloride	**51.3**	**34.2**	**33.9**	**40.4**	**28.8**	**12.1**	**11.2**	5.0	mg / l
Nitrogen, Kjeldahl, Total	**0.53**	**0.86**	**0.88**	**0.72**	**1.1**	**0.61**	**0.54**	0.50	mg / L
Ammonium as Nitrogen	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	0.10	mg / L
Unionized Ammonia as N2	<.013	<.016	<.036	<0.78	<0.46	<0.03	<0.03	varies	ug/L
Sulfate	**366**	**276**	**250**	**260**	**162**	**33.8**	<2.0	2.0	mg / L
Analytes - Other									
Total Dissolved Solids	**Inflow 1**	**652**	**623**	**622**	**436**	**174**	**124**	10.0	mg / L
Total Suspended Solids	<1.0	<1.0	**1.6**	**1.2**	**2**	<1.2	**5.2**	1.0	mg / L
Alkalinity, Total as HCO3	**199**	**205**	**210**	**195**	**143**	**57.8**	**47.8**	**12.2**	mg / L
Alkalinity, Total as CaCO3	**163**	**168**	**172**	**160**	**117**	**47.4**	**39.2**	5.0	mg / L
Dissolved Organic Carbon	**12.9**	**18.8**	**19.3**	**17**	**18.8**	**17.5**	**16.2**	1.0	mg / L
Total Hardness by 2340B	**560**	**480**	**461**	**465**	**313**	**97.9**	**53.3**	10.0	mg / L
UV Absorbance @ 254 nm	NM	NM	NM	NM	NM	NM	NM	0.009	cm^{-1}
SUVA	NM	NM	NM	NM	NM	NM	NM	0.1	L / mg*m
YSI Data									
pH	**7.7**	**7.8**	**8.1**	**8.4**	**8.2**	**7.0**	**7.1**	± 0.2	Units
Temperature	**13.9**	**14.3**	**15.7**	**16.7**	**15.8**	**14.6**	**13.6**	± 0.1	ºC
Specific Conductance	**1074**	**976**	**866**	**890**	**632**	**219**	**119**	± 1%	uS / cm
Dissolved Oxygen	NM	NM	NM	NM	NM	NM	NM	± 0.01	mg / L
Calculations									
Total Cations	12.9	10.8	10.4	10.7	7.2	2.3	1.4	-	meq
Total Anions	12.4	10.1	9.7	9.8	6.6	2.0	1.2	-	meq
Calculated TDS	821	685	657	664	449	144	89	-	mg/L
Actual TDS - Calc. (diff)	-22.5	-32.6	-34.5	-42.1	-13.2	29.8	34.6	-	mg/L
% Na to Tot. Cations	11.7	10.3	10.6	11.8	12.2	12.8	13.1	-	%

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Twin Lakes
Inflow / Outflow Sampling Event

9/25/2015

	Little Sandy Inflow 1	Little Sandy Inflow 2	Little Sandy Inflow 3	Little Sandy Middle	Sandy Middle	Twin Lakes Outflow	Culvert Inflow	Reporting Limits	Reporting Units
Analytes - Cations									
Aluminum	**124**	**54.3**	**16.4**	NM	**14.0**	**35.8**	**39.4**	10.0	ug / L
Arsenic	NM	NM	NM	NM	NM	NM	NM	0.50	ug / L
Barium	NM	NM	NM	NM	NM	NM	NM	10.0	ug / L
Calcium	**75.7**	**27.9**	**30.5**	**52.0**	**41.1**	**35.2**	**12.2**	0.50	mg / L
Iron	**2030**	**4170**	**352**	NM	**301**	**811**	**2860**	50.0	ug / L
Magnesium	**104**	**38.2**	**46.5**	**75.3**	**61.0**	**50.1**	**4.4**	0.50	mg / L
Manganese	**309**	**67.0**	**31.5**	NM	**61.5**	**67.5**	**97.6**	10.0	ug / L
Phosphorus	NM	NM	NM	NM	NM	NM	NM	0.10	mg / L
Potassium	**8.9**	**1.8**	**1.6**	NM	**4.2**	**3.8**	**1.8**	0.10	mg / L
Rubidium	NM	NM	NM	NM	NM	NM	NM	1.0	ug / L
Sodium	**42.2**	**13.7**	**11.1**	**27.6**	**23.6**	**20.3**	**4.4**	0.50	mg / L
Strontium	NM	NM	NM	NM	NM	NM	NM	10.0	ug / L
Analytes - Anions									
Chloride	**68.5**	**25.3**	**13.2**	**40.9**	**34.2**	**28.1**	**11.7**	5.0	mg / l
Nitrogen, Kjeldahl, Total	**0.98**	**1.6**	**1.2**	**1.1**	**0.95**	**1.0**	**0.83**	0.50	mg / L
Ammonia as Nitrogen	**0.10**	**0.17**	**0.12**	<0.10	<0.10	<0.10	<0.10	0.10	mg / L
Unionized Ammonia as N2	**0.03**	**0.03**	**0.03**	<0.22	<0.17	<0.08	<0.01	varies	ug/L
Sulfate	**338**	**157**	**52.5**	**238**	**195**	**147**	<2.0	10.0	mg / L
Analytes - Other									
Total Dissolved Solids	**838**	**399**	**309**	**576**	**447**	**371**	**95**	10.0	mg / L
Total Suspended Solids	**3.6**	**2.0**	<1.0	<1.0	<1.0	**2.4**	**1.2**	1.0	mg / L
Alkalinity, Total as HCO3	**246**	**156**	**245**	**216**	**163**	**140**	**47.8**	12.2	mg / L
Alkalinity, Total as CaCO3	**202**	**128**	**201**	**177**	**134**	**115**	**39.2**	5.0	mg / L
Dissolved Organic Carbon	**17.6**	**28.5**	**30.7**	**20.1**	**20.3**	**19.3**	**16.3**	1.0	mg / L
Total Hardness by 2340B	**615**	**227**	**268**	**440**	**354**	**294**	**48.5**	10.0	mg / L
UV Absorbance @ 254 nm	NM	NM	NM	NM	NM	NM	NM	0.009	cm^{-1}
SUVA	NM	NM	NM	NM	NM	NM	NM	0.1	L / mg*m
YSI Data									
pH	**7.1**	**7.0**	**7.1**	**7.9**	**7.8**	**7.5**	**6.7**	± 0.2	Units
Temperature	**14.6**	**14.6**	**13.8**	**15.3**	**15.2**	**14.8**	**13.1**	± 0.1	ºC
Specific Conductance	**1224**	**779**	**476**	**875**	**721**	**568**	**118**	± 1%	uS / cm
Dissolved Oxygen	NM	NM	NM	NM	NM	NM	NM	± 0.01	mg / L
Calculations									
Total Cations	14.5	5.3	5.9	10.0	8.2	6.9	1.3	-	meq
Total Anions	13.1	6.7	5.6	9.7	7.8	6.2	1.2	-	meq
Calculated TDS	887	426	402	651	524	427	88	-	mg/L
Actual TDS - Calc. (diff)	-49.0	-26.9	-93.2	-74.8	-76.8	-55.7	6.9	-	mg/L
% Na to Tot. Cations	12.7	11.2	8.2	12.0	12.5	12.8	14.6	-	%

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Twin Lakes
Inflow / Outflow Sampling Event

10/19/2015

	Little Sandy Inflow 1	Little Sandy Inflow 2	Little Sandy Inflow 3	Little Sandy Middle	Sandy Middle	Twin Lakes Outflow	Culvert Inflow	Reporting Limits	Reporting Units
Analytes - Cations									
Aluminum	**80.8**	<50.0	<50.0	NM	<50.0	<50.0	<50.0	<50.0	ug / L
Arsenic	NM	NM	NM	NM	NM	NM	NM	0.50	ug / L
Barium	NM	NM	NM	NM	NM	NM	NM	10.0	ug / L
Calcium	**91.7**	**68.0**	**45.4**	**59.1**	**47.4**	**42.2**	**10.8**	0.50	mg / L
Iron	**1130**	**218**	**448**	NM	**315**	**479**	**2400**	50.0	ug / L
Magnesium	**133**	**97**	**66.2**	**83.9**	**69.5**	**59.1**	**4.0**	0.50	mg / L
Manganese	**237**	**55.7**	**258**	NM	**42.2**	**54.4**	**133**	10.0	ug / L
Phosphorus	NM	NM	NM	NM	NM	NM	NM	0.10	mg / L
Potassium	**11.6**	**4.1**	**3.3**	NM	**4.7**	**4.3**	**1.6**	0.10	mg / L
Rubidium	NM	NM	NM	NM	NM	NM	NM	1.0	ug / L
Sodium	**52.4**	**30.6**	**21.1**	**31.3**	**26.5**	**23.2**	**4.7**	0.50	mg / L
Strontium	NM	NM	NM	NM	NM	NM	NM	10.0	ug / L
Analytes - Anions									
Chloride	**85.4**	**43.5**	**33.3**	**47.6**	**39.1**	**35.4**	**13.4**	5.0	mg / l
Nitrogen, Kjeldahl, Total	<0.50	**0.86**	**0.86**	**0.81**	**0.86**	**0.77**	**<0.50**	0.50	mg / L
Ammonia as Nitrogen	<0.10	<0.10	<0.10	<0.10	**0.15**	<0.10	<0.10	0.10	mg / L
Unionized Ammonia as N2	<0.04	<0.02	<0.19	<0.38	**2.69**	<.018	<0.02	varies	ug/L
Sulfate	**498**	**340**	**215**	**279**	**223**	**192**	**2.8**	10.0	mg / L
Analytes - Other									
Total Dissolved Solids	**1040**	**737**	**514**	**649**	**546**	**473**	**121**	10.0	mg / L
Total Suspended Solids	**2.4**	**1.2**	**2**	**3.2**	**4**	**4**	**3.5**	1.0	mg / L
Alkalinity, Total as HCO3	**284**	**270**	**224**	**217**	**187**	**163**	**42.1**	12.2	mg / L
Alkalinity, Total as CaCO3	**233**	**221**	**184**	**178**	**153**	**134**	**34.5**	5.0	mg / L
Dissolved Organic Carbon	**9.4**	**17.7**	**21**	**17.8**	**18.9**	**349**	**7.5**	1.0	mg / L
Total Hardness by 2340B	**776**	**569**	**386**	**493**	**405**	**17.5**	**43.3**	10.0	mg / L
UV Absorbance @ 254 nm	NM	NM	NM	NM	NM	NM	NM	0.009	cm^{-1}
SUVA	NM	NM	NM	NM	NM	NM	NM	0.1	L / mg*m
YSI Data									
pH	**7.4**	**7.1**	**8.1**	**8.4**	**8.1**	**8.1**	**7.1**	± 0.2	Units
Temperature	**6.9**	**6.3**	**7.3**	**7.3**	**6.6**	**6.4**	**7.3**	± 0.1	ºC
Specific Conductance	**1435**	**1150**	**943**	**949**	**746**	**666**	**117**	± 1%	uS / cm
Dissolved Oxygen	NM	NM	NM	NM	NM	NM	NM	± 0.01	mg / L
Calculations									
Total Cations	18.1	12.8	8.7	11.2	9.4	8.1	1.2	-	meq
Total Anions	17.5	12.8	9.2	10.8	8.9	7.7	1.2	-	meq
Calculated TDS	1158	854	610	719	598	521	82	-	mg/L
Actual TDS - Calc. (diff)	-118.2	-117.0	-96.3	-69.9	-52.1	-48.0	38.6	-	mg/L
% Na to Tot. Cations	12.6	10.4	10.5	12.1	12.3	12.4	17.0	-	%

Bold Print indicates the sample is above the detection limit
"<" indicates value below reporting limit
NM indicates that the analyte was not measured
[blue shading] Exceeds MN WQ Standard

Twin Lakes
Inflow / Outflow Sampling Event

5/26/2016

	Little Sandy Inflow 1	Little Sandy Inflow 2	Little Sandy Inflow 3	Little Sandy Middle	Sandy Middle	Twin Lakes Outflow	Culvert Inflow	Reporting Limits	Reporting Units
Analytes - Cations									
Aluminum	**55.8**	<0.50	<0.50	NM	NM	<0.50	<0.50	**0.50**	ug / L
Arsenic	NM	NM	NM	NM	NM	NM	NM	**0.05**	ug / L
Barium	NM	NM	NM	NM	NM	NM	NM	**10.0**	ug / L
Calcium	**64.7**	**30.7**	**34.5**	**28.2**	**38.3**	**24.3**	**11.3**	**0.50**	mg / L
Iron	**1270**	**531**	**381**	NM	NM	**502**	**1560**	**50.0**	ug / L
Magnesium	**86.4**	**41.9**	**47.5**	**38.3**	**51.3**	**31.2**	**4.1**	**0.50**	mg / L
Manganese	**183**	**51.9**	**77.2**	NM	NM	**46.8**	**62.9**	**10.0**	ug / L
Phosphorus	NM	NM	NM	NM	NM	NM	NM	**0.10**	mg / L
Potassium	**9.5**	**4.6**	**4.3**	**4.0**	**5.2**	**3.5**	**1.6**	**0.50**	mg / L
Rubidium	NM	NM	NM	NM	NM	NM	NM	**1.0**	ug / L
Sodium	**34.8**	**14.3**	**14.8**	**13.5**	**17.5**	**11.5**	**4.1**	**0.50**	mg / L
Strontium	NM	NM	NM	NM	NM	NM	NM	**10.0**	ug / L
Analytes - Anions									
Chloride	**51.8**	**20.5**	**21.7**	**19.8**	**26.4**	**16.4**	**9.4**	**1.0**	mg / l
Nitrogen, Kjeldahl, Total	**0.68**	**0.96**	**0.92**	**0.80**	**0.76**	**0.71**	<0.50	**0.50**	mg / L
Ammonia as Nitrogen	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	**0.10**	mg / L
Unionized ammonia as N	<0.05	<0.06	<0.04	<0.58	<0.42	<0.12	<0.03	varies	ug/L
Sulfate	**338**	**216**	**156**	**129**	**183**	**92.7**	**<2.0**	**2.0**	mg / L
Analytes - Other									
Total Dissolved Solids	**761**	**407**	**417**	**363**	**438**	**295**	**141**	**10.0**	mg / L
Total Suspended Solids	**4.0**	**18.7**	**6.5**	**2.0**	**2.8**	**1.6**	**2.4**	**1.0**	mg / L
Alkalinity, Total as HCO3-	**212**	**146**	**171**	**129**	**168**	**113**	**45.3**	**7.4**	mg / L
Alkalinity, Total as CaCO3	**174**	**120**	**140**	**106**	**138**	**92.4**	**37.1**	**6.1**	mg / L
Dissolved Organic Carbon	**10.5**	**15.6**	**16.2**	NM	NM	**14.8**	**13.9**	**1.0**	mg / L
Total Hardness by 2340B	**517**	**249**	**282**	**228**	**307**	**189**	**45.1**	**3.3**	mg / L
UV Absorbance @ 254 nm	NM	NM	NM	NM	NM	NM	NM	**0.009**	cm^{-1}
SUVA	NM	NM	NM	NM	NM	NM	NM	**0.1**	L / mg*m
YSI Data									
pH	**7.3**	**7.3**	**7.2**	**8.2**	**8.1**	**7.6**	**7.0**	**± 0.2**	Units
Temperature	**15.0**	**16.6**	**15.3**	**18.2**	**17.6**	**16.2**	**14.2**	**± 0.1**	ºC
Specific Conductance	**1109**	**574**	**560**	**682**	**517**	**359**	**112**	**± 1%**	uS / cm
Dissolved Oxygen	NM	NM	NM	NM	NM	NM	NM	**± 0.01**	mg / L
Calculations									
Total Cations	12.1	5.7	6.4	5.1	6.1	4.4	1.2	-	meq
Total Anions	12.0	7.5	6.7	5.4	7.3	4.3	1.1	-	meq
Calculated TDS	800	476	451	358	745	294	80	-	mg/L
Actual TDS - Calc. (diff)	-38.6	-68.9	-34.0	4.9	NM	1.4	61.1	-	mg/L
% Na to Tot. Cations	12.5	10.8	10.1	11.4	12.4	11.4	15.1	-	%

Highlighted (Exceeds MN WQ Standard): Sulfate 338, 216, 156, 129, 183, 92.7; Total Dissolved Solids 761; Total Hardness by 2340B 517; Specific Conductance 1109.

Bold Print indicates the sample is above the detection limit
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NM indicates that the analyte was not measured
[blue box] Exceeds MN WQ Standard

Twin Lakes
Inflow / Outflow Sampling Event

6/24/2016

	Little Sandy Inflow 1	Little Sandy Inflow 2	Little Sandy Inflow 3	Little Sandy Middle	Sandy Middle	Twin Lakes Outflow	Culvert Inflow	Reporting Limits	Reporting Units
Analytes - Cations									
Aluminum	<50.0	<200	<200	NM	NM	<200	<200	**200**	ug / L
Arsenic	NM	NM	NM	NM	NM	NM	NM	**0.05**	ug / L
Barium	NM	NM	NM	NM	NM	NM	NM	**10.0**	ug / L
Calcium	**43.6**	**34.0**	**34.4**	**35.5**	**31.5**	**25.2**	**11.8**	**0.50**	mg / L
Iron	**2590**	**929**	**439**	NM	NM	**724**	**5360**	**50.0**	ug / L
Magnesium	**54.5**	**47.5**	**49.0**	**48.9**	**42.9**	**33.4**	**3.9**	**0.50**	mg / L
Manganese	**81.3**	**101**	**82.8**	NM	NM	**70.6**	**411**	**5.0**	ug / L
Phosphorus	NM	NM	NM	NM	NM	NM	NM	**0.10**	mg / L
Potassium	**4.87**	**3.52**	**3.2**	NM	**3.62**	**3.05**	<2.5	**2.50**	mg / L
Rubidium	NM	NM	NM	NM	NM	NM	NM	**1.0**	ug / L
Sodium	**22.5**	**14.9**	**14.6**	**15.9**	**15.2**	**12.4**	**3.1**	**1.0**	mg / L
Strontium	NM	NM	NM	NM	NM	NM	NM	**10.0**	ug / L
Analytes - Anions									
Chloride	**31.8**	21.0	**20.6**	**23.0**	**22.0**	**19.5**	**7.1**	**1.0**	mg / L
Nitrogen, Kjeldahl, Total	**0.73**	0.70	**0.60**	<0.50	<0.50	<0.50	**0.67**	**0.50**	mg / L
Ammonia as Nitrogen	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	**0.10**	mg / L
Unionized ammonia as N	<0.04	<0.07	<0.07	<0.23	<0.22	<0.10	<0.01	varies	ug/L
Sulfate	**212**	160	**163**	**170**	**147**	**114**	<2.0	**2.0**	mg / L
Analytes - Other									
Total Dissolved Solids	**530**	**447**	**447**	**465**	**389**	**316**	**145**	**10.0**	mg / L
Total Suspended Solids	**1.5**	**3.5**	**2.8**	**3.2**	**1.2**	**2.0**	**10**	**1.0**	mg / L
Alkalinity, Total as HCO3-	**182**	**185**	**199**	**182**	**155**	**128**	**49.8**	**7.4**	mg / L
Alkalinity, Total as CaCO3	**149**	**152**	**163**	**149**	**127**	**105**	**40.8**	**6.1**	mg / L
Dissolved Organic Carbon	**23.4**	**26.1**	**21.5**	NM	NM	**18.3**	**25.7**	**1.0**	mg / L
Total Hardness by 2340B	**333**	**281**	**287**	**290**	**255**	201	**45.6**	**3.3**	mg / L
UV Absorbance @ 254 nm	NM	NM	NM	NM	NM	NM	NM	**0.009**	cm^{-1}
SUVA	NM	NM	NM	NM	NM	NM	NM	**0.1**	L / mg*m
YSI Data									
pH	**7.0**	**7.1**	**7.2**	**7.7**	**7.7**	**7.4**	**6.5**	**± 0.2**	Units
Temperature	**19.1**	**22.5**	**20.3**	**22.8**	**22.3**	**21.3**	**19.8**	**± 0.1**	ºC
Specific Conductance	**743**	**606**	**644**	**637**	**540**	**445**	**102**	**± 1%**	uS / cm
Dissolved Oxygen	NM	NM	NM	NM	NM	NM	NM	**± 0.01**	mg / L
Calculations									
Total Cations	7.9	6.4	6.5	6.5	5.8	4.7	1.3	-	meq
Total Anions	8.3	7.0	7.3	7.2	6.3	5.1	1.1	-	meq
Calculated TDS	554	468	485	476	656	337	87	-	mg / L
Actual TDS - Calc. (diff)	-24.5	-21.1	-37.8	-10.6	NM	-20.9	58.4	-	mg / L
% Na to Tot. Cations	12.5	10.2	9.8	10.7	11.5	11.6	10.3	-	%

Bold Print indicates the sample is above the detection limit
"<" indicates value below reporting limit
NM indicates that the analyte was not measured
(blue shading) Exceeds MN WQ Standard

Twin Lakes
Inflow / Outflow Sampling Event

7/22/2016

	Little Sandy Inflow 1	Little Sandy Inflow 2	Little Sandy Inflow 3	Little Sandy Middle	Sandy Middle	Twin Lakes Outflow	Culvert Inflow	Reporting Limits	Reporting Units
Analytes - Cations									
Aluminum	**284**	**55.0**	**69.1**	NM	NM	**51.0**	**107**	**50.0**	ug / L
Arsenic	NM	NM	NM	NM	NM	NM	NM	**0.50**	ug / L
Barium	NM	NM	NM	NM	NM	NM	NM	**10.0**	ug / L
Calcium	**39.4**	**36.1**	**36.6**	**30.1**	**36.5**	**27.4**	**14.1**	**0.50**	mg / L
Iron	**20700**	**2320**	**3270**	NM	NM	**2510**	**10400**	**50.0**	ug / L
Magnesium	**45.6**	**48.7**	**49.2**	**39.7**	**49.1**	**35.3**	**4.7**	**0.50**	mg / L
Manganese	**429**	**179**	**197**	NM	NM	**138**	**419**	**10.0**	ug / L
Phosphorus	NM	NM	NM	NM	NM	NM	NM	**0.10**	mg / L
Potassium	**2.6**	**2.9**	**2.9**	**2.9**	**3.0**	**2.8**	**0.94**	**0.50**	mg / L
Rubidium	NM	NM	NM	NM	NM	NM	NM	**1.0**	ug / L
Sodium	**17.1**	**15.1**	**15.1**	**13.8**	**15.6**	**12.6**	**3.4**	**0.50**	mg / L
Strontium	NM	NM	NM	NM	NM	NM	NM	**10.0**	ug / L
Analytes - Anions									
Chloride	**20.9**	**17.9**	**17.6**	**17.8**	**18.4**	**16.8**	**7.5**	**1.0**	mg / l
Nitrogen, Kjeldahl, Total	**2.6**	**1.5**	**1.6**	**1.4**	**1.3**	**1.3**	**1.3**	**0.50**	mg / L
Ammonia as Nitrogen	**0.36**	**0.15**	**0.12**	**0.15**	**0.11**	**0.13**	**0.12**	**0.10**	mg / L
Unionized ammonia as N	**0.85**	**0.61**	**1.1**	**1.7**	**1.2**	**1.5**	**0.14**	varies	ug/L
Sulfate	**120**	**121**	**121**	**104**	**125**	**92.1**	**2.3**	**2.0**	mg / L
Analytes - Other									
Total Dissolved Solids	**431**	**409**	**372**	**378**	**398**	**276**	**126**	**10.0**	mg / L
Total Suspended Solids	**14.0**	<2.5	<2.5	**2.0**	<1.0	**3.6**	**5.0**	**1.0**	mg / L
Alkalinity, Total as HCO3-	**187**	**214**	**218**	**139**	**195**	**153**	**49.0**	**7.4**	mg / L
Alkalinity, Total as CaCO3	**153**	**175**	**179**	**114**	**160**	**125**	**40.2**	**6.1**	mg / L
Dissolved Organic Carbon	**63.7**	**36.1**	**38.2**	NM	NM	**31.6**	**35.4**	**1.0**	mg / L
Total Hardness by 2340B	**286**	**291**	**294**	**239**	**293**	**214**	**54.5**	**3.3**	mg / L
UV Absorbance @ 254 nm	NM	NM	NM	NM	NM	NM	NM	**0.009**	cm^{-1}
SUVA	NM	NM	NM	NM	NM	NM	NM	**0.1**	L / mg*m
YSI Data									
pH	**6.7**	**6.9**	**7.3**	**7.3**	**7.3**	**7.3**	**6.5**	**± 0.2**	Units
Temperature	**21.4**	**24.2**	**23.6**	**25.1**	**24.8**	**25.0**	**19.2**	**± 0.1**	ºC
Specific Conductance	**547**	**572**	**585**	**567**	**459**	**422**	**107**	**± 1%**	uS / cm
Dissolved Oxygen	NM	NM	NM	NM	NM	NM	NM	**± 0.01**	mg / L
Calculations									
Total Cations	7.3	6.6	6.7	5.4	6.6	5.0	1.6	-	meq
Total Anions	6.3	6.6	6.7	5.0	6.4	5.0	1.2	-	meq
Calculated TDS	456	459	466	346	717	343	94	-	mg/L
Actual TDS - Calc. (diff)	-25.0	-50.2	-93.8	32.1	NM	-67.4	31.9	-	mg/L
% Na to Tot. Cations	10.2	9.9	9.8	11.2	10.3	11.0	9.0	-	%

Bold Print indicates the sample is above the detection limit
"<" indicates value below reporting limit
NM indicates that the analyte was not measured
Exceeds MN WQ Standard (blue shading: Aluminum – Little Sandy Inflow 1; Sulfate – Little Sandy Inflow 1 through Twin Lakes Outflow)

Twin Lakes
Inflow / Outflow Sampling Event

8/25/2016

Analytes - Cations	Little Sandy Inflow 1	Little Sandy Inflow 2	Little Sandy Inflow 3	Little Sandy Middle	Sandy Middle	Twin Lakes Outflow	Culvert Inflow	Reporting Limits	Reporting Units
Aluminum	**70.5**	**111**	<10.0	NM	NM	**57.3**	**132**	50.0	ug / L
Arsenic	NM	NM	NM	NM	NM	NM	NM	0.50	ug / L
Barium	NM	NM	NM	NM	NM	NM	NM	10.0	ug / L
Calcium	**69.6**	**38.6**	**40.0**	NM	NM	**28.0**	**14.2**	0.50	mg / L
Iron	**2060**	**2250**	**1650**	NM	NM	**3280**	**10700**	50.0	ug / L
Magnesium	**99.3**	**53.5**	**56.0**	NM	NM	**33.4**	**4.9**	0.50	mg / L
Manganese	**138**	**214**	**220**	NM	NM	**136**	**304**	10.0	ug / L
Phosphorus	NM	NM	NM	NM	NM	NM	NM	0.10	mg / L
Potassium	**5.5**	**2.3**	**2.5**	NM	NM	**2.2**	**1.1**	0.50	mg / L
Rubidium	NM	NM	NM	NM	NM	NM	NM	1.0	ug / L
Sodium	**39.0**	**15.4**	**16.8**	NM	NM	**11.7**	**4.1**	0.50	mg / L
Strontium	NM	NM	NM	NM	NM	NM	NM	10.0	ug / L
Analytes - Anions									
Chloride	**56.5**	**18.6**	**20.2**	NM	NM	**15.4**	**9.5**	1.0	mg / l
Nitrogen, Kjeldahl, Total	**0.87**	**2.1**	**1.3**	NM	NM	**1.5**	**0.99**	0.50	mg / L
Ammonia as Nitrogen	<0.10	**0.29**	**0.16**	NM	NM	**0.32**	<0.10	0.10	mg / L
Unionized ammonia as N	<0.50	**2.94**	**0.91**	NM	NM	**2.5**	<0.14	varies	ug/L
Sulfate	**314**	**96.7**	**108**	NM	NM	**64.3**	<2.0	2.0	mg / L
Analytes - Other									
Total Dissolved Solids	**836**	**434**	**473**	NM	NM	**356**	**155**	10.0	mg / L
Total Suspended Solids	**2.8**	**22.0**	**5.2**	NM	NM	<1.0	**26.0**	1.7	mg / L
Alkalinity, Total as HCO3-	**339**	**293**	**289**	NM	NM	**185**	**59**	7.4	mg / L
Alkalinity, Total as CaCO3	**278**	**240**	**237**	NM	NM	**152**	**48.4**	6.1	mg / L
Dissolved Organic Carbon	**22.1**	**38.9**	**37.1**	NM	NM	**39.1**	**26.9**	1.0	mg / L
Total Hardness by 2340B	**582**	**317**	**330**	NM	NM	**207**	**55.5**	3.3	mg / L
UV Absorbance @ 254 nm	NM	NM	NM	NM	NM	NM	NM	0.009	cm^{-1}
SUVA	NM	NM	NM	NM	NM	NM	NM	0.1	L / mg*m
YSI Data									
pH	**7.1**	**7.4**	**7.2**	NM	NM	**7.3**	**6.7**	± 0.2	Units
Temperature	**19.1**	**20.2**	**19.8**	NM	NM	**20.0**	**16.1**	± 0.1	ºC
Specific Conductance	**1141**	**600**	**576**	NM	NM	**417**	**119**	± 1%	uS / cm
Dissolved Oxygen	NM	NM	NM	NM	NM	NM	NM	± 0.01	mg / L
Calculations									
Total Cations	13.6	7.1	7.5	NM	NM	4.8	1.7	-	meq
Total Anions	13.8	7.5	7.7	NM	NM	4.9	1.3	-	meq
Calculated TDS	926	522	536	NM	NM	345	107	-	mg/L
Actual TDS - Calc. (diff)	-90.1	-88.5	-62.8	NM	NM	10.6	48.2	-	mg/L
% Na to Tot. Cations	12.5	9.4	9.8	NM	NM	10.5	10.4	-	%

Bold Print indicates the sample is above the detection limit

"<" indicates value below reporting limit

NM indicates that the analyte was not measured

[blue shading] Exceeds MN WQ Standard

Twin Lakes
Inflow / Outflow Sampling Event

9/28/2016

	Little Sandy Inflow 1	Little Sandy Inflow 2	Little Sandy Inflow 3	Little Sandy Middle	Sandy Middle	Twin Lakes Outflow	Culvert Inflow	Reporting Limits	Reporting Units
Analytes - Cations									
Aluminum	**84.6**	<50.0	<50.0	NM	NM	<50.0	**54.5**	**50.0**	ug / L
Arsenic	NM	NM	NM	NM	NM	NM	NM	**0.50**	ug / L
Barium	NM	NM	NM	NM	NM	NM	NM	**10.0**	ug / L
Calcium	**54.4**	**47.4**	**30.9**	NM	NM	**28.6**	**10.4**	**0.50**	mg / L
Iron	**1150**	**455**	**353**	NM	NM	**1420**	**2750**	**50.0**	ug / L
Magnesium	**72.6**	**65.9**	**49.4**	NM	NM	**36.0**	**3.7**	**0.50**	mg / L
Manganese	**84.7**	**84.0**	**90.6**	NM	NM	**54.1**	**101**	**10.0**	ug / L
Phosphorus	NM	NM	NM	NM	NM	NM	NM	**0.10**	mg / L
Potassium	**5.8**	**3.3**	**1.5**	NM	NM	**2.6**	**1.5**	**0.50**	mg / L
Rubidium	NM	NM	NM	NM	NM	NM	NM	**1.0**	ug / L
Sodium	**28.4**	**20.9**	**9.2**	NM	NM	**13.3**	**4.0**	**0.50**	mg / L
Strontium	NM	NM	NM	NM	NM	NM	NM	**10.0**	ug / L
Analytes - Anions									
Chloride	**47.0**	**31.5**	**12.5**	NM	NM	**21.1**	**10.4**	**1.0**	mg / l
Nitrogen, Kjeldahl, Total	**0.71**	**0.88**	**0.85**	NM	NM	**0.94**	<0.60	**0.60**	mg / L
Ammonia as Nitrogen	<0.10	<0.10	<0.10	NM	NM	**0.11**	<0.10	**0.10**	mg / L
Unionized ammonia as N	<0.36	<1.3	<0.59	NM	NM	**1.0**	<0.12	varies	ug/L
Sulfate	**229**	**165**	**39.6**	NM	NM	**81.9**	<2.0	**2.0**	mg / L
Analytes - Other									
Total Dissolved Solids	**661**	**561**	**367**	NM	NM	**346**	**120**	**10.0**	mg / L
Total Suspended Solids	**3.2**	**3.6**	**2.4**	NM	NM	**2.4**	**3.5**	**1.0**	mg / L
Alkalinity, Total as HCO3-	**253**	**306**	**311**	NM	NM	**177**	**42**	12.3	mg / L
Alkalinity, Total as CaCO3	**207**	**251**	**255**	NM	NM	**145**	**34.8**	**6.1**	mg / L
Dissolved Organic Carbon	**19.5**	**27.7**	**32.2**	NM	NM	**27.9**	**16.9**	**1.0**	mg / L
Total Hardness by 2340B	**435**	**390**	**280**	NM	NM	**220**	**41.2**	**3.3**	mg / L
UV Absorbance @ 254 nm	NM	NM	NM	NM	NM	NM	NM	**0.009**	cm^{-1}
SUVA	NM	NM	NM	NM	NM	NM	NM	**0.1**	L / mg*m
YSI Data									
pH	**7.3**	**7.8**	**7.4**	NM	NM	**7.6**	**6.8**	**± 0.2**	Units
Temperature	**10.9**	**11.7**	**11.8**	NM	NM	**11.0**	**11.2**	**± 0.1**	ºC
Specific Conductance	**895**	**781**	**517**	NM	NM	**462**	**103**	**± 1%**	uS / cm
Dissolved Oxygen	NM	NM	NM	NM	NM	NM	NM	**± 0.01**	mg / L
Calculations									
Total Cations	10.1	8.8	6.1	NM	NM	5.1	1.1	-	meq
Total Anions	10.3	9.4	6.3	NM	NM	5.3	1.1	-	meq
Calculated TDS	692	642	455	NM	NM	363	78	-	mg/L
Actual TDS - Calc. (diff)	-30.7	-80.6	-88.5	NM	NM	-16.8	41.8	-	mg/L
% Na to Tot. Cations	12.2	10.3	6.6	NM	NM	11.4	15.2	-	%

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(shaded) Exceeds MN WQ Standard

Twin Lakes
Inflow / Outflow Sampling Event

10/20/2016

	Little Sandy Inflow 1	Little Sandy Inflow 2	Little Sandy Inflow 3	Little Sandy Middle	Sandy Middle	Twin Lakes Outflow	Culvert Inflow	Reporting Limits	Reporting Units
Analytes - Cations									
Aluminum	**83.1**	<50.0	<50.0	<50.0	<50.0	<50.0	<50.0	**50.0**	ug / L
Arsenic	NM	NM	NM	NM	NM	NM	NM	**0.50**	ug / L
Barium	NM	NM	NM	NM	NM	NM	NM	**10.0**	ug / L
Calcium	**63.7**	**47.2**	**30.1**	**46.0**	**38.7**	**33.4**	**10.0**	**0.50**	mg / L
Iron	**1250**	**442**	**268**	**388**	**650**	**880**	**2220**	**50.0**	ug / L
Magnesium	**92.4**	**69.1**	**54.2**	**67.2**	**55.6**	**46.5**	**3.8**	**0.50**	mg / L
Manganese	**143**	**96.1**	**94.1**	**63.3**	**38.4**	**68.1**	**98.7**	**10.0**	ug / L
Phosphorus	NM	NM	NM	NM	NM	NM	NM	**0.10**	mg / L
Potassium	**7.7**	**3.9**	**1.5**	**4.1**	**3.6**	**3.1**	**1.6**	**0.50**	mg / L
Rubidium	NM	NM	NM	NM	NM	NM	NM	**1.0**	ug / L
Sodium	**35.7**	**23.0**	**10.6**	**23.0**	**20.1**	**17.1**	**4.2**	**0.50**	mg / L
Strontium	NM	NM	NM	NM	NM	NM	NM	**10.0**	ug / L
Analytes - Anions									
Chloride	**53.6**	**33.7**	**15.1**	**34.7**	**30.2**	**26.1**	**10.6**	**1.0**	mg / l
Nitrogen, Kjeldahl, Total	<0.60	**0.80**	**0.66**	**0.75**	**0.79**	**0.79**	<0.60	**0.60**	mg / L
Ammonia as Nitrogen	<0.10	<0.10	<0.10	<0.10	<.010	<0.10	<0.10	**0.10**	mg / L
Unionized ammonia as N	<0.18	<0.10	<0.20	<1.4	<1.3	<0.59	<0.13	varies	ug/L
Sulfate	**294**	**172**	**84.3**	**176**	**135**	**109**	**<2.0**	**2.0**	mg / L
Analytes - Other									
Total Dissolved Solids	**739**	**532**	**375**	**548**	**460**	**392**	**113**	**10.0**	mg / L
Total Suspended Solids	**2.4**	**4.4**	**2.0**	**2.4**	**1.6**	**2.0**	**3.2**	**1.0**	mg / L
Alkalinity, Total as HCO3-	**262**	**264**	**260**	**271**	**218**	**179**	**44.7**	7.4	mg / L
Alkalinity, Total as CaCO3	**215**	**216**	**213**	**222**	**179**	**147**	**36.6**	**6.1**	mg / L
Dissolved Organic Carbon	**15.0**	**22.3**	**24.0**	**21.6**	**25.1**	**23.8**	**11.7**	**1.0**	mg / L
Total Hardness by 2340B	**540**	**402**	**298**	**392**	**326**	**275**	**40.4**	**3.3**	mg / L
UV Absorbance @ 254 nm	NM	NM	NM	NM	NM	NM	NM	**0.009**	cm^{-1}
SUVA	NM	NM	NM	NM	NM	NM	NM	**0.1**	L / mg*m
YSI Data									
pH	**7.1**	**6.9**	**7.2**	**8.0**	**8.0**	**7.6**	**7.0**	**± 0.2**	Units
Temperature	**5.8**	**6.0**	**5.4**	**7.6**	**7.3**	**6.5**	**5.8**	**± 0.1**	ºC
Specific Conductance	**1057**	**632**	**526**	**732**	**619**	**527**	**105**	**± 1%**	uS / cm
Dissolved Oxygen	NM	NM	NM	NM	NM	NM	NM	**± 0.01**	mg / L
Calculations									
Total Cations	12.6	9.2	5.8	8.9	7.5	6.3	1.1	-	meq
Total Anions	12.0	8.9	5.2	9.1	7.3	6.0	1.1	-	meq
Calculated TDS	811	614	358	352	610	416	80	-	mg/L
Actual TDS - Calc. (diff)	-72.4	-81.8	-44.3	195.8	NM	-24.3	33.2	-	mg/L
% Na to Tot. Cations	12.3	10.9	9.4	11.2	11.7	11.7	16.3	-	%

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(blue shading) Exceeds MN WQ Standard

Twin Lakes
Inflow / Outflow Sampling Event

5/25/2017

Analytes - Cations	Little Sandy Inflow 1	Little Sandy Inflow 2	Sandy South Inflow	Little Sandy Middle	Sandy Middle	Twin Lakes Outflow	Culvert Inflow	Reporting Limits	Reporting Units
Calcium	**48.2**	**30.0**	**4.8**	**37.3**	**27.3**	**25.8**	**11.0**	0.50	mg / L
Iron	**831**	**784**	**448**	**408**	**377**	**527**	**1610**	50.0	ug / L
Magnesium	**65.1**	**44.1**	**5.8**	**53.1**	**38.3**	**34.7**	**3.8**	0.50	mg / L
Manganese	**48.1**	**32.7**	<10.0	**24.7**	**22.7**	**38.5**	**86.7**	10.0	ug / L
Potassium	**6.9**	**3.4**	**0.69**	**4.8**	**3.6**	**3.4**	**1.7**	0.50	mg / L
Sodium	**25.8**	**12.5**	**5.6**	**17.4**	**12.6**	**11.7**	**4.0**	0.50	mg / L
Analytes - Anions									
Chloride	**39.1**	**16.6**	**10.4**	**24.4**	**18.2**	**17.5**	**10.4**	1.0	mg / l
Nitrogen, Kjeldahl, Total	**<0.60**	**0.89**	**0.64**	<0.60	**1.3**	**0.66**	<0.60	0.60	mg / L
Ammonia as Nitrogen	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	0.10	mg / L
Unionized ammonia as N	<0.05	<1.0	<0.38	<0.08	<0.04	<0.14	<0.17	varies	ug/L
Sulfate	**250**	**126**	**6.9**	**173**	**122**	**110**	**2.1**	2.0	mg / L
Analytes - Other									
Total Dissolved Solids	**534**	**314**	**74.0**	**367**	**281**	**269**	**61.0**	10.0	mg / L
Total Suspended Solids	**1.2**	**2.0**	**1.6**	**<1.0**	<1.0	**1.2**	**2.0**	1.2	mg / L
Alkalinity, Total as HCO3-	**134**	**124**	**17.9**	**132**	**100**	**94.0**	**30.9**	12.3	mg / L
Alkalinity, Total as CaCO3	**110**	**102**	**14.7**	**108**	**82**	**77.0**	**25.3**	10.1	mg / L
Dissolved Organic Carbon	**13.1**	**23.3**	**19.4**	**15.2**	**16.2**	**15.5**	**12.0**	1.0	mg / L
Total Hardness by 2340B	**388**	**257**	**36.0**	**312**	**226**	**207**	**43.0**	3.3	mg / L
YSI Data									
pH	**7.4**	**7.6**	**7.3**	**7.6**	**7.3**	**7.8**	**7.9**	± 0.2	Units
Temperature	**10.6**	**13.5**	**9.4**	**12.6**	**12.7**	**11.5**	**11.6**	± 0.1	ºC
Specific Conductance	**802**	**527**	**97**	**620**	**472**	**430**	**105**	± 1%	uS / cm
Calculations									
Total Cations	**9.1**	**5.8**	**1.0**	**7.1**	**5.2**	**4.8**	**1.1**	-	meq
Total Anions	**8.5**	**5.2**	**0.8**	**6.5**	**4.8**	**4.4**	**0.9**	-	meq
Calculated TDS	**571**	**358**	**53**	**443**	**324**	**298**	**66**	-	mg/L
Actual TDS - Calc. (diff)	**-36.6**	**-44.3**	**20.8**	**-76.0**	**-42.7**	**-29.3**	**-5.2**	-	mg/L
% Na to Tot. Cations	**12.3**	**9.4**	**24.5**	**10.6**	**10.6**	**10.7**	**15.3**	-	%

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[blue shading] Exceeds MN WQ Standard

Twin Lakes
Inflow / Outflow Sampling Event

6/22/2017

	Little Sandy Inflow 1	Little Sandy Inflow 2	Sandy South Inflow	Little Sandy Middle	Sandy Middle	Twin Lakes Outflow	Culvert Inflow	Reporting Limits	Reporting Units
Analytes - Cations									
Calcium	**47.0**	**34.6**	**7.8**	**40.4**	**34.1**	**29.0**	**10.8**	0.50	mg / L
Iron	**1780**	**1160**	**2380**	**387**	**325**	**740**	**3270**	50.0	ug / L
Magnesium	**63.1**	**50.3**	**9.0**	**58.7**	**47.6**	**37.9**	**3.6**	0.50	mg / L
Manganese	**87.9**	**95.9**	**59.6**	**121**	**111**	**125**	**143**	10.0	ug / L
Potassium	**4.3**	**3.1**	**0.79**	**3.8**	**4.0**	**3.4**	**0.99**	0.50	mg / L
Sodium	**24.4**	**14.4**	**8.3**	**17.3**	**15.9**	**13.2**	**4.0**	0.50	mg / L
Analytes - Anions									
Chloride	**31.5**	**17.7**	**16.1**	**23.7**	**22.7**	**19.6**	**8.8**	varies	mg / L
Nitrogen, Kjeldahl, Total	**0.77**	**1.0**	**0.94**	**0.73**	**0.94**	**0.84**	**0.68**	0.60	mg / L
Ammonia as Nitrogen	<0.10	<0.10	**0.14**	<0.10	<0.10	<0.10	<0.10	0.10	mg / L
Unionized ammonia as N	<0.08	<0.53	**0.14**	<0.29	<0.21	<0.14	<0.02	varies	ug/L
Sulfate	**217**	**136**	**<2.0**	**170**	**145**	**116**	<2.0	varies	mg / L
Analytes - Other									
Total Dissolved Solids	**598**	**434**	**154**	**490**	**437**	**387**	**115**	10.0	mg / L
Total Suspended Solids	**2.0**	**5.6**	**2.4**	**1.6**	**1.2**	**2.4**	**6.0**	1.0/5.0	mg / L
Alkalinity, Total as HCO3-	**143**	**138**	**45.2**	**158**	**129**	**108**	**28.4**	12.3	mg / L
Alkalinity, Total as CaCO3	**117**	**113**	**37.0**	**130**	**106**	**88.5**	**23.3**	10.1	mg / L
Dissolved Organic Carbon	**21.4**	**24.0**	**31.3**	**19.0**	**17.5**	**17.2**	**21.8**	1.0	mg / L
Total Hardness by 2340B	**377**	**293**	**56.6**	**343**	**281**	**228**	**41.9**	3.3	mg / L
YSI Data									
pH	**7.4**	**7.1**	**6.6**	**7.9**	**7.7**	**7.6**	**6.7**	± 0.2	Units
Temperature	**18.0**	**20.7**	**14.7**	**20.0**	**19.8**	**18.7**	**16.4**	± 0.1	ºC
Specific Conductance	**748**	**496**	**135**	**655**	**560**	**473**	**91.5**	± 1%	uS / cm
Calculations									
Total Cations	**8.8**	**6.6**	**1.6**	**7.7**	**6.4**	**5.3**	**1.2**	-	meq
Total Anions	**7.8**	**5.7**	**1.3**	**6.9**	**5.8**	**4.8**	**0.8**	-	meq
Calculated TDS	**533**	**396**	**91**	**473**	**400**	**329**	**63**	-	mg/L
Actual TDS - Calc. (diff)	**65.1**	**37.6**	**63.4**	**16.9**	**37.3**	**58.2**	**52.3**	-	mg/L
% Na to Tot. Cations	**12.1**	**9.5**	**22.6**	**9.8**	**10.8**	**10.9**	**15.0**	-	%

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(Shaded cells: Sulfate values for Little Sandy Inflow 1, Little Sandy Inflow 2, Little Sandy Middle, Sandy Middle, Twin Lakes Outflow.)

Twin Lakes
Inflow / Outflow Sampling Event

7/27/2017

Analytes - Cations	Little Sandy Inflow 1	Little Sandy Inflow 2	Sandy South Inflow	Little Sandy Middle	Sandy Middle	Twin Lakes Outflow	Culvert Inflow	Reporting Limits	Reporting Units
Calcium	**74.6**	**49.5**	**14.7**	**47.1**	**37.2**	**32.1**	**15.9**	0.50	mg / L
Iron	**1180**	**609**	**15000**	**257**	**421**	**657**	**3410**	50.0	ug / L
Magnesium	**109**	**69.9**	**14.6**	**68.1**	**53.1**	**41.9**	**5.2**	0.50	mg / L
Manganese	**18.5**	**141**	**313**	**85**	**99.7**	**88.3**	**158**	10.0	ug / L
Potassium	**3.7**	**2.2**	**1.3**	**3.0**	**3.1**	**2.8**	**1.4**	0.50	mg / L
Sodium	**42**	**18.8**	**8.4**	**21.1**	**17.5**	**14.6**	**4.7**	0.50	mg / L
Analytes - Anions									
Chloride	**58.2**	**25.3**	**15.9**	**27.6**	**24.0**	**21.0**	**14.2**	1.0/4.0	mg / l
Nitrogen, Kjeldahl, Total	**0.94**	**1.0**	**2.3**	**0.79**	**0.97**	**0.89**	<0.60	0.60	mg / L
Ammonia as Nitrogen	<0.10	<0.10	**0.62**	<0.10	<0.10	<0.10	<0.10	0.10	mg / L
Unionized ammonia as N	<0.11	<0.40	**0.77**	<0.96	<0.13	<0.19	<0.02	varies	ug/L
Sulfate	**388**	**183**	<2.0	**195**	**149**	**113**	**2.8**	2.0/8.0	mg / L
Analytes - Other									
Total Dissolved Solids	**863**	**511**	**218**	**461**	**412**	**330**	**116**	10.0	mg / L
Total Suspended Solids	**<2.5**	**5.0**	**22**	**4.0**	<2.5	**3.0**	**6.0**	2.5/5.0	mg / L
Alkalinity, Total as HCO3-	**246**	**218**	**85.5**	**205**	**162**	**146**	**46.7**	12.3	mg / L
Alkalinity, Total as CaCO3	**202**	**179**	**70.1**	**168**	**133**	**120**	**38.3**	12.3	mg / L
Dissolved Organic Carbon	**25.6**	**25.1**	**55.6**	**23.8**	**26.2**	**23.6**	**13.2**	1.0/2.0	mg / L
Total Hardness by 2340B	**636**	**411**	**96.6**	**398**	**311**	**253**	**61**	3.3	mg / L
YSI Data									
pH	**7.4**	**7.0**	**6.6**	**8.3**	**7.4**	**7.6**	**6.7**	± 0.2	Units
Temperature	**22.5**	**20.0**	**17.1**	**24.0**	**23.0**	**21.7**	**18.2**	± 0.1	ºC
Specific Conductance	**1228**	**796**	**219**	**788**	**606**	**514**	**143**	± 1%	uS / cm
Calculations									
Total Cations	**14.7**	**9.1**	**2.9**	**9.0**	**7.1**	**5.8**	**1.6**	-	meq
Total Anions	**13.8**	**8.2**	**2.0**	**8.3**	**6.5**	**5.4**	**1.3**	-	meq
Calculated TDS	**924**	**568**	**158**	**568**	**447**	**373**	**95**	-	mg/L
Actual TDS - Calc. (diff)	**-60.6**	**-57.5**	**60.0**	**-107.0**	**-35.4**	**-43.0**	**20.9**	-	mg/L
% Na to Tot. Cations	**12.5**	**9.0**	**12.7**	**10.2**	**10.7**	**11.0**	**12.9**	-	%

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[blue fill] Exceeds MN WQ Standard

Highlighted (exceeds MN WQ Standard): Sulfate – Little Sandy Inflow 1, Little Sandy Inflow 2, Little Sandy Middle, Sandy Middle, Twin Lakes Outflow; Total Dissolved Solids, Total Hardness by 2340B and Specific Conductance – Little Sandy Inflow 1.

Twin Lakes
Inflow / Outflow Sampling Event

8/24/2017

	Little Sandy Inflow 1	Little Sandy Inflow 2	Sandy South Inflow	Little Sandy Middle	Sandy Middle	Twin Lakes Outflow	Culvert Inflow	Reporting Limits	Reporting Units
Analytes - Cations									
Calcium	**57.9**	**45.4**	**10.6**	**46.6**	**36.4**	**30.5**	**14.0**	0.50	mg / L
Iron	**1090**	**327**	**4000**	**233**	**208**	**450**	**3040**	50.0	ug / L
Magnesium	**80.5**	**69.5**	**12.6**	**71.1**	**54.2**	**42.8**	**4.7**	0.50	mg / L
Manganese	**54.0**	**68.3**	**170**	**69.3**	**34.1**	**41.7**	**120**	10.0	ug / L
Potassium	**3.8**	**2.8**	**1.6**	**3.0**	**2.9**	**2.6**	**1.4**	0.50	mg / L
Sodium	**30.3**	**21.2**	**9.3**	**22.6**	**18.8**	**15.4**	**4.6**	0.50	mg / L
Analytes - Anions									
Chloride	**44.1**	**26.9**	**19.6**	**29.8**	**24.6**	**22.2**	**12.5**	1.0/2.0	mg / l
Nitrogen, Kjeldahl, Total	**0.63**	**0.81**	**0.97**	<0.60	**0.70**	**0.86**	<0.60	0.60	mg / L
Ammonia as Nitrogen	<0.10	<0.10	**0.13**	<0.10	<0.10	<0.10	<0.10	0.10	mg / L
Unionized ammonia as N	<0.04	<2.2	**0.09**	<4.2	<4.0	<1.5	<0.38	varies	ug/L
Sulfate	**290**	**186**	**<2.0**	**201**	**146**	**117**	**3.0**	2.0/4.0	mg / L
Analytes - Other									
Total Dissolved Solids	**647**	**505**	**157**	**507**	**399**	**340**	**109**	10.0	mg / L
Total Suspended Solids	**2.0**	**3.6**	<1.7	**1.6**	<1.0	**2.0**	**2.8**	1.0/1.7	mg / L
Alkalinity, Total as HCO3-	**186**	**217**	**64.6**	**211**	**170**	**144**	**48.9**	6.1	mg / L
Alkalinity, Total as CaCO3	**152**	**178**	**53.0**	**173**	**139**	**118**	**40.1**	6.1	mg / L
Dissolved Organic Carbon	**22.6**	**23.6**	**35.0**	**21.8**	**22.6**	**22.0**	**15.3**	1.0/2.0	mg / L
Total Hardness by 2340B	**476**	**399**	**78.1**	**409**	**314**	**253**	**54.2**	3.3	mg / L
YSI Data									
pH	**7.2**	**7.8**	**6.5**	**8.1**	**8.1**	**7.7**	**7.2**	± 0.2	Units
Temperature	**14.7**	**18.9**	**13.1**	**18.4**	**18.0**	**16.3**	**13.7**	± 0.1	ºC
Specific Conductance	**943**	**700**	**182**	**780**	**600**	**521**	**121**	± 1%	uS / cm
Calculations									
Total Cations	**11.0**	**9.0**	**2.2**	**9.2**	**7.2**	**5.8**	**1.4**	-	meq
Total Anions	**10.4**	**8.2**	**1.7**	**8.5**	**6.6**	**5.5**	**1.3**	-	meq
Calculated TDS	**694**	**570**	**123**	**586**	**454**	**376**	**93**	-	mg/L
Actual TDS - Calc. (diff)	**-47.4**	**-65.0**	**33.6**	**-79.0**	**-54.8**	**-35.9**	**16.1**	-	mg/L
% Na to Tot. Cations	**12.0**	**10.3**	**18.7**	**10.6**	**11.4**	**11.6**	**13.9**	-	%

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[blue shading] Exceeds MN WQ Standard

Twin Lakes
Inflow / Outflow Sampling Event

9/28/2017

Analytes - Cations	Little Sandy Inflow 1	Little Sandy Inflow 2	Sandy South Inflow	Little Sandy Middle	Sandy Middle	Twin Lakes Outflow	Culvert Inflow	Reporting Limits	Reporting Units
Calcium	**50.7**	**42.8**	**8.6**	**44.3**	**37.3**	**28.0**	**11**	**0.50**	mg / L
Iron	**1810**	**671**	**3880**	**479**	**1050**	**1330**	**3550**	**50.0**	ug / L
Magnesium	**70.7**	**66.8**	**10.2**	**68.8**	**56**	**39.0**	**3.8**	0.50	mg / L
Manganese	**76.6**	**58.6**	**142**	**56.5**	**57.6**	**68.2**	**156**	10.0	ug / L
Potassium	**5.9**	**2.9**	**2.3**	**3.4**	**3.1**	**2.5**	**1.6**	0.50	mg / L
Sodium	**26.8**	**18.6**	**8.7**	**21.1**	**18.6**	**13.9**	**4.1**	0.50	mg / L
Analytes - Anions									
Chloride	**43.2**	**27.7**	**21.6**	**32.3**	**28.4**	**22.1**	**11.4**	varies	mg / l
Nitrogen, Kjeldahl, Total	**0.64**	**0.86**	**0.69**	**0.61**	**0.80**	**0.68**	**0.57**	0.60/0.50	mg / L
Ammonia as Nitrogen	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	<0.10	0.10	mg / L
Unionized ammonia as N	<0.06	<1.0	**<0.32**	**<2.4**	**<1.3**	**<1.1**	**<0.17**	varies	ug/L
Sulfate	**230**	**170**	**<2.0**	**192**	**153**	**99.5**	<2.0	2.0/8.0	mg / L
Analytes - Other									
Total Dissolved Solids	**360**	**468**	**116**	**472**	**376**	**272**	**80**	40.0	mg / L
Total Suspended Solids	**1.2**	**2.0**	**1.6**	**1.6**	**1.6**	**1.6**	**4.0**	1.0	mg / L
Alkalinity, Total as HCO3-	**181**	**223**	**52.3**	**220**	**178**	**132**	**36.2**	12.3	mg / L
Alkalinity, Total as CaCO3	**148**	**183**	**42.9**	**180**	**146**	**108**	**29.7**	12.3	mg / L
Dissolved Organic Carbon	**21.6**	**24.2**	**26.2**	**22.7**	**24.9**	**24.1**	**20.4**	1.0/2.0	mg / L
Total Hardness by 2340B	**418**	**382**	**63.5**	**394**	**324**	**231**	**42.9**	3.3	mg / L
YSI Data									
pH	**7.4**	**7.6**	**7.1**	**7.9**	**7.7**	**7.6**	**6.9**	**± 0.2**	Units
Temperature	**13.1**	**14.8**	**12.7**	**15.1**	**14.7**	**13.6**	**11.6**	**± 0.1**	ºC
Specific Conductance	**863**	**763**	**171**	**802**	**673**	**480**	**65.5**	**± 1%**	uS / cm
Calculations									
Total Cations	**9.7**	**8.5**	**1.8**	**8.9**	**7.4**	**5.3**	**1.2**	-	meq
Total Anions	**9.0**	**8.0**	**1.5**	**8.6**	**7.0**	**4.9**	**1.0**	-	meq
Calculated TDS	**611**	**553**	**108**	**583**	**476**	**339**	**74**	-	mg/L
Actual TDS - Calc. (diff)	**-250.8**	**-85.4**	**7.6**	**-111.0**	**-100.3**	**-67.1**	**5.6**	-	mg/L
% Na to Tot. Cations	**12.0**	**9.5**	**20.5**	**10.3**	**10.9**	**11.4**	**14.7**	-	%

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[blue shading] Exceeds MN WQ Standard

Twin Lakes
Inflow / Outflow Sampling Event

10/26/2017

	Little Sandy Inflow 1	Little Sandy Inflow 2	Sandy South Inflow	Little Sandy Middle	Sandy Middle	Twin Lakes Outflow	Culvert Inflow	Reporting Limits	Reporting Units
Analytes - Cations									
Calcium	**56.4**	**41.1**	**7.8**	**41.2**	**34.5**	**31.3**	**11.2**	0.50	mg / L
Iron	**1840**	**1020**	**3750**	**722**	**1100**	**1080**	**2710**	50.0	ug / L
Magnesium	**81.5**	**63.8**	**9.7**	**62.3**	**52.2**	**45.2**	**3.9**	0.50	mg / L
Manganese	**106**	**42.4**	**128**	**29.5**	**43.3**	**41.6**	**129**	10.0	ug / L
Potassium	**7.2**	**3.4**	**1.8**	**3.9**	**3.5**	**3.1**	**1.5**	0.50	mg / L
Sodium	**30.7**	**18.0**	**7.8**	**19.4**	**17.2**	**15.6**	**4.4**	0.50	mg / L
Analytes - Anions									
Chloride	**50.1**	**28.6**	**16.7**	**31.4**	**28.3**	**26.0**	**12.9**	2.0	mg / l
Nitrogen, Kjeldahl, Total	**0.70**	**0.83**	**0.83**	**0.65**	**0.76**	**0.82**	**0.46**	0.20	mg / L
Ammonia as Nitrogen	<0.10	**0.14**	**0.19**	**0.10**	**0.18**	**0.15**	**0.16**	0.10	mg / L
Unionized ammonia as N	<0.03	**0.58**	**0.11**	**1.8**	**2.8**	**1.3**	**0.13**	varies	ug/L
Sulfate	**282**	**176**	**2.3**	**190**	**152**	**128**	**2.8**	4.0	mg / L
Analytes - Other									
Total Dissolved Solids	**674**	**474**	**126**	**446**	**412**	**390**	**84.0**	10.0	mg / L
Total Suspended Solids	**1.2**	**1.6**	**2.0**	<1.0	<1.0	**1.2**	**3.2**	1.0	mg / L
Alkalinity, Total as HCO3-	**174**	**171**	**42.6**	**162**	**133**	**119**	**36.3**	10.0	mg / L
Alkalinity, Total as CaCO3	**143**	**140**	**34.9**	**133**	**109**	**97.5**	**29.8**	10.0	mg / L
Dissolved Organic Carbon	**20.4**	**25.6**	**25.7**	**23.1**	**25.4**	**24.7**	**12.2**	1.0	mg / L
Total Hardness by 2340B	**477**	**365**	**59.3**	**359**	**301**	**264**	**44.2**	3.3	mg / L
YSI Data									
pH	**7.3**	**7.5**	**6.6**	**8.1**	**8.0**	**7.8**	**6.8**	± 0.2	Units
Temperature	**5.8**	**6.1**	**6.1**	**6.9**	**6.8**	**6.9**	**6.2**	± 0.1	ºC
Specific Conductance	**989**	**719**	**158**	**730**	**721**	**558**	**118**	± 1%	uS / cm
Calculations									
Total Cations	**11.1**	**8.2**	**1.7**	**8.2**	**6.9**	**6.1**	**1.2**	-	meq
Total Anions	**10.2**	**7.3**	**1.3**	**7.5**	**6.2**	**5.4**	**1.1**	-	meq
Calculated TDS	**685**	**504**	**93**	**512**	**423**	**370**	**76**	-	mg/L
Actual TDS - Calc. (diff)	**-10.5**	**-29.8**	**32.6**	**-65.6**	**-10.6**	**19.9**	**7.7**	-	mg/L
% Na to Tot. Cations	**12.0**	**9.5**	**19.8**	**10.4**	**10.9**	**11.2**	**15.8**	-	%

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(blue shading) Exceeds MN WQ Standard

Twin Lakes
Inflow / Outflow Sampling Event
5/31/2018

	Little Sandy Inflow 1	Little Sandy Inflow 2	Sandy South Inflow	Little Sandy Middle	Sandy Middle	Culvert Inflow	Twin Lakes Outflow	Reporting Limits	Reporting Units
Analytes - Cations									
Calcium	**43.4**	**40.4**	**5.6**	**31.1**	**40.0**	**11.3**	**30.6**	0.50	mg / L
Iron	**1440**	**335**	**2310**	**243**	**329**	**2930**	**521**	50.0	ug / L
Magnesium	**57.0**	**60.1**	**6.2**	**46.0**	**59.6**	**3.8**	**43.9**	0.50	mg / L
Manganese	**75.6**	**99**	**54.3**	**64.6**	130	**153**	**105**	10.0	ug / L
Potassium	**6.7**	**5.5**	**1.7**	**4.4**	**5.5**	**1.8**	**4.3**	0.50	mg / L
Sodium	**23.9**	**18.9**	**6.6**	**15.3**	**18.8**	**4.5**	**14.7**	0.50	mg / L
Analytes - Anions									
Chloride	**35.9**	**29.3**	**9.2**	**26**	**30.1**	**11.1**	< 1.0	1.0	mg / l
Nitrogen, Kjeldahl, Total	**0.85**	**0.65**	**0.97**	NM	NM	< 0.60	**0.65**	0.60	mg / L
Ammonia as Nitrogen	< 0.10	< 0.10	**0.13**	NM	NM	**0.11**	< 0.10	0.10	mg / L
Unionized ammonia as N	0.42	0.29	**0.20**	NM	NM	**0.35**	2.24	varies	ug/L
Sulfate	**193**	**186**	< 2.0	**148**	**186**	< 2.0	**6.0**	2.0/40.0	mg / L
Analytes - Other									
Total Dissolved Solids	**546**	**480**	**140**	NM	NM	**136**	**368**	10.0/20.0	mg / L
Total Suspended Solids	**2.0**	**5.3**	**10**	NM	NM	**7.3**	**4.7**	1.7	mg / L
Alkalinity, Total as HCO3-	**138**	**173**	**40.5**	NM	NM	**38.4**	**134**	12.2	mg / L
Alkalinity, Total as CaCO3	**113**	**142**	**33.2**	NM	NM	**31.5**	**110**	10.0	mg / L
Dissolved Organic Carbon	**18.9**	**15.5**	**27.8**	NM	NM	**17.0**	**14.2**	1.0	mg / L
Total Hardness by 2340B	**343**	**348**	**39.7**	NM	NM	**43.8**	**257**	3.3	mg / L
YSI Data									
pH	**7.1**	**6.8**	**6.7**	**7.8**	**7.8**	**7.1**	**7.7**	± 0.2	Units
Temperature	**17.0**	**21.0**	**15.6**	**22.4**	**22.4**	**14.7**	**21.6**	± 0.1	ºC
Specific Conductance	**734**	**712**	**553**	**721**	**605**	**115**	**553**	± 1%	uS / cm
Calculations									
Total Cations	**8.1**	**6.2**	**1.2**	**6.1**	**7.9**	**1.2**	**5.9**	-	meq
Total Anions	**7.4**	**6.4**	**1.0**	NM	NM	**1.0**	**2.4**	-	meq
Calculated TDS	**500**	**433**	**75**	NM	NM	**77**	**236**	-	mg/L
Actual TDS - Calc. (diff)	**45.9**	**-1.2**	**64.9**	NM	NM	**59.4**	**132.0**	-	mg/L
% Na to Tot. Cations	**12.8**	**10.1**	**23.8**	NM	NM	**15.9**	**10.8**	-	%

Sulfate values 193 (Little Sandy Inflow 1), 186 (Little Sandy Inflow 2), 148 (Little Sandy Middle) and 186 (Sandy Middle) are highlighted as exceeding the WQ standard.

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[blue shading] Exceeds WQ Standard

Twin Lakes
Inflow / Outflow Sampling Event

6/29/2018

	Little Sandy Inflow 1	Little Sandy Inflow 2	Sandy South Inflow	Little Sandy Middle	Sandy Middle	Culvert Inflow	Twin Lakes Outflow	Reporting Limits	Reporting Units
Analytes - Cations									
Calcium	**35.5**	**31.9**	**6.2**	**37.2**	**29.2**	**8.5**	**26.7**	0.50	mg / L
Iron	**2100**	**923**	**2490**	**417**	**414**	**3520**	**916**	50.0	ug / L
Magnesium	**47.3**	**47.0**	**7.3**	**56.3**	**43.7**	**2.9**	**37.7**	0.50	mg / L
Manganese	**64.0**	**101**	**69.6**	**117**	**96.1**	**133**	**102**	5.0	ug / L
Potassium	**3.4**	**3.2**	< 2.5	**3.9**	**3.9**	< 2.5	**3.4**	2.5	mg / L
Sodium	**18.9**	**14.4**	**3.9**	**17.3**	**15.1**	**3.5**	**13.2**	1.0	mg / L
Analytes - Anions									
Chloride	**27.1**	**22.0**	**3.8**	**26.4**	**24.4**	**8.0**	**21.7**	1.0	mg / L
Nitrogen, Kjeldahl, Total	**1.1**	**0.96**	**1.1**	**0.71**	**0.76**	**0.78**	**0.66**	0.50	mg / L
Ammonia as Nitrogen	**0.14**	**0.15**	**0.20**	< 0.11	< 0.11	**0.12**	**0.16**	0.11	mg / L
Unionized ammonia as N	**0.57**	**0.77**	**0.14**	<2.5	<2.0	**0.19**	**2.55**	varies	ug/L
Sulfate	**164**	**137**	< 2.0	**164**	**135**	< 2.0	**109**	2.0	mg / L
Analytes - Other									
Total Dissolved Solids	**459**	**432**	**120**	NM	NM	**104**	**345**	10.0/20.0	mg / L
Total Suspended Solids	**1.2**	< 1.0	**6.4**	NM	NM	**5.3**	**1.6**	1.0/1.7	mg / L
Alkalinity, Total as HCO3-	**154**	**176**	**44.4**	NM	NM	**33.1**	**131**	12.2	mg / L
Alkalinity, Total as CaCO3	**126**	**144**	**36.4**	NM	NM	**27.1**	**107**	10.0	mg / L
Dissolved Organic Carbon	**28.8**	**25.1**	**33.0**	NM	NM	**22.0**	**17.8**	1.0	mg / L
Total Hardness by 2340B	**283**	**273**	**45.7**	NM	NM	**33.3**	**222**	3.3	mg / L
YSI Data									
pH	**7.1**	**7.1**	**6.4**	**7.7**	**7.6**	**6.8**	**7.6**	± 0.2	Units
Temperature	**18.8**	**20.7**	**16.6**	**22.0**	**21.4**	**15.2**	**20.4**	± 0.1	ºC
Specific Conductance	**625**	**606**	**94**	**678**	**571**	**83.4**	**481**	± 1%	uS / cm
Calculations									
Total Cations	**6.6**	**6.2**	**1.2**	**7.4**	**5.8**	**1.0**	**5.1**	-	meq
Total Anions	**-6.8**	**-6.4**	**-1.3**	NM	NM	**-0.9**	**-5.1**	-	meq
Calculated TDS	**453**	**433**	**86**	NM	NM	**65**	**344**	-	mg/L
Actual TDS - Calc. (diff)	**5.8**	**-1.2**	**33.9**	NM	NM	**39.1**	**1.1**	-	mg/L
% Na to Tot. Cations	**12.4**	**10.1**	**13.7**	NM	NM	**15.1**	**11.2**	-	%

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Exceeds WQ Standard

Twin Lakes
Inflow / Outflow Sampling Event
7/27/2018

	Little Sandy Inflow 1	Little Sandy Inflow 2	Sandy South Inflow	Little Sandy Middle	Sandy Middle	Culvert Inflow	Twin Lakes Outflow	Reporting Limits	Reporting Units
Analytes - Cations									
Calcium	**59.2**	**38.7**	**10**	**37.7**	**29.9**	**13.6**	**27.2**	0.10	mg / L
Iron	**1560**	**2670**	**8730**	**2580**	**1120**	**3000**	**1320**	50.0	ug / L
Magnesium	**76.8**	**51.9**	**10.4**	**52.2**	**43.9**	**4.9**	**36.6**	0.10	mg / L
Manganese	**160**	**201**	**186**	**200**	**59.2**	**144**	**55.7**	0.50	ug / L
Potassium	**3.2**	**2.5**	**0.5**	**2.7**	**2.9**	**1.3**	**2.6**	0.1	mg / L
Sodium	**31.4**	**16.4**	**3.5**	**17.4**	**15.4**	**5.2**	**12.9**	0.10	mg / L
Analytes - Anions									
Chloride	**44.9**	**22.7**	**3.6**	**24.1**	**21.3**	**15.1**	**19.3**	1.0	mg / l
Nitrogen, Kjeldahl, Total	**0.53**	**1.0**	**1.5**	NM	NM	< 0.50	**0.61**	0.50	mg / L
Ammonia as Nitrogen	**0.12**	**0.18**	**0.75**	NM	NM	**0.16**	**0.18**	0.11	mg / L
Unionized ammonia as N	**0.53**	**0.54**	**0.95**	NM	NM	**0.22**	**1.40**	varies	ug/L
Sulfate	**214**	**131**	< 2.0	**136**	**113**	**2.9**	**92.6**	2.0/6.0	mg / L
Analytes - Other									
Total Dissolved Solids	**716**	**478**	**188**	NM	NM	**118**	**328**	20.0	mg / L
Total Suspended Solids	< 1.0	**7.0**	< 2.5	NM	NM	**3.0**	**1.2**	1.0/2.5	mg / L
Alkalinity, Total as HCO3-	**285**	**238**	**72.7**	NM	NM	**49.4**	**161**	12.2	mg / L
Alkalinity, Total as CaCO3	**234**	**195**	**59.6**	NM	NM	**40.5**	**132**	10.0	mg / L
Dissolved Organic Carbon	**26.7**	**35.4**	**52.1**	NM	NM	**12.1**	**28.4**	1.0/4.0	mg / L
Total Hardness by 2340B	**464**	**310**	**67.7**	NM	NM	**54.0**	**219**	0.66	mg / L
YSI Data									
pH	**7.1**	**6.9**	**6.6**	**7.7**	**7.8**	**6.7**	**7.4**	± 0.2	Units
Temperature	**17.5**	**19.7**	**15.8**	**19.5**	**19.0**	**14.0**	**17.9**	± 0.1	ºC
Specific Conductance	**1024**	**672**	**150**	**673**	**553**	**147.8**	**487**	± 1%	uS / cm
Calculations									
Total Cations	**10.8**	**7.1**	**1.8**	**7.1**	**5.9**	**1.5**	**5.0**	-	meq
Total Anions	**-10.4**	**-7.3**	**-1.4**	**-3.5**	**-3.0**	**-1.3**	**-5.2**	-	meq
Calculated TDS	**717**	**505**	**113**	NM	NM	**96**	**354**	-	mg/L
Actual TDS - Calc. (diff)	**-1.3**	**-27.0**	**74.9**	NM	NM	**22.0**	**-26.2**	-	mg/L
% Na to Tot. Cations	**12.7**	**10.1**	**8.3**	NM	NM	**15.6**	**11.1**	-	%

Bold Print indicates the sample is above the detection limit
"<" indicates value below reporting limit
NM indicates that the analyte was not measured
(blue shading) Exceeds WQ Standard

Twin Lakes
Inflow / Outflow Sampling Event
8/29/2018

	Little Sandy Inflow 1	Little Sandy Inflow 2	Sandy South Inflow	Little Sandy Middle	Sandy Middle	Culvert Inflow	Twin Lakes Outflow	Reporting Limits	Reporting Units
Analytes - Cations									
Calcium	**105**	**49.3**	**10.0**	**34.8**	**49.4**	**14.6**	**27.5**	0.50	mg / L
Iron	**656**	**177**	**10900**	**144**	**114**	**2010**	**652**	50.0	ug / L
Magnesium	**334**	**74.3**	**9.0**	**52.0**	**75.0**	**4.7**	**35.3**	0.50	mg / L
Manganese	**53.1**	**65.7**	**188**	**33.9**	**34.1**	**105**	**88.7**	5.0	ug / L
Potassium	**11.1**	**3.4**	< 2.5	**3.0**	**3.5**	< 2.5	**2.5**	2.5	mg / L
Sodium	**67.3**	**24.3**	**3.4**	**17.2**	**25.1**	**5.2**	**12.6**	1.0	mg / L
Analytes - Anions									
Chloride	**111**	**35.0**	**3.5**	**24.6**	**36.9**	**17.9**	**22.2**	1.0	mg / l
Nitrogen, Kjeldahl, Total	< 0.50	**0.64**	**1.7**	**0.75**	**0.61**	< 0.50	**0.53**	0.50	mg / L
Ammonia as Nitrogen	**0.18**	**0.23**	**1.1**	**0.18**	**0.18**	**0.20**	**0.22**	0.11	mg / L
Unionized ammonia as N	**3.35**	**4.47**	**0.61**	**14.37**	**4.95**	**0.36**	**1.41**	varies	ug/L
Sulfate	**652**	**188**	< 2.0	**121**	**199**	**4.1**	**79.1**	2.0/10.0	mg / L
Analytes - Other									
Total Dissolved Solids	**1440**	**580**	**150**	NM	NM	**120**	**318**	20.0	mg / L
Total Suspended Solids	**2.0**	**2.4**	**15.0**	NM	NM	**2.4**	**2.0**	1.0/2.5	mg / L
Alkalinity, Total as HCO3-	**407**	**290**	**75.6**	NM	NM	**57.2**	**161**	12.2	mg / L
Alkalinity, Total as CaCO3	**334**	**238**	**62.0**	NM	NM	**46.9**	**132**	10.0	mg / L
Dissolved Organic Carbon	**10.7**	**27.0**	**29.6**	NM	NM	**6.8**	**20.2**	1.0	mg / L
Total Hardness by 2340B	**986**	**429**	**62.0**	NM	NM	**55.6**	**214**	3.3	mg / L
YSI Data									
pH	**7.8**	**7.8**	**6.3**	**8.4**	**7.9**	**6.9**	**7.3**	± 0.2	Units
Temperature	**17.2**	**18.1**	**14.5**	**17.6**	**17.2**	**13.4**	**16.2**	± 0.1	ºC
Specific Conductance	**1925**	**921**	**171**	**890**	**635**	**164**	**480**	± 1%	uS / cm
Calculations									
Total Cations	**23.0**	**9.7**	**1.8**	**6.8**	9.8	1.5	**4.9**	-	meq
Total Anions	**23.4**	**9.7**	**1.5**	NM	NM	1.6	**5.0**	-	meq
Calculated TDS	**1531**	**666**	**119**	NM	NM	109	**342**	-	mg/L
Actual TDS - Calc. (diff)	**-91.1**	**-85.5**	**31.2**	NM	NM	11.2	**-23.5**	-	mg/L
% Na to Tot. Cations	**12.8**	**10.9**	**8.0**	NM	NM	15.3	**11.1**	-	%

Bold Print indicates the sample is above the detection limit
"<" indicates value below reporting limit
NM indicates that the analyte was not measured
(blue shading) Exceeds WQ Standard

Twin Lakes
Inflow / Outflow Sampling Event
9/26/2018

	Little Sandy Inflow 1	Little Sandy Inflow 2	Sandy South Inflow	Little Sandy Middle	Sandy Middle	Culvert Inflow	Twin Lakes Outflow	Reporting Limits	Reporting Units
Analytes - Cations									
Calcium	**53.5**	**50.7**	**5**	**50.3**	**46.2**	**9.8**	**34.2**	0.50	mg / L
Iron	**634**	**245**	**1110**	**201**	**250**	**1420**	**386**	50.0	ug / L
Magnesium	**65.6**	**72.5**	**5.3**	**71.8**	**64**	**3.4**	**46.4**	0.50	mg / L
Manganese	**67.2**	**35.2**	**13.9**	**26.3**	**31.2**	**61.4**	**40.4**	5.0	ug / L
Potassium	**4.85**	**3.93**	**0.89**	**4.12**	**4.07**	**1.56**	**3.27**	2.5	mg / L
Sodium	**25.7**	**24.1**	**2.9**	**25.2**	**23.2**	**5.8**	**17.6**	1.0	mg / L
Analytes - Anions									
Chloride	**44.6**	**38.2**	**4.6**	**41.1**	**37.3**	**15.1**	**26.5**	1.0	mg / l
Nitrogen, Kjeldahl, Total	< 0.5	< 0.5	**0.56**	< 0.5	< 0.5	< 0.5	< 0.5	0.50	mg / L
Ammonia as Nitrogen	< 0.11	< 0.11	**0.15**	< 0.11	0.11	**0.11**	**0.13**	0.11	mg / L
Unionized ammonia as N	0.57	0.44	**0.34**	2.33	**1.22**	**0.12**	**0.59**	varies	ug/L
Sulfate	**292**	**220**	< 2.0	**241**	**207**	< 2.0	**127**	2.0/10.0	mg / L
Analytes - Other									
Total Dissolved Solids	**638**	**632**	**109**	NM	NM	**98**	**400**	20.0	mg / L
Total Suspended Solids	< 1.0	< 1.0	< 1.0	NM	NM	< 1.0	< 1.0	1.0/2.5	mg / L
Alkalinity, Total as HCO3-	**150**	**264**	**36.5**	NM	NM	**35.0**	**193**	12.2	mg / L
Alkalinity, Total as CaCO3	**123**	**216**	**29.9**	NM	NM	**28.7**	**158.0**	10.0	mg / L
Dissolved Organic Carbon	**14.3**	**21**	**30.8**	NM	NM	**14.5**	**21.5**	1.0	mg / L
Total Hardness by 2340B	**404**	**425**	**34.3**	NM	NM	**38.6**	**276**	3.3	mg / L
YSI Data									
pH	**7.5**	**7.4**	**7.1**	**8.1**	**7.8**	**6.8**	**7.4**	± 0.2	Units
Temperature	**9.3**	**10.0**	**9.4**	**10.5**	**10.4**	**9.1**	**10.0**	± 0.1	ºC
Specific Conductance	**914**	**910**	**80**	**927**	**830**	**116**	**612**	± 1%	uS / cm
Calculations									
Total Cations	**9.3**	**9.7**	**0.9**	**9.6**	**8.7**	**1.1**	**6.4**	-	meq
Total Anions	**-9.8**	**-10.0**	**-0.8**	NM	NM	**-1.1**	**-6.6**	-	meq
Calculated TDS	**638**	**674**	**59**	NM	NM	**75**	**449**	-	mg/L
Actual TDS - Calc. (diff)	**0.5**	**-41.7**	**50.1**	NM	NM	**23.3**	**-48.7**	-	mg/L
% Na to Tot. Cations	**12.0**	**10.9**	**14.4**	NM	NM	**22.6**	**12.0**	-	%

Highlighted (exceeds WQ Standard): Sulfate values 292, 220, 241, 207, 127.

Bold Print indicates the sample is above the detection limit	
"<" indicates value below reporting limit	
NM indicates that the analyte was not measured	
[blue fill]	Exceeds WQ Standard

Twin Lakes
Inflow / Outflow Sampling Event
10/22/2018

	Little Sandy Inflow 1	Little Sandy Inflow 2	Sandy South Inflow	Little Sandy Middle	Sandy Middle	Culvert Inflow	Twin Lakes Outflow	Reporting Limits	Reporting Units
Analytes - Cations									
Calcium	**44.3**	**23.0**	**3.69**	**38.9**	**34.8**	**9.4**	**33.1**	0.50	mg / L
Iron	**541**	**5760**	**871**	**354**	**561**	**1010**	**522**	100.0	ug / L
Magnesium	**67.9**	**34.8**	**4.46**	**67.4**	**55.8**	**3.37**	**52.0**	0.50	mg / L
Manganese	**26.8**	**227**	**8.31**	**18.6**	**25.2**	**55.6**	**23.5**	10.0	ug / L
Potassium	**5.61**	**1.58**	**0.652**	**3.43**	**0.107**	**1.40**	**3.22**	0.50	mg / L
Sodium	**27.1**	**9.14**	**2.35**	**19.1**	**17.9**	**5.02**	**16.9**	0.50	mg / L
Analytes - Anions									
Chloride	**40.9**	**20.7**	**2.8**	**28.4**	**31.3**	**12.7**	**27.4**	2.0	mg / l
Nitrogen, Kjeldahl, Total	< 0.50	**1.4**	**0.62**	**0.57**	**0.52**	< 0.5	< 0.5	0.50	mg / L
Ammonia as Nitrogen	< 0.11	**0.14**	**0.13**	< 0.11	< 0.11	**0.12**	**0.11**	0.11	mg / L
Unionized ammonia as N	0.19	**0.64**	**0.16**	0.95	0.69	**0.02**	**0.77**	varies	ug/L
Sulfate	**246**	**165**	**3.8**	**181**	**223**	**2.5**	**165**	4.0	mg / L
Analytes - Other									
Total Dissolved Solids	**552**	**394**	**72.0**	NM	NM	**74.0**	**382**	10.0	mg / L
Total Suspended Solids	< 1.0	**2.4**	**6.0**	NM	NM	< 1.0	**2.4**	1.0	mg / L
Alkalinity, Total as HCO3-	**155**	**80.5**	**24.5**	NM	NM	**31.8**	**137**	12.2	mg / L
Alkalinity, Total as CaCO3	**127**	**66.0**	**20.1**	NM	NM	**26.1**	**112**	10.0	mg / L
Dissolved Organic Carbon	**12.0**	**37.2**	**21.9**	NM	NM	**10.7**	**18**	1.0	mg / L
Total Hardness by 2340B	**390**	**201**	**27.6**	**375**	**317**	**37.3**	**297**	2.5	mg / L
YSI Data									
pH	**7.3**	**7.6**	**7.1**	**7.9**	**7.8**	**6.3**	**7.8**	± 0.2	Units
Temperature	**2.0**	**4.0**	**2.5**	**3.6**	**3.9**	**3.4**	**4.3**	± 0.1	ºC
Specific Conductance	**805**	**683**	**56.9**	**726**	**614**	**102**	**573**	± 1%	uS / cm
Calculations									
Total Cations	**9.1**	**4.7**	**0.7**	**8.4**	**7.1**	**1.0**	**6.8**	-	meq
Total Anions	**8.9**	**5.4**	**0.6**	NM	NM	**1.0**	**6.5**	-	meq
Calculated TDS	**588**	**342**	**44**	NM	NM	**68**	**435**	-	mg/L
Actual TDS - Calc. (diff)	**-35.8**	**51.9**	**28.2**	NM	NM	**6.2**	**-53.3**	-	mg/L
% Na to Tot. Cations	**12.9**	**8.5**	**14.6**	NM	NM	**21.1**	**10.9**	-	%

Bold Print indicates the sample is above the detection limit
"<" indicates value below reporting limit
NM indicates that the analyte was not measured
[blue shading] Exceeds WQ Standard

APPENDIX B

RESULTS OF WILD RICE GROWTH STUDIES IN SEDIMENT FROM MINING-INFLUENCED LAKES IN ONTARIO, CANADA

RESULTS OF WILD RICE GROWTH STUDIES IN SEDIMENT FROM MINING-INFLUENCED LAKES IN ONTARIO, CANADA

Separate studies related to wild rice restoration have been completed on two mining-influenced lakes in Ontario, Canada. The subject Canadian lakes are significantly different from the Twin Lakes in that they are both meromictic (i.e., chemically stratified), with diverse and complex chemical characteristics below the chemocline, and receive significantly greater inputs of dissolved constituents. Similar to the studies described above, sediment from the two subject Canadian lakes were used to evaluate the growth potential of wild rice in contrast to sediment from a non-industry influenced aquatic system. Results of the evaluation indicated that there were no significant differences in wild rice seed germination between the three sediment sources. Subsequent mesocosm growth studies using sediment from the subject mining-influenced, as well as non-industry influenced, Canadian lakes resulted in the successful growth of wild rice seedlings into reproductively mature plants from all three sediment sources.

Two lakes in Ontario, Canada, which have received similar mining influences for a similar duration of time, have been subjects of various studies focused on remediation and restoration, and the potential for complete mixing – both lakes are meromictic, with diverse and complex chemical characteristics below the chemocline. Tables 1 – 3 (below) detail specific chemical and physical characteristics of sediment obtained from cores of Sandy Lake (SL), Little Sandy Lake (LSL), and the two mining influenced lakes in Ontario, Canada, referred to as 'Lake A' and 'Lake B' to protect site and client confidentiality.

Sediment samples from Lakes A and B were used, and continue to be used, in a series of experiments designed to determine responses of wild rice to exposures of these sediments. During winter 2017-2018, Lake A and Lake B sediments were used in wild rice growth experiments in a greenhouse at Lakehead University in Thunder Bay, Ontario. One overall conclusion obtained during these experiments was that there appeared to be no germination difference between wild rice seeds exposed to Lake A or Lake B sediment, and sediment from Rat River Bay, a non-industry influenced aquatic system. Therefore, based on these germination data, during summer 2018 wild rice seeds were germinated into seedlings inside a temperature / light / humidity-controlled incubator, and planted in multiple buckets in three different mesocosms each, mesocosm containing a different sediment (Lake A, B, or Rat River Bay).

Despite obvious differences in chemical characteristics between Lakes A and B and the Twin Lakes (Sandy and Little Sandy Lakes; most often orders of magnitude difference in measured concentrations of specific elements), wild rice seedlings grew and developed into reproductively mature plants in both Lake A and Lake B sediments in these mesocosm studies. Mature, seed-producing wild rice plants grown in Lake A (Figures 1-4) and Lake B (Figures 5-8) are detailed below.

Based on these observations, and observations of wild rice seedlings having grown in Sandy Lake sediment in 2013 and 2014 bioassay tests, Sandy Lake, and likely Little Sandy Lake, sediments will support germination, growth, and development of wild rice into mature reproductively viable (i.e., seed producing) plants under field conditions.

Based on the data collection and observations obtained during the Plan between 2013 and 2015, wild rice seeding events of select areas within each lake were developed and completed. Specifics of these wild rice seeding efforts are detailed in Section 8.0 of this report. However, in summary, over the course of two years of observations of wild rice seeded areas, wild rice plants in the aerial developmental stage were observer in all areas seeded within the Twin Lakes system. Therefore, in areas of appropriate water depth and lack of competing vegetation, both Little Sandy and Sandy Lakes' sediment will support germination, growth, and development of wild rice into mature, seed producing plants. Overall, the quality of the sediment in both Little Sandy and Sandy Lakes is more than sufficient to support germination, growth, and development of wild rice into reproductively mature, seed producing plants. With proper management of water depth and competing vegetation, and sufficiently intense, multi-year seeding efforts, development of a self-sustaining population of wild rice in the Twin Lakes is entirely possible.

TABLE 1. CHARACTERISTICS OF SEDIMENT CORE SAMPLES FROM LITTLE SANDY LAKE (LSL), SANDY LAKE (SL) – THE CURRENT STUDY TWIN LAKES SYSTEM – AND TWO INDUSTRY-INFLUENCED LAKES IN ONTARIO. SEDIMENT CORES WERE OBTAINED NEAR AQUEOUS INFLOWS TO EACH RESPECTIVE SYSTEM. CONCENTRATIONS ARE AVERAGES OF TWO SEPARATE CORE SECTIONS. TWIN LAKES CONCENTRATIONS ARE THE AVERAGE OF 0-5 AND 6-10 CM SECTIONS OF THE SAME CORE; 'LAKE A' AND 'LAKE B' CONCENTRATIONS ARE THE AVERAGE OF 0-4 AND 5-8 CM SECTION OF THE SAME CORE.

	SL INFLOW (S10; 0-10 CM AVG.)	LSL INFLOW 1 (LSL2; 0-10 CM AVG.)	LSL INFLOW 2 (LSL10; 0-10 CM AVG.)	* 'LAKE A' INFLOW (0-8 CM AVG.)	* 'LAKE B' INFLOW (0-8 CM AVG.)
% MOISTURE	39.005	85.145	87.43	28.405	46.3
AVS (UMOL/G)	4.835	117.7785	5.865	** NC	NC
SEM [CD,CU,NI,PB,ZN] (UMOL/G)	0.035	0.1135	0.0975	9.376	1.0831
BULK DENSITY (G/CM^3)	1.045	0.18	0.155	0.49	0.16
AS, TOTAL (UG/G)	NC	0.01028	0.00828	NC	NC
CD, TOTAL (UG/G)	NC	0.00039	0.000675	1.16	0.94
CO, TOTAL (UG/G)	0.002465	0.009945	0.00438	12.275	17.275
CR, TOTAL (UG/G)	0.007275	0.023025	0.01561	20.595	38.635
CU, TOTAL (UG/G)	0.00252	0.011735	0.01001	33.745	67.515
FE, TOTAL (UG/G)	10.503375	85.9214	37.7677	11801.15	15987.45
MN, TOTAL (UG/G)	0.059625	0.53445	0.404295	221.12	401.19
MO, TOTAL (UG/G)	NC	NC	NC	NC	24.98
NI, TOTAL (UG/G)	0.00353	0.01088	0.008045	14.45	39.945
PB, TOTAL (UG/G)	0.00744	0.037365	0.02286	NC	43.025
S, TOTAL (UG/G)	5.91756	71.9824	44.87095	607.43	8300.325
SE, TOTAL (UG/G)	NC	NC	NC	NC	NC
ZN, TOTAL (UG/G)	0.01864	0.091185	0.07302	282.77	141.59
TOTAL CARBON (%C)	2.44	16.445	19.925	3.23	18.485
N IN SEDIMENT (%N)	0.2	1.35	1.715	0.15	1.22

* Labeled 'Lake A' and 'Lake B' to protect site and client confidentiality. 'Lake A' is a legacy mining industry influenced lake at the further-more upstream position in a chain of lakes; 'Lake B' is a currently industry-influenced lake in a chain of lakes. Outflow from lakes in these two discreet systems terminate into Lake Superior.

** Not Calculable.

Table 2. Characteristics of sediment core samples from Little Sandy Lake, Sandy Lake – the current study Twin Lakes system – and two industry-influenced lakes in Ontario. Sediment cores were obtained near the middle of each respective system. Concentrations are averages of two separate core sections. Twin Lakes concentrations are the average of 0-5 and 6-10 cm sections of the same core; 'Lake A' and 'Lake B' concentrations are the average of 0-4 and 5-8 cm sections of the same core.

	SL MID (S5; 0-10 CM AVG.)	SL MID (S8; 0-10 CM AVG.)	LSL MID (LSL4; 0-10 CM AVG.)	LSL MID (LSL7; 0-10 CM AVG.)	* 'LAKE A' MID (0-8 CM AVG.)	* 'LAKE B' MID (0-8 CM AVG.)
% MOISTURE	86.945	80.875	86.305	86.635	48.42	49.57
AVS (UMOL/G)	9.67	7.8	43.1845	33.435	441.56	89.18
SEM [CD,CU,NI,PB,ZN] (UMOL/G)	1.3325	0.103	0.0935	0.094	3.15275	0.87115
BULK DENSITY (G/CM^3)	0.09	0.22	0.18	0.16	0.145	0.155
AS, TOTAL (UG/G)	0.006995	0.00671	0.00692	0.00935	** NC	NC
CD, TOTAL (UG/G)	0.00103	0.00101	0.00059	0.00044	2.635	0.805
CO, TOTAL (UG/G)	0.006785	0.00721	0.00519	0.004795	29.975	14.365
CR, TOTAL (UG/G)	0.021725	0.021285	0.020355	0.019005	33.765	30.805
CU, TOTAL (UG/G)	0.01294	0.010705	0.010865	0.009805	108.82	60.395
FE, TOTAL (UG/G)	36.3702	29.25135	38.63325	44.6435	28235.25	12226.85
MN, TOTAL (UG/G)	0.3416	0.24049	0.41017	0.381715	427.53	223.665
MO, TOTAL (UG/G)	NC	NC	NC	NC	NC	14.24
NI, TOTAL (UG/G)	0.0155	0.01368	0.01109	0.0094	23.85	35.395
PB, TOTAL (UG/G)	0.021855	0.01268	0.018545	0.019	17.2	27.635
S, TOTAL (UG/G)	31.22735	20.3085	37.2311	42.1746	7554.09	9050.5
SE, TOTAL (UG/G)	NC	NC	NC	NC	NC	NC
ZN, TOTAL (UG/G)	0.097105	0.087625	0.069835	0.06304	743.415	113.32
TOTAL CARBON (%C)	19.605	14.755	16.99	16.595	22.235	19.45
N IN SEDIMENT (%N)	1.585	1.2	1.66	1.565	1.46	1.395

* Labeled 'Lake A' and 'Lake B' to protect site and client confidentiality. 'Lake A' is a legacy mining industry influenced lake at the further-more upstream position in a chain of lakes; 'Lake B' is a currently industry-influenced lake in a chain of lakes. Outflow from lakes in these two discreet systems terminate into Lake Superior.

** Not Calculable.

Table 3. Characteristics of sediment core samples from Little Sandy Lake (LSL), Sandy Lake (SL) – the current study Twin Lakes system – and two industry-influenced lakes in Ontario. Sediment cores were obtained near aqueous outflows from each respective system. Concentrations are averages of two separate core sections. Twin Lakes concentrations are the average of 0-5 and 6-10 cm sections of the same core; 'Lake A' and 'Lake B' concentrations are the average of 0-4 and 5-8 cm sections of the same core.

	SL OUTFLOW (S1; 0-10 CM AVG.)	SL OUTFLOW (S3; 0-10 CM AVG.)	LSL OUTFLOW (LSL1; 0-10 CM AVG.)	* 'LAKE A' OUTFLOW (0-8 CM AVG.)	* 'LAKE B' OUTFLOW (0-8 CM AVG.)
% MOISTURE	86.995	86.945	85.88	52.35	50.08
AVS (UMOL/G)	6.705	0.0225	79.601	1090.59	** NC
SEM [CD,CU,NI,PB,ZN] (UMOL/G)	1.6165	7.02	0.101	6.1745	0.7788
BULK DENSITY (G/CM^3)	0.075	1.9395	0.18	0.14	0.14
AS, TOTAL (UG/G)	0.014565	0.085	0.008235	NC	NC
CD, TOTAL (UG/G)	0.0004	0.00757	0.00038	3.87	0.79
CO, TOTAL (UG/G)	0.00979	0.01623	0.00628	29.89	14.83
CR, TOTAL (UG/G)	0.01517	0.00103	0.019105	27.745	22.225
CU, TOTAL (UG/G)	0.009745	0.00683	0.011555	90.235	38.53
FE, TOTAL (UG/G)	48.4	0.019455	71.6897	11745.25	9369.585
MN, TOTAL (UG/G)	0.58315	0.012835	0.70984	237.05	206.705
MO, TOTAL (UG/G)	NC	41.66965	NC	2.11	9.48
NI, TOTAL (UG/G)	0.012485	0.36301	0.009385	29.34	31.895
PB, TOTAL (UG/G)	0.02454	NC	0.042385	17.91	15.025
S, TOTAL (UG/G)	22.1156	0.01399	53.4509	5233.115	6468.965
SE, TOTAL (UG/G)	NC	0.0302	NC	NC	NC
ZN, TOTAL (UG/G)	0.09266	37.3131	0.066545	1019.205	104.09
TOTAL CARBON (%C)	34.555	NC	17.055	15.48	19.465
N IN SEDIMENT (%N)	2.155	0.10355	1.605	1.215	1.445

* Labeled 'Lake A' and 'Lake B' to protect site and client confidentiality. 'Lake A' is a legacy mining industry influenced lake at the further-more upstream position in a chain of lakes; 'Lake B' is a currently industry-influenced lake in a chain of lakes. Outflow from lakes in these two discreet systems terminate into Lake Superior.

** Not Calculable.

FIGURE 1. AUGUST 2018: WILD RICE PLANTS GROWING IN 'LAKE A' SEDIMENT.

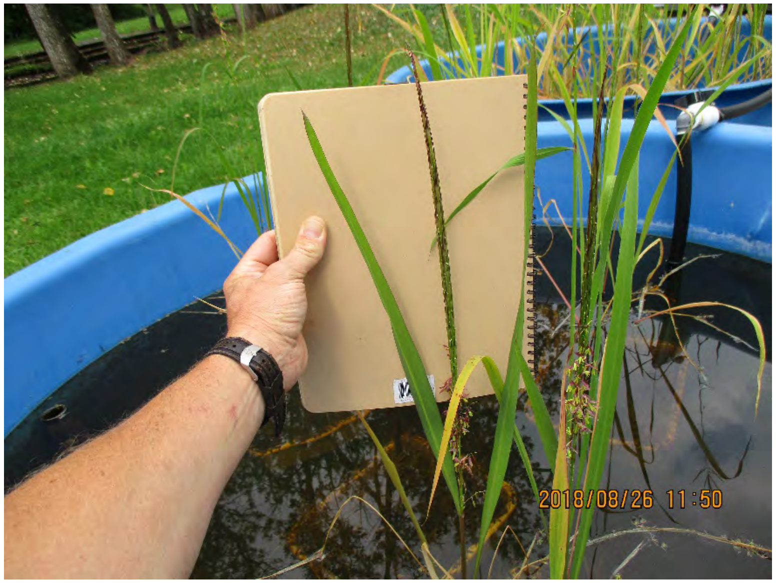

FIGURE 2. AUGUST 2018: WILD RICE PLANT PANICLE IN 'LAKE A' SEDIMENT_2.

FIGURE 3. AUGUST 2018: WILD RICE PLANT PANICLE IN 'LAKE A' SEDIMENT_1.

FIGURE 4. AUGUST 2018: WILD RICE PLANT PANICLE IN 'LAKE A' SEDIMENT_3.

FIGURE 5. AUGUST 2018: WILD RICE PLANTS GROWING IN 'LAKE B' SEDIMENT.

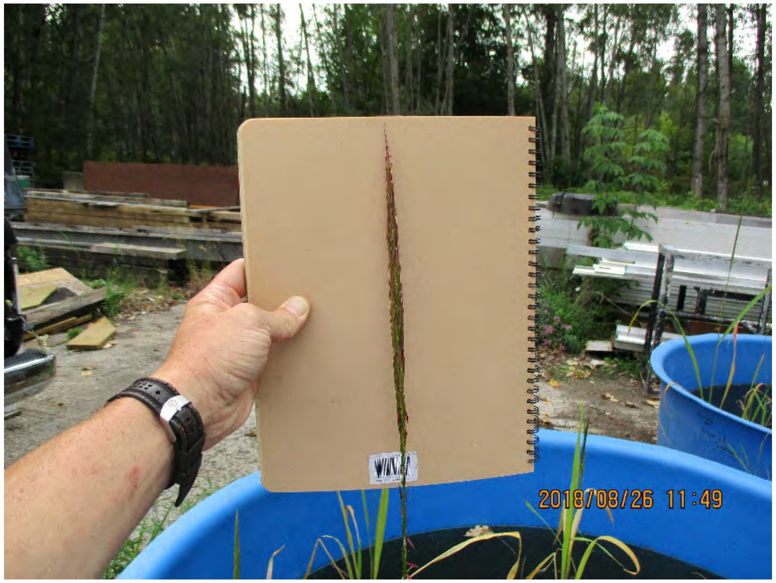

FIGURE 6. AUGUST 2018: WILD RICE PLANT PANICLE IN 'LAKE B' SEDIMENT_2.

FIGURE 7. AUGUST 2018: WILD RICE PLANT PANICLE IN 'LAKE B' SEDIMENT_1.

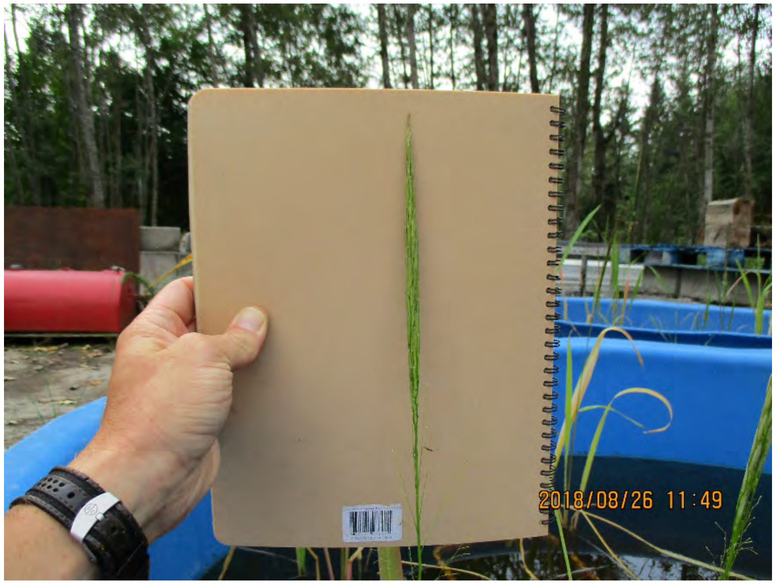

FIGURE 8. AUGUST 2018: WILD RICE PLANT PANICLE IN 'LAKE B' SEDIMENT_

APPENDIX C

TECHNICAL MEMORANDUM FROM DR. PETER LEE

Sediment Core Analysis / Evaluation. Dr. Peter Lee, Lakehead University, Thunder Bay, Ontario, CA.

Values for all sediment cores by 5 cm sections (top of sediment to 25 cm core depth) for Sandy and Little Sandy Lakes are contained in Appendix A. The results for both total and pore water values are summarized in Tables 1 and 2 and compared to data collected by the MPCA during 2011 (Myrbo et al, 2012) and other data from wild rice lakes in Ontario. Not all the same parameters as per the twin lakes were collected for the comparison data, but they do provide a useful comparison.

Comparing total values (Table 1) in the top 5 cm layer for Sandy versus Little Sandy, Little Sandy had noticeably higher values for AVS, Bo, Fe, Mn, and S and lower values for SEM. Other parameters were similar in values. Both lakes had values for Fe, S, AVS, Mn, and Pb decline considerably from the top 5 cm layer to the 6-10 cm layer. This declining trend continued to the 21-25 cm layer with S levels lower by a factor of 10 and Fe by a factor of 5 at these depths in the sediment. Presumably the concentrations for these chemical constituents at the lower depths were reflective of original background levels prior to mining operations.

Compared to values found by Myrbo et al. (2012) and the Ontario data, values in Sandy and Little Sandy sediment for Moisture, As, Cd, Co, Cu, Mn, Pb, and Zn were all within the ranges found elsewhere. AVS, Fe, and S were above the ranges.

Table 2 contains the pore water values for Sandy and Little Sandy Lakes in comparison to the MPCA data and that of Jorgenson (2013). Cl values were somewhat elevated in the Twin Lakes versus the comparison data but were in range for Ca, Fe, K, Mg, Na and Sr. Comparing the 21-25 cm layer in Sandy Lake (this layer was not available for Little Sandy Lake), there was a noticeable decline in values for K, Fe, Mn, Na, S, and SO_4 from the top layer. Although changes in Fe, Mn, S and SO_4 could be attributed to mining activities, the declines in K and Na were similarly found in natural sediment cores by Jorgenson (2013). Most of the values for sulfides (Appendix A) were below detection limits versus those found by Myrbo et al. (2012). This may reflect the fact that the MPCA collected sulfides *in situ* at their field sites. This same approach will be done at the Twin Lakes in 2015 to see if sulfide values differ when sampled directly.

In terms of whether or not the sediments in Sandy and Little Sandy will support wild rice growth, it will depend on the effects on growth of the elevated values of metals and sulfur compounds present versus normal concentrations in lake sediments. Ideally, a bioassay for wild rice growth that examined site specific effects could be used to test the wild rice response, but this is not available. MPCA (2014) in the draft analysis for scientific peer review suggested that sulfides were responsible for wild rice growth reduction. They further correlated the presence of sulfides to iron concentrations. If iron in pore water were sufficiently high, no sulfides would be expected. In both Sandy and Little Sandy Lakes, elevated sulfur levels in the sediment also correlated to elevated iron levels. The MPCA (2014) also determined there was a significantly positive correlation of AVS, standardized with total organic carbon, versus sulfate in surface waters. This relationship could potentially be used to determine if there was sufficient iron present to counter the increases in sulfides. Again, a bioassay of the response of wild rice in the twin lake sediments would be a true test of whether or not there was sufficient iron present to buffer the production of detrimental sulfides.

References:

Jorgenson, K. 2013. Northern wild rice (*Zizania palustris* L.) as a phytoremediation species in eutrophic wetlands – investigation of root-sediment interactions. M.Sc. Thesis, Lakehead University, Thunder Bay, ON. 270 pp.

Minnesota Pollution Control Agency, 2014. Analysis of the wild rice sulfate standard study: draft of scientific peer review. 91 pp.

Myrbo, A., Ramstack, J., and R. Thompson. 2012. Wild rice sulfate preliminary field survey 2011. University of Minnesota. Prepared for MPCA. 150 pp.

Table 1. Total values (digested) for parameters in sediment cores collected from Sandy and Little Sandy Lakes compared to other studies (Myrbo et al. 2012; Jorgenson, 2013; Whitefish, unpublished, LUEL).

Parameter			Sandy Lake			Little Sandy Lake			Mybro	Mybro	Mybro	Whitefish	Jorgenson
	MDL	UNITS	0 - 5 cm	6 - 10 cm	21 - 25 cm	0 - 5 cm	6 - 10 cm	21 - 25 cm	(mean)	(min)	(max)		
% Moisture Content	n / a	%	86.87	82.26	85.41	86.7	85.34	83.26	76.50	20.10	96.00		
Acid Volatile Sulfides	0.0001	%	0.034	0.024	0.005	0.192	0.083	0.0051					
Acid Volatile Sulfides	0.003	umole / g	10.71	7.53	1.64	60.0	25.93	1.60	0.72	0.00	6.25	1.90	
SEM [Cd,Cu,Ni,Pb,Zn]	0.002	umole / g	0.991	0.733	0.916	0.125	0.112	0.084				1.390	
Bulk Density	0.05	g / cm3	0.12	0.19	0.12	0.16	0.18	0.21					
Total Recoverable Arsenic in sediment	2	ug / g	9.63	6.99	5.01	9.6	8.79	4.02	2.64	0.44	11.92		1.00
Total Recoverable Boron in sediment	2	ug / g	28.7	17.71	20.37	61.58	45.12	44.63					
Total Recoverable Cadmium in sediment	0.25	ug / g	0.80	1.014	0.93	0.35	0.83	0.53	0.37	0.02	0.88	1.66	
Total Recoverable Cobalt in sediment	0.2	ug / g	8.04	6.10	5.14	5.83	6.09	5.75	2.11	0.19	10.26	0.71	
Total Recoverable Chromium in sediment	0.03	ug / g	19.62	19.76	21.07	17.76	21.76	24.30				7.07	
Total Recoverable Copper in sediment	0.05	ug / g	11.47	11.67	12.2	9.69	11.94	11.62	7.19	0.68	22.65	25.84	
Total Recoverable Iron in sediment	0.1	ug / g	59414.6	35683.6	15315.47	68833.9	39081.4	13125.70	8328.4	1298.4	50389.0	7852.65	1210.0
Total Recoverable Manganese in sediment	0.05	ug / g	436.62	298.25	259.38	624.39	267.45	181.91	608.60	45.52	3814.96	135.41	134.25
Total Recoverable Molybdenum in sediment	2	ug / g	< DL	< DL	< DL	< DL	< DL	< DL					
Total Recoverable Nickel in sediment	0.2	ug / g	12.55	13.04	14.86	8.44	11.4	14.30				8.43	
Total Recoverable Lead in sediment	1	ug / g	30.18	22.20	6.30	33.36	23.36	4.95	11.11	0.60	76.64	13.42	
Total Recoverable Sulfur in sediment	1	ug / g	47172.4	28590.4	6374.58	64517.3	32975.5	4071.13	3116.0	55.0	12515.0	247.19	4519.0
Total Recoverable Selenium in sediment	2	ug / g	< DL	< DL	< DL	< DL	< DL	< DL					
Total Recoverable Zinc in sediment	0.03	ug / g	98.36	92.20	75.23	68.16	82.90	61.61	38.05	4.92	103.98	49.70	75.14
Total Carbon in sediment	0.01	%	20.63	18.71	24.50	17.31	16.76	18.23					
N in sediment	0.01	%	1.72	1.47	1.69	1.7	1.43	1.32					

Table 2. Pore water values for parameters in sediment cores collected from Sandy and Little Sandy Lakes compared to other studies (Myrbo et al. 2012; Jorgenson, 2013).

Parameter	MDL	UNITS	Sandy Lake 0 - 5 cm	Sandy Lake 21 - 25 cm	L. Sandy 0 - 5 cm	Mybro (mean)	Mybro (min)	Mybro (max)	Jorgenson
Sulfide(S2-) in porewater	0.01	mg / L	<DL	<DL	0.223	0.305	0.01	14.84	
Chloride (IC) in porewater	0.05	mg / L	38.00	46.97	56.98	21.85	4.91	36.36	
Dissolved Arsenic in porewater	0.05	mg / L	<DL	<DL	<DL				
Dissolved Boron in porewater	0.05	mg / L	0.052	<DL	0.071				
Dissolved Calcium in porewater	0.01	mg / L	45.8	11.80	69.82	50.4	24.54	80.77	39.96
Dissolved Cadmium in porewater	0.002	mg / L	<DL	<DL	<DL				
Dissolved Cobalt in porewater	0.004	mg / L	<DL	<DL	<DL				
Dissolved Chromium in porewater	0.002	mg / L	<DL	<DL	<DL				
Dissolved Copper in porewater	0.004	mg / L	<DL	<DL	<DL				
Dissolved Iron in porewater	0.025	mg / L	1.642	0.997	0.552	10	0.012	35.59	1.735
Dissolved Potassium in porewater	0.1	mg / L	11.296	3.263	12.42	3.43	0.03	26.68	0.75
Dissolved Magnesium in porewater	0.01	mg / L	44.26	10.251	75.21	26.67	7.80	134.38	7.91
Dissolved Manganese in porewater	0.005	mg / L	0.539	0.211	0.334	1.97	0.025	16.72	0.313
Dissolved Molybdenum in porewater	0.05	mg / L	<DL	<DL	<DL				
Dissolved Sodium in porewater	0.05	mg / L	24.57	9.979	37.06	7.2	0.06	92	5.16
Dissolved Nickel in porewater	0.025	mg / L	<DL	<DL	<DL				
Dissolved Lead in porewater	0.025	mg / L	<DL	<DL	<DL				
Dissolved Sulfur in porewater	0.05	mg / L	23.639	5.00	51.19				0.4
Dissolved Selenium in porewater	0.05	mg / L	<DL	<DL	<DL				
Dissolved Strontium in porewater	0.01	mg / L	0.165	0.053	0.248	0.166	0.067	0.511	0.104
Dissolved Zinc in porewater	0.005	mg / L	0.019	0.016	0.007	0.061	0.01	0.275	0.005
Sulphate (SO4) [IC] in porewater	0.03	mg / L	69.19	42.04	145.39				

APPENDIX D

2013 SEDIMENT PORE WATER RESULTS

SANDY LAKE AND LITTLE SANDY LAKE SEDIMENT PORE WATER SAMPLE RESULTS

				Sandy Lake Core 1					Sandy Lake Core 2					Sandy Lake Core 3					Sandy Lake Core 4					Sandy Lake Core 5				
Parameter	**Description**	**MDL**	**UNITS**	Section 1	Section 2	Section 3	Section 4	Section 5	Section 1	Section 2	Section 3	Section 4	Section 5	Section 1	Section 2	Section 3	Section 4	Section 5	Section 1	Section 2	Section 3	Section 4	Section 5	Section 1	Section 2	Section 3	Section 4	Section 5
WH2S	Sulfide(S2-) in porewater	0.01	mg / L	<DL	IV	IV	IV	IV	<DL	IV	<DL	IV	IV	<DL	IV	IV	IV	IV	<DL	IV	<DL	IV	<DL	<DL	IV	<DL	IV	<DL
WICCL	Chloride (IC) in porewater	0.05	mg / L	24.18	IV	IV	IV	IV	33.73	IV	39	IV	IV	36.38	IV	IV	IV	IV	44.68	IV	47.32	IV	43.28	47.99	IV	52.81	IV	50.66
WICP4AS	Dissolved Arsenic in porewater	0.05	mg / L	<DL	IV	IV	IV	IV	<DL	IV	<DL	IV	IV	<DL	IV	IV	IV	IV	<DL	IV	<DL	IV	<DL	<DL	IV	<DL	IV	<DL
WICP4B	Dissolved Boron in porewater	0.05	mg / L	0.056	IV	IV	IV	IV	0.083	IV	<DL	IV	IV	0.073	IV	IV	IV	IV	0.082	IV	0.066	IV	<DL	0.078	IV	0.071	IV	<DL
WICP4CA	Dissolved Calcium in porewater	0.01	mg / L	31.64	IV	IV	IV	IV	56.44	IV	8.74	IV	IV	41.78	IV	IV	IV	IV	55.48	IV	43.53	IV	20.03	48.93	IV	36.92	IV	3.56
WICP4CD	Dissolved Cadmium in porewater	0.002	mg / L	<DL	IV	IV	IV	IV	<DL	IV	<DL	IV	IV	<DL	IV	IV	IV	IV	<DL	IV	<DL	IV	<DL	<DL	IV	<DL	IV	<DL
WICP4CO	Dissolved Cobalt in porewater	0.004	mg / L	<DL	IV	IV	IV	IV	<DL	IV	<DL	IV	IV	<DL	IV	IV	IV	IV	<DL	IV	<DL	IV	<DL	<DL	IV	<DL	IV	<DL
WICP4CR	Dissolved Chromium in porewater	0.002	mg / L	<DL	IV	IV	IV	IV	<DL	IV	<DL	IV	IV	<DL	IV	IV	IV	IV	<DL	IV	<DL	IV	<DL	<DL	IV	<DL	IV	<DL
WICP4CU	Dissolved Copper in porewater	0.004	mg / L	<DL	IV	IV	IV	IV	<DL	IV	<DL	IV	IV	<DL	IV	IV	IV	IV	<DL	IV	<DL	IV	<DL	<DL	IV	<DL	IV	<DL
WICP4FE	Dissolved Iron in porewater	0.025	mg / L	7.988	IV	IV	IV	IV	0.523	IV	0.326	IV	IV	1.591	IV	IV	IV	IV	0.604	IV	1.759	IV	1.698	0.82	IV	1.192	IV	0.296
WICP4K	Dissolved Potassium in porewater	0.1	mg / L	6.896	IV	IV	IV	IV	11.69	IV	2.174	IV	IV	11.04	IV	IV	IV	IV	19.41	IV	12.15	IV	4.984	13.56	IV	12.59	IV	1.541
WICP4MG	Dissolved Magnesium in porewater	0.01	mg / L	26.48	IV	IV	IV	IV	54.14	IV	9.279	IV	IV	33.52	IV	IV	IV	IV	50.21	IV	38.05	IV	17.14	51.57	IV	35.08	IV	3.361
WICP4MN	Dissolved Manganese in porewater	0.005	mg / L	0.844	IV	IV	IV	IV	0.588	IV	0.103	IV	IV	0.707	IV	IV	IV	IV	0.592	IV	0.545	IV	0.347	0.544	IV	0.597	IV	0.075
WICP4MO	Dissolved Molybdenum in porewater	0.05	mg / L	<DL	IV	IV	IV	IV	<DL	IV	<DL	IV	IV	<DL	IV	IV	IV	IV	<DL	IV	<DL	IV	<DL	<DL	IV	<DL	IV	<DL
WICP4NA	Dissolved Sodium in porewater	0.05	mg / L	13.463	IV	IV	IV	IV	22.643	IV	6.049	IV	IV	23.472	IV	IV	IV	IV	27.732	IV	27.962	IV	15.563	28.673	IV	30.303	IV	4.395
WICP4NI	Dissolved Nickel in porewater	0.025	mg / L	<DL	IV	IV	IV	IV	<DL	IV	<DL	IV	IV	<DL	IV	IV	IV	IV	<DL	IV	<DL	IV	<DL	<DL	IV	<DL	IV	<DL
WICP4PB	Dissolved Lead in porewater	0.025	mg / L	<DL	IV	IV	IV	IV	<DL	IV	<DL	IV	IV	<DL	IV	IV	IV	IV	<DL	IV	<DL	IV	<DL	<DL	IV	<DL	IV	<DL
WICP4S	Dissolved Sulfur in porewater	0.05	mg / L	13.761	IV	IV	IV	IV	11.711	IV	2.346	IV	IV	16.131	IV	IV	IV	IV	28.811	IV	17.951	IV	7.45	25.571	IV	20.011	IV	2.552
WICP4SE	Dissolved Selenium in porewater	0.05	mg / L	<DL	IV	IV	IV	IV	<DL	IV	<DL	IV	IV	<DL	IV	IV	IV	IV	<DL	IV	<DL	IV	<DL	<DL	IV	<DL	IV	<DL
WICP4SR	Dissolved Strontium in porewater	0.01	mg / L	0.119	IV	IV	IV	IV	0.2	IV	0.036	IV	IV	0.165	IV	IV	IV	IV	0.199	IV	0.176	IV	0.088	0.187	IV	0.16	IV	0.018
WICP4ZN	Dissolved Zinc in porewater	0.005	mg / L	0.006	IV	IV	IV	IV	<DL	IV	0.011	IV	IV	0.013	IV	IV	IV	IV	0.006	IV	0.015	IV	0.014	0.01	IV	0.007	IV	0.018
WICSO4	Sulphate (SO4) [IC] in porewater	0.03	mg / L	40.3	IV	IV	IV	IV	33.14	IV	26.7	IV	IV	46.58	IV	IV	IV	IV	86.58	IV	51.93	IV	35.23	75.77	IV	58.48	IV	48.84

				Sandy Lake Core 5					Sandy Lake Core 6					Sandy Lake Core 7					Sandy Lake Core 8				Sandy Lake Core 9				Sandy Lake Core 10	
Parameter	**Description**	**MDL**	**UNITS**	Section 1	Section 2	Section 3	Section 4	Section 5	Section 1	Section 2	Section 3	Section 4	Section 5	Section 1	Section 2	Section 3	Section 4	Section 5	Section 1	Section 2	Section 3	Section 4	Section 1	Section 2	Section 3	Section 4	Section 1	Section 2
WH2S	Sulfide(S2-) in porewater	0.01	mg / L	<DL	IV	<DL	IV	<DL	<DL	<DL	IV	IV	IV	<DL	<DL	IV	IV	IV	<DL	IV	IV	IV	<DL	<DL	IV	IV	IV	IV
WICCL	Chloride (IC) in porewater	0.05	mg / L	47.99	IV	52.81	IV	50.66	37.38	38.99	IV	IV	IV	37.24	48.74	IV	IV	IV	31.60	IV	IV	IV	48.85	46.59	IV	IV	IV	IV
WICP4AS	Dissolved Arsenic in porewater	0.05	mg / L	<DL	IV	<DL	IV	<DL	<DL	<DL	IV	IV	IV	<DL	<DL	IV	IV	IV	<DL	IV	IV	IV	<DL	<DL	IV	IV	IV	IV
WICP4B	Dissolved Boron in porewater	0.05	mg / L	0.078	IV	0.071	IV	<DL	<DL	<DL	IV	IV	IV	<DL	<DL	IV	IV	IV	<DL	IV	IV	IV	<DL	<DL	IV	IV	IV	IV
WICP4CA	Dissolved Calcium in porewater	0.01	mg / L	48.93	IV	36.92	IV	3.56	40.13	38.80	IV	IV	IV	47.57	47.04	IV	IV	IV	38.20	IV	IV	IV	52.03	54.55	IV	IV	IV	IV
WICP4CD	Dissolved Cadmium in porewater	0.002	mg / L	<DL	IV	<DL	IV	<DL	<DL	<DL	IV	IV	IV	<DL	<DL	IV	IV	IV	<DL	IV	IV	IV	<DL	<DL	IV	IV	IV	IV
WICP4CO	Dissolved Cobalt in porewater	0.004	mg / L	<DL	IV	<DL	IV	<DL	<DL	<DL	IV	IV	IV	<DL	<DL	IV	IV	IV	0.005	IV	IV	IV	<DL	<DL	IV	IV	IV	IV
WICP4CR	Dissolved Chromium in porewater	0.002	mg / L	<DL	IV	<DL	IV	<DL	<DL	<DL	IV	IV	IV	<DL	<DL	IV	IV	IV	<DL	IV	IV	IV	<DL	<DL	IV	IV	IV	IV
WICP4CU	Dissolved Copper in porewater	0.004	mg / L	<DL	IV	<DL	IV	<DL	0.013	<DL	IV	IV	IV	<DL	<DL	IV	IV	IV	0.010	IV	IV	IV	<DL	<DL	IV	IV	IV	IV
WICP4FE	Dissolved Iron in porewater	0.025	mg / L	0.82	IV	1.192	IV	0.296	0.523	0.921	IV	IV	IV	0.889	1.830	IV	IV	IV	0.511	IV	IV	IV	1.327	0.826	IV	IV	IV	IV
WICP4K	Dissolved Potassium in porewater	0.1	mg / L	13.56	IV	12.59	IV	1.541	10.160	7.644	IV	IV	IV	10.890	7.909	IV	IV	IV	10.463	IV	IV	IV	7.558	7.603	IV	IV	IV	IV
WICP4MG	Dissolved Magnesium in porewater	0.01	mg / L	51.57	IV	35.08	IV	3.361	37.000	31.987	IV	IV	IV	54.540	47.025	IV	IV	IV	38.961	IV	IV	IV	51.960	54.750	IV	IV	IV	IV
WICP4MN	Dissolved Manganese in porewater	0.005	mg / L	0.544	IV	0.597	IV	0.075	0.236	0.331	IV	IV	IV	0.413	0.314	IV	IV	IV	0.307	IV	IV	IV	0.624	0.504	IV	IV	IV	IV
WICP4MO	Dissolved Molybdenum in porewater	0.05	mg / L	<DL	IV	<DL	IV	<DL	<DL	<DL	IV	IV	IV	<DL	<DL	IV	IV	IV	<DL	IV	IV	IV	<DL	<DL	IV	IV	IV	IV
WICP4NA	Dissolved Sodium in porewater	0.05	mg / L	28.673	IV	30.303	IV	4.395	26.750	27.300	IV	IV	IV	27.190	32.025	IV	IV	IV	22.567	IV	IV	IV	28.680	30.580	IV	IV	IV	IV
WICP4NI	Dissolved Nickel in porewater	0.025	mg / L	<DL	IV	<DL	IV	<DL	<DL	<DL	IV	IV	IV	<DL	<DL	IV	IV	IV	<DL	IV	IV	IV	<DL	<DL	IV	IV	IV	IV
WICP4PB	Dissolved Lead in porewater	0.025	mg / L	<DL	IV	<DL	IV	<DL	<DL	<DL	IV	IV	IV	<DL	<DL	IV	IV	IV	0.041	IV	IV	IV	<DL	<DL	IV	IV	IV	IV
WICP4S	Dissolved Sulfur in porewater	0.05	mg / L	25.571	IV	20.011	IV	2.552	20.408	17.260	IV	IV	IV	34.598	41.397	IV	IV	IV	26.792	IV	IV	IV	34.968	33.218	IV	IV	IV	IV
WICP4SE	Dissolved Selenium in porewater	0.05	mg / L	<DL	IV	<DL	IV	<DL	<DL	<DL	IV	IV	IV	<DL	<DL	IV	IV	IV	<DL	IV	IV	IV	<DL	<DL	IV	IV	IV	IV
WICP4SR	Dissolved Strontium in porewater	0.01	mg / L	0.187	IV	0.16	IV	0.018	0.143	0.157	IV	IV	IV	0.163	0.189	IV	IV	IV	0.129	IV	IV	IV	0.183	0.185	IV	IV	IV	IV
WICP4ZN	Dissolved Zinc in porewater	0.005	mg / L	0.01	IV	0.007	IV	0.018	0.030	0.011	IV	IV	IV	0.021	0.012	IV	IV	IV	0.041	IV	IV	IV	0.023	0.011	IV	IV	IV	IV
WICSO4	Sulphate (SO4) [IC] in porewater	0.03	mg / L	75.77	IV	58.48	IV	48.84	53.16	47.50	IV	IV	IV	94.67	123.84	IV	IV	IV	80.53	IV	IV	IV	111.98	95.16	IV	IV	IV	IV

Appendix E

Twin Lakes Peeper Pore Water Results (2015-2018)

2015 Twin Lakes Peeper Pore Water Sample Results

PARAMETER	UNITS	DATE	Twin Lakes Outflow	Sandy Lake Mid	Little Sandy Lake Outlet	Little Sandy Lake Inflow 1	Little Sandy Lake Inflow 2	Little Sandy Lake Inflow 3	Field Blank	MDL
Sulfide	mg/L	8/5/2015	<DL	**0.115**	**0.077**	**0.045**	**2.55**	**0.014**		0.01
		9/3/2015	**0.572**	**0.079**	**5.8**	**1.815**	**1.265**	**4.457**	<DL	
		10/2/2015	**0.44**	**0.871**	**3.23**	**3.18**	**7.7**	**7.12**		
Chloride	mg/L	8/5/2015	**6.46**	**23.73**	**50.37**	**41.56**	**58.97**	**28.25**		0.05
		9/3/2015	**6.28**	**29.82**	**44.94**	**42.91**	**62.22**	**27.23**	**0.51**	
		10/2/2015	**5.1**	**37.89**	**46.38**	**50.6**	**53.17**	**26.82**		
Arsenic, Dissolved	mg/L	8/5/2015	<DL	<DL	<DL	<DL	<DL	<DL		0.03
		9/3/2015	<DL	<DL	**0.033**	<DL	<DL	<DL	<DL	
		10/2/2015	NM	NM	NM	NM	NM	NM		
Boron, Dissolved	mg/L	8/5/2015	<DL	<DL	**0.061**	**0.049**	**0.101**	<DL		0.025
		9/3/2015	<DL	<DL	**0.051**	<DL	**0.101**	<DL	<DL	
		10/2/2015	**<DL**	**0.05**	**0.473**	**0.044**	**0.103**	**0.026**		
Calcium, Dissolved	mg/L	8/5/2015	**26.68**	**23.88**	**57.24**	**39.4**	**92.31**	**28.13**		0.01
		9/3/2015	**24.99**	**31.39**	**49.64**	**30.53**	**104.9**	**31.6**	**0.44**	
		10/2/2015	**34.91**	**45.41**	**47.7**	**44.41**	**109.92**	**39.98**		
Cobalt, Dissolved	mg/L	8/5/2015	<DL	<DL	<DL	<DL	<DL	<DL		0.004
		9/3/2015	<DL	<DL	<DL	<DL	<DL	<DL	<DL	
		10/2/2015	<DL	<DL	<DL	<DL	<DL	<DL		
Copper, Dissolved	mg/L	8/5/2015	<DL	<DL	<DL	<DL	<DL	<DL		0.004
		9/3/2015	<DL	<DL	<DL	<DL	<DL	<DL	<DL	
		10/2/2015	<DL	<DL	<DL	<DL	<DL	<DL		
Iron, Dissolved	mg/L	8/5/2015	**3.243**	**8.72**	**0.78**	**5.586**	**0.174**	**1.763**		0.025
		9/3/2015	**0.892**	**0.15**	**0.205**	**1.049**	<DL	**0.814**	<DL	
		10/2/2015	**1.18**	**0.027**	**1.212**	**0.198**	**0.026**	**0.317**		
Potassium, Dissolved	mg/L	8/5/2015	**4.813**	**5.904**	**8.683**	**6.762**	**7.453**	**4.602**		0.1
		9/3/2015	**4.431**	**5.137**	**8.104**	**6.223**	**7.277**	**4.508**	<DL	
		10/2/2015	**5.863**	**4.627**	**8.029**	**7.243**	**7.217**	**5.42**		
Magnesium, Dissolved	mg/L	8/5/2015	**10.85**	**17.72**	**45.78**	**33.07**	**107.3**	**25.49**		0.01
		9/3/2015	**9.249**	**32.89**	**39.63**	**23.86**	**122.1**	**23.43**	**0.124**	
		10/2/2015	**13.45**	**59.34**	**42.53**	**45.07**	**124.2**	**41.46**		
Manganese, Dissolved	mg/L	8/5/2015	**0.384**	**1.621**	**0.266**	**0.468**	**0.037**	**0.304**		0.005
		9/3/2015	**0.398**	**0.031**	**0.214**	**0.392**	**0.006**	**0.377**	<DL	
		10/2/2015	**0.98**	<DL	**0.427**	**0.222**	**0.018**	**0.799**		
Sodium, Dissolved	mg/L	8/5/2015	**5.325**	**13.79**	**28.91**	**23.83**	**35.42**	**13.66**		0.05
		9/3/2015	**4.576**	**16.97**	**26.27**	**21**	**37.92**	**15.42**	**0.196**	
		10/2/2015	**4.972**	**25.76**	**27.4**	**28.02**	**39.64**	**20.13**		
Lead, Dissolved	mg/L	8/5/2015	<DL	<DL	<DL	<DL	<DL	<DL		0.025
		9/3/2015	<DL	<DL	<DL	<DL	<DL	<DL	<DL	
		10/2/2015	<DL	<DL	<DL	<DL	<DL	<DL		
Sulfur, Dissolved	mg/L	8/5/2015	**3.235**	**4.711**	**17.39**	**22.37**	**116.6**	**5.583**		0.05
		9/3/2015	**3.882**	**18.6**	**6.722**	**7.026**	**84.52**	**2.986**	**0.167**	
		10/2/2015	**2.122**	**71.35**	**2.474**	**7.199**	**52.3**	**5.546**		
Strontium, Dissolved	mg/L	8/5/2015	**0.085**	**0.081**	**0.19**	**0.15**	**0.287**	**0.114**		0.01
		9/3/2015	**0.078**	**0.112**	**0.17**	**0.123**	**0.328**	**0.139**	<DL	
		10/2/2015	**0.115**	**0.171**	**0.171**	**0.158**	**0.334**	**0.147**		
Zinc, Dissolved	mg/L	8/5/2015	<DL	**0.01**	<DL	<DL	<DL	<DL		0.005
		9/3/2015	**0.021**	**0.074**	**0.116**	**0.03**	**0.025**	**0.03**	**0.032**	
		10/2/2015	**0.011**	**0.008**	**0.013**	**0.009**	<DL	<DL		
Sulfate	mg/L	8/5/2015	**5.05**	**8.02**	**41.28**	**51.37**	**174.17**	**12.24**		0.03
		9/3/2015	**12.94**	**59.59**	**19.45**	**25.53**	**294.34**	**14.01**	**1.98**	
		10/2/2015								

MDL = Method Detection Limit

<DL - Below lab detection limit

NM - Not measured

2016 Twin Lakes Peeper Pore Water Sample Results

PARAMETER	UNITS	DATE	Twin Lakes Outflow	Sandy Lake Mid	Little Sandy Lake Outlet	Little Sandy Lake Inflow 1	Little Sandy Lake Inflow 2	Little Sandy Lake Inflow 3	MDL
Sulfide	mg/L	5/26/2016	**0.23**	**0.25**	**3.5**	**1.4**	**11.8**	**0.61**	Varies
		6/24/2016	**0.11**	**0.13**	**0.28**	**0.63**	**11.3**	**2.4**	
		7/22/2016	**0.34**	**0.18**	**0.37**	**1.5**	**41.9**	**0.97**	
		8/25/2016	**0.18**	**0.17**	**0.77**	**0.37**	**20.8**	**2.3**	
Iron, Dissolved	ug/L	5/26/2016	**2100**	**8550**	**870**	**2600**	**57.9**	**2700**	50.0
		6/24/2016	**14000**	**6240**	**12700**	**3620**	**176**	**4800**	
		7/22/2016	**13200**	**989**	**3350**	**855**	**73.8**	**1360**	
		8/25/2016	**15600**	**729**	**4110**	**4840**	**124**	**377**	
Sulfate	mg/L	5/26/2016	**39.7**	**105**	**18.2**	**81.3**	**82.8**	**3.0**	2.0
		6/24/2016	**2.3**	**16.1**	<2.0	**2.0**	**24.3**	**14.1**	
		7/22/2016	**2.1**	**27.3**	**2.1**	**3.0**	**17.0**	**2.6**	
		8/25/2016	<2.0	<2.0	<2.0	<2.0	**8.2**	<2.0	
Chloride	mg/L	5/26/2016	**23.1**	**21.0**	**39.3**	**31.6**	**26.2**	**12.0**	1.0
		6/24/2016	**32.6**	**29.0**	**37.3**	**40.6**	**52.9**	**18.6**	
		7/22/2016	**33.0**	**31.3**	**40.7**	**43.7**	**40.4**	**15.3**	
		8/25/2016	**19.1**	**24.4**	**41.5**	**44.7**	**47.4**	**20.7**	
Sodium, Dissolved	ug/L	5/26/2016	**13100**	**12600**	**20000**	**21400**	**15400**	**9010**	1000
		6/24/2016	**20200**	**16800**	**18400**	**21800**	**29400**	**11400**	
		7/22/2016	**18800**	**16500**	**19300**	**24000**	**24500**	**10600**	
		8/25/2016	**13600**	**14400**	**24800**	**27600**	**34400**	**16700**	
Calcium, Dissolved	ug/L	5/26/2016	**28800**	**31800**	**34400**	**46900**	**49200**	**18400**	500
		6/24/2016	**50600**	**25900**	**37500**	**33200**	**53700**	**22900**	
		7/22/2016	**50400**	**30100**	**45200**	**37600**	**73700**	**25200**	
		8/25/2016	**40100**	**26600**	**45500**	**40100**	**82700**	**36700**	
Potassium, Dissolved	ug/L	5/26/2016	**4530**	**4260**	**5770**	**7590**	**3460**	**3190**	2500
		6/24/2016	**7130**	**5290**	**5550**	**7150**	**5450**	**4080**	
		7/22/2016	**6950**	**4920**	**5460**	**7530**	**6750**	**4010**	
		8/25/2016	**8910**	**4720**	**7810**	**8800**	**8800**	**4970**	
Magnesium, Dissolved	ug/L	5/26/2016	**28700**	**35400**	**30400**	**53700**	**42300**	**19600**	500
		6/24/2016	**49100**	**25200**	**23000**	**31900**	**63300**	**23200**	
		7/22/2016	**46200**	**30100**	**29800**	**38700**	**69500**	**25600**	
		8/25/2016	**34800**	**28000**	**39400**	**38400**	**93900**	**42700**	
Manganese, Dissolved	ug/L	5/26/2016	**604**	**720**	**302**	**633**	**63.9**	**231**	5.0
		6/24/2016	**1270**	**1370**	**720**	**502**	**257**	**355**	
		7/22/2016	**958**	**287**	**522**	**366**	**341**	**247**	
		8/25/2016	**1260**	**376**	**604**	**664**	**121**	**281**	

MDL - Method Detection Limit

Vaires - MDL changes based on result's concentration.

2017 Twin Lakes Peeper Pore Water Sample Results

PARAMETER	UNITS	DATE	Twin Lakes Outflow	Sandy Lake Mid	Sandy Lake South Inflow	Little Sandy Lake Inflow 1	Little Sandy Lake Inflow 2	Little Sandy Lake Outlet	MDL
Sulfide	mg/L	5/25/2017	**0.73**	**0.23**	**0.10**	<0.10	**30.3**	**0.12**	Varies
		6/22/2017	**0.41**	**0.35**	**0.10**	**<0.10**	**41.9**	**1.3**	"
		7/27/2017	**0.39**	**0.11**	**0.17**	**<0.10**	**71.0**	**4.4**	"
		8/24/2017	**0.22**	**0.36**	<0.10	**0.31**	**34.2**	**NS**	"
		9/25/2017	**0.422**	<0.078	**0.095**	**0.42**	**29.6**	<0.078	"
		10/26/2017	**0.650**	<0.078	<0.078	<0.078	**52.6**	**0.65**	"
Iron, Dissolved	ug/L	5/25/2017	**7020**	**9870**	**429**	**778**	**139**	**4760**	50.0
		6/22/2017	**5590**	**3160**	**1430**	**9490**	**592**	**2800**	"
		7/27/2017	**8810**	**5060**	**20200**	**467**	**55.8**	**62.8**	"
		8/24/2017	**5130**	**3520**	**15600**	**2050**	**81.3**	**NS**	"
		9/25/2017	**5020**	**279**	**5250**	**873**	**<50.0**	**1170**	"
		10/26/2016	**1990**	**729**	**881**	**1820**	**215**	**316**	"
Sulfate	mg/L	5/25/2017	**3.6**	**6.1**	**51.3**	**215**	**82.8**	**10.8**	Varies
		6/22/2017	**19.7**	**9.1**	39.1	**227**	**19.0**	**6.7**	"
		7/27/2017	**<2.0**	**<2.0**	**<2.0**	**345**	**11.2**	**5.2**	"
		8/24/2017	<2.0	<2.0	**17.8**	**3.5**	**12.7**	**NS**	"
		9/25/2017	<2.0	<2.0	**48.0**	<2.0	**6.5**	**64.3**	"
		10/26/2017	<2.0	<2.0	**107**	**225**	**22.8**	**6.0**	"
Manganese, Dissolved	ug/L	5/25/2017	**828**	**287**	**38.1**	**108**	**87.5**	**525**	10.0
		6/22/2017	**942**	**298**	**58.0**	**336**	**59.7**	**348**	"
		7/27/2017	**1200**	**268**	**420**	**<10.0**	**53.8**	**241**	"
		8/24/2017	**627**	**283**	**281**	**293**	**73.5**	**NS**	"
		9/25/2017	**1160**	**220**	**146**	**293**	**307**	**399**	"
		10/26/2017	**655**	**217**	**18.9**	**199**	**158**	**346**	"

MDL - Method Detection Limit

Varies - MDL changes based on result's concentration.

2018 Twin Lakes Peeper Pore Water Sample Results - Phase 1

PARAMETER	UNITS	DATE	Inflow 2	Phase 1 - A	Phase 1 - B	Phase 1 - C	Phase 1 - D	Phase 1 - E	Phase 1 - F	MDL
Sulfide	mg/L	6/18/2018	**44.4**	**9.13**	**11.7**	**14.3**	**12.1**	**3.75**	**2.49**	Varies
Sulfide	mg/L	7/20/2018	**46.7**	**10.10**	**2.83***	**16.8**	**18.9**	**11.4**	**8.62**	"
Average	mg/L		**45.6**	**9.6**	**11.7**	**15.6**	**15.5**	**7.6**	**5.6**	"
Iron, Dissolved	ug/L	6/18/2018	**65.2**	**292**	**212**	**86.5**	**96.1**	**381**	**397**	50.0
Iron, Dissolved	ug/L	7/20/2018	**50**	**146.00**	**50**	**73.1**	**50**	**328**	**164**	"
Average	ug/L		**57.6**	**219.0**	**131.0**	**79.8**	**73.1**	**354.5**	**280.5**	"
Sulfate	mg/L	6/8/2018	**15.7**	**5.8**	**2.1**	**17.3**	**30.6**	**72.5**	**73.3**	Varies
Sulfate	mg/L	7/20/2018	**15.1**	**4.70**	**25.1**	**10.8**	**8.1**	**37.5**	**25.2**	"
Average	mg/L		**15.4**	**5.3**	**13.6**	**14.1**	**19.4**	**55.0**	**49.3**	"
Manganese, Dissolved	ug/L	6/18/2018	**40.0**	**342**	**407**	**183**	**221**	**289**	**387**	10.0
Manganese, Dissolved	ug/L	7/20/2018	**41.7**	**143.00**	**197**	**168**	**242**	**222**	**215**	"
Average	ug/L		**40.9**	**242.5**	**302.0**	**175.5**	**231.5**	**255.5**	**301.0**	"

MDL - Method Detection Limit

Varies - MDL changes based on result's concentration.

* Broken peeper. This data point is not valid.

2018 Twin Lakes Peeper Pore Water Sample Results - Phase 2

PARAMETER	UNITS	DATE	Inflow 2	Phase 2 - A	Phase 2 - B	Phase 2 - C	Phase 2 - D	Phase 2 - E	Phase 2 - F	Phase 2 - G	Phase 2 - H	MDL
Sulfide	mg/L	8/20/2018	**74.2**	**15.6**	**11.7**	**3.43**	**1.38**	**8.91**	**18.6**	**8.3**	**1.42**	Varies
Sulfide	mg/L	9/20/2018	**72.9**	**14.3**	**9.53**	**0.52**	**0.778**	**4.55**	< 7.79	**9.88**	**0.216**	
Average	mg/L		**73.6**	**15.0**	**10.6**	**2.0**	**1.1**	**6.7**	**13.2**	**9.1**	**0.8**	"
Iron, Dissolved	ug/L	8/20/2018	**972**	**197**	**215**	**170**	**1160**	**404**	**107**	**631**		50.0
Iron, Dissolved	ug/L	9/20/2018	< 50.0	**265**	< 50.0	**1440**	**2860**	**259**	**536**	**509**	**701**	"
Average	ug/L		**511.0**	**231.0**	**132.5**	**805.0**	**2010.0**	**331.5**	**321.5**	**570.0**	**701.0**	"
Sulfate	mg/L	8/20/2018	**14.1**	**5**	**3.8**	< 2.0	< 2.0	**3.3**	**5.7**	< 2.0	< 2.0	Varies
Sulfate	mg/L	9/20/2018	**14.9**	**6.4**	**17**	**5.1**	< 2.0	**3.8**	**2.8**	**3.2**	**2.3**	"
Average	mg/L		**14.5**	**5.7**	**10.4**	**3.6**	**2.0**	**3.6**	**4.3**	**2.6**	**2.2**	"
Manganese, Dissolved	ug/L	8/20/2018		**124**	**162**	**166**	**326**	**76**	**84.7**	**3430**		10.0
Manganese, Dissolved	ug/L	9/20/2018	**3.5**	**125**	**150**	**247**	**341**	**80.3**	**248**	**173**	301	"
Average	ug/L		**3.5**	**124.5**	**156.0**	**206.5**	**333.5**	**78.3**	**166.4**	**1801.5**	**301.0**	"
Manganese, Dissolved	ug/L	9/20/2018	**3.5**	**125**	**150**	**247**	**341**	**80.3**	**248**			"
Average	ug/L		**3.5**	**124.8**	**153.0**	**226.8**	**337.3**	**79.3**	**207.2**	**1801.5**	**301.0**	"

MDL - Method Detection Limit

Varies - MDL changes based on result's concentration.

APPENDIX F

COMMENTS FROM MIKE MADDEN ON BOIS FORTE SANDY AND LITTLE SANDY LAKES ANNUAL MONITORING REPORT (2018)

Tracy Muck

From: Moe, Tom A <tmoe@uss.com>
Sent: Friday, January 18, 2019 9:48 AM
To: Mike and Mary
Cc: Tracy Muck
Subject: RE: [External]-Re: Sandy Lake and Little Sandy Lake monitoring report - 2018

Mike,

Thanks for including me on your distribution list. Very interesting observations. I would like your permission to use your comments in our final report currently in preparation. Do you have any problem with that?

Thanks again.

Tom Moe
Environmental Control Engineer
U. S. Steel Minnesota Ore Operations
8771 Park Ridge Drive, PO Box 417
Mt. Iron, MN 55768
218-749-7485 (office)
218-248-0028 (cell)
tmoe@uss.com

From: Mike and Mary [mailto:mikeandmary@mikeandmaryrange.com]
Sent: Friday, January 18, 2019 9:44 AM
To: Darren Vogt <Dvogt@1854treatyauthority.org>; 'Tom Rusch' <Tom.Rusch@state.mn.us>; 'Ann Geisen' <ann.geisen@state.mn.us>; 'Daniel C Ryan' <dcryan@fs.fed.us>; 'Melissa Thompson' <melissa.a.thompson@state.mn.us>; 'Rod Ustipak' <rodustipak@charter.net>; 'Seth Moore' <samoore@boreal.org>; 'Wayne DuPuis' <WayneDuPuis@fdlrez.com>; 'Nancy Schuldt' <nancyschuldt@fdlrez.com>; 'Bill Latady' <blatady@boisforte-NSN.gov>; 'Gerald Blaha' <gerald.blaha@state.mn.us>; 'Ed Swain' <edward.swain@state.mn.us>; Tyler Kaspar <Tkaspar@1854treatyauthority.org>; 'amyrbo@umn.edu' <amyrbo@umn.edu>; Thomas Howes <thomashowes@fdlrez.com>; Edie Evarts <Edie.Evarts@state.mn.us>; Esteban Chiriboga <esteban@glifwc.org>; John Coleman <jcoleman@glifwc.org>; 'Tara Geschick' <tgeshick@boisforte-nsn.gov>; Krista McKim <mckim.krista@epa.gov>; John Thomas <john.thomas@state.mn.us>; Smith, Erik (MPCA) <Erik.Smith@state.mn.us>; Suzanne Baumann <suzanne.baumann@state.mn.us>; Nathan Johnson <nwjohnso@d.umn.edu>; John Pastor <jpastor@d.umn.edu>; Bartovich, Chrissy L <clbartovich@uss.com>; Moe, Tom A <tmoe@uss.com>; Margaret Watkins <mwatkins@grandportage.com>; Brad Johnson <Brad.A.Johnson@usace.army.mil>; Jeremy Maslowski <jeremy.maslowski@state.mn.us>; steve.sommer@state.mn.us; phil.monson@state.mn.us; pmaccabee@justchangelaw.com; khoffman@mncenter.org; Ralph.J.Augustin@usace.army.mil; jtbutcher@fs.fed.us; emilybcreighton@fs.fed.us; Jeff Udd <Jeff.Udd@state.mn.us>; Jessica Holmes <jessica.holmes@state.mn.us>; Lee Johnson <leejohnson@fs.fed.us>; Tony Swader <tswader@grandportage.com>; gcng@umn.edu; Curt Goodsky (cgoodsky@boisforte-nsn.gov) <cgoodsky@boisforte-nsn.gov>; marko.katharine@epa.gov; Jill.C.Bathke@usace.army.mil; jillhoppe@fdlrez.com; Spading, Kenton E CIV USARMY CEMVP (US) <Kenton.E.Spading@usace.army.mil>; Morningstar, Desiree L CIV USARMY CEHQ (US) <Desiree.L.Morningstar@usace.army.mil>; Marty Rye <mrye@fs.fed.us>; Bev Miller <bmiller@boisforte-nsn.gov>; sarah.beimers@mnhs.org; Rick Gitar <richardgitar@fdlrez.com>; Mary Ann Gagnon <maryanng@grandportage.com>; Robin, Jim (MPCA) <jim.robin@state.mn.us>; Patrick O'Hara <ohara060@umn.edu>; Laura Matson <matso092@umn.edu>; Mae Davenport <mdaven@umn.edu>; Lotthammer, Shannon (MPCA) <shannon.lotthammer@state.mn.us>; Wester, Barbara <wester.barbara@epa.gov>; moody.jonathan@epa.gov;

pierard.kevin@epa.gov; haugland.john@epa.gov; holst.linda@epa.gov
Subject: [External]-Re: Sandy Lake and Little Sandy Lake monitoring report - 2018

Darren,

Thank You for including me with this.

Two things stand out to me after reading the report(skimming) that are probably not relevant but I thought I would pass on. In the vegetation study there is no mention of cattails. Back in the 70's there were no cattails. The entire shore around the lake where cattails grow now was spruce bog or as we called it cranberry bog. The cattails started showing up around the same time the rice started to disappear, which is also when the water levels started to rise. Even the creek to Admiral lake was completely open and passable by small boat. Now its completely choked off.

Secondly and less important, looking at the water level chart many of the drops in water level over the years can be attributed to myself and other locals attempting to remove beavers and dams. We have spent countless hours removing dams and beavers but it's a losing battle for us. Former CO Gerry McHugh was convinced high water levels were the problem with the rice and he encouraged us in our efforts to lower the levels. Even with US Steels recent efforts at controlling the water level during their recent permit time we never had a full growing season free of high water.

Thank you all for your efforts. Feel free to contact me if you have any questions.

Mike Madden

218 780 3993

From: Darren Vogt <Dvogt@1854treatyauthority.org>
Sent: Thursday, January 17, 2019 8:09 AM
To: 'Tom Rusch'; 'Ann Geisen'; 'Daniel C Ryan'; 'Melissa Thompson'; 'Rod Ustipak'; 'Seth Moore'; 'Wayne DuPuis'; 'Nancy Schuldt'; 'Bill Latady'; 'Gerald Blaha'; 'Ed Swain'; Tyler Kaspar; 'amyrbo@umn.edu'; Thomas Howes; Edie Evarts; Esteban

Chiriboga; John Coleman; 'Tara Geschick'; Krista McKim; John Thomas; Smith, Erik (MPCA); Suzanne Baumann; Nathan Johnson; John Pastor; 'Chrissy Bartovich'; Tom Moe; Margaret Watkins; Brad Johnson; Jeremy Maslowski; steve.sommer@state.mn.us; phil.monson@state.mn.us; pmaccabee@justchangelaw.com; khoffman@mncenter.org; Ralph.J.Augustin@usace.army.mil; jtbutcher@fs.fed.us; emilybcreighton@fs.fed.us; Mike and Mary; Jeff Udd; Jessica Holmes; Lee Johnson; Tony Swader; gcng@umn.edu; Curt Goodsky (cgoodsky@boisforte-nsn.gov); marko.katharine@epa.gov; Jill.C.Bathke@usace.army.mil; jillhoppe@fdlrez.com; Spading, Kenton E CIV USARMY CEMVP (US); Morningstar, Desiree L CIV USARMY CEHQ (US); Marty Rye; Bev Miller; sarah.beimers@mnhs.org; Rick Gitar; Mary Ann Gagnon; Robin, Jim (MPCA); Patrick O'Hara; Laura Matson; Mae Davenport; Lotthammer, Shannon (MPCA); Wester, Barbara; moody.jonathan@epa.gov; pierard.kevin@epa.gov; haugland.john@epa.gov; holst.linda@epa.gov
Subject: Sandy Lake and Little Sandy Lake monitoring report - 2018

Hi all,
I have attached a report summarizing information from monitoring activities completed at Sandy and Little Sandy lakes in 2010-2018.

Thank you, and please let me know any questions on things.

Darren Vogt
Resource Management Division Director
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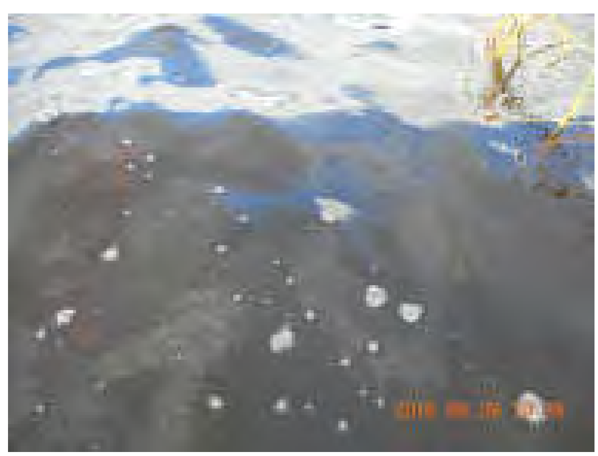
APPENDIX G

PHOTOS OF WILD RICE SEED PLOT GROWTH

Twin Lakes Wild Rice Growth in Seeded Areas
August 9, 2016

Sandy Lake Northwest

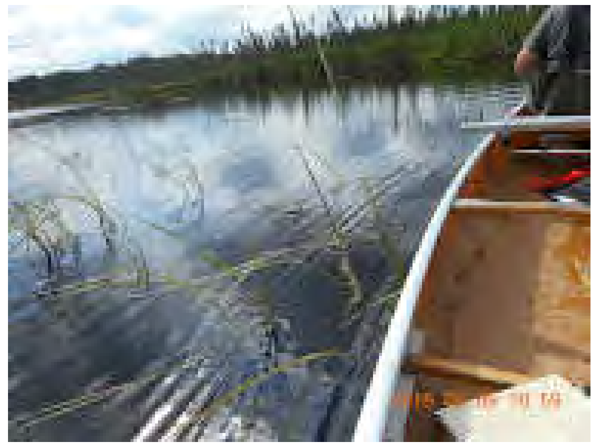
Sandy Lake East



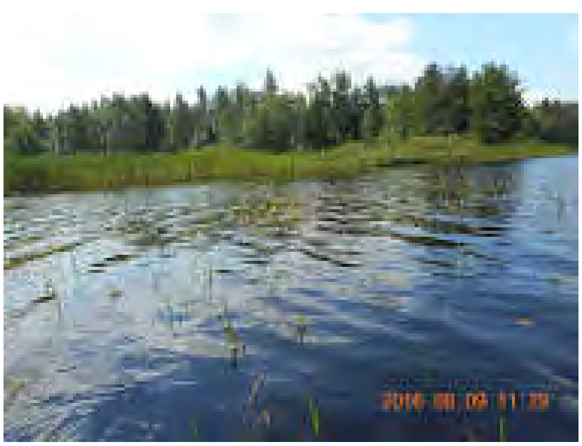
Sandy Lake East (Con't)

Sandy Lake Southwest

Sandy Lake Southwest (Con't)

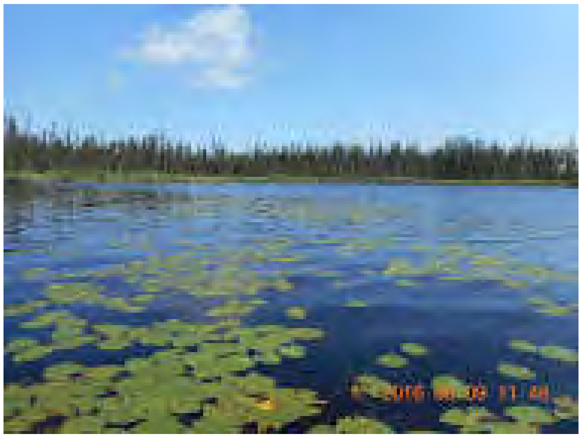


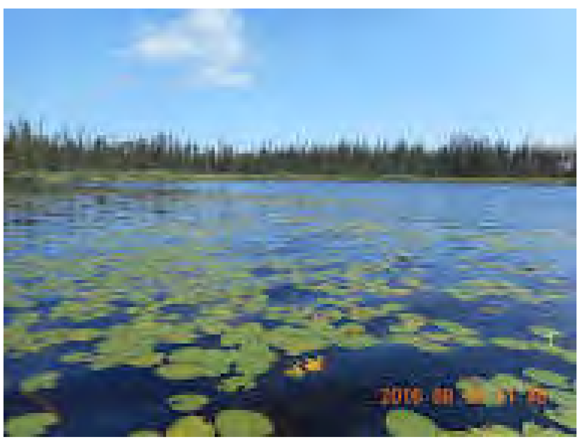
Little Sandy South



Little Sandy Northwest

Little Sandy Northeast





APPENDIX H

WILD RICE SEED PLOT DENSITIES

Wild Rice Densities 2016-2018

	2016	2017	2018
Sandy Lake North	31 plants at 2.7-2.9 ft. depth	4 Plants at 3.0 ft. depth	8 plants at 0.75 ft. depth
Sandy Lake Southeast	> 200 plants at 3.8-4.0 ft. depth	3 plants at 3.25 ft. depth	1 plant at 2.25 ft. depth
Sandy Lake West	> 200 plants at 3.5 ft. depth	50-60 plants at 3.25-3.75 ft. de	20 plants at 2.25 ft. depth
Sandy Lake South Inflow	15-20 plants at 2.7 ft. depth	18-20 plants at 1.25 ft. depth	15 plants at 2 ft.
Little Sandy Lake Northeast	10 plants at 3.2-3.9 ft. depth	60 plants at 3.0 ft. depth	8 plants at 1.75 ft. depth
Little Sandy Lake Northwest	None	2 plants at 1.25 ft. depth	12 plants at 2.5 ft. depth
Little Sandy Lake South	>200 plants at 3.75-4.0 ft.depth	50 plants at 3.5 ft. depth	50 plants at 1.75 ft. depth

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Research article

A comparison of results from a hydrologic transport model (HSPF) with distributions of sulfate and mercury in a mine-impacted watershed in northeastern Minnesota

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ABSTRACT

The St. Louis River watershed in northeast Minnesota hosts a major iron mining district that has operated continuously since the 1890s. Concern exists that chemical reduction of sulfate that is released from mines enhances the methylation of mercury in the watershed, leading to increased mercury concentrations in St. Louis River fish. This study tests this idea by simulating the behavior of chemical tracers using a hydrologic flow model (Hydrologic Simulation Program FORTRAN; HSPF) and comparing the results with measured chemistry from several key sites located both upstream and downstream from the mining region. It was found that peaks in measured methylmercury (MeHg), total mercury (THg), dissolved organic carbon (DOC), and dissolved iron (Fe) concentrations correspond to periods in time when modeled recharge was dominated by active groundwater throughout the watershed. This helps explain why the timing and size of the MeHg peaks was nearly the same at sites located just upstream and downstream from the mining region. Both the modeled percentages of mine water and the measured sulfate concentrations were low and computed transit times were short for sites downstream from the mining region at times when measured MeHg reached its peak. Taken together, the data and flow model imply that MeHg is released into groundwater that recharges the river through riparian sediments following periods of elevated summer rainfall. The measured sulfate concentrations at the upstream site reached minimum concentrations of approximately 1 mg/L just as MeHg reached its peak, suggesting that reduction of sulfate from non-point sources exerts an important influence on MeHg concentrations at this site. While mines are the dominant source of sulfate to sites downstream from them, it appears that the background sulfate which is present at only 1–6 mg/L, has the largest influence on MeHg concentrations. This is because point sourced sulfate is transported generally under oxidized conditions and is not flushed through riparian sediments in a gaining stream watershed system.

1. Introduction

When a river is legally classified as *impaired* with respect to a constituent, the causes of the impairment need to be studied to determine what corrective steps may be needed to bring the river back to an unimpaired state. This can become a time consuming, high-stakes process, especially when considering changes to a watershed that contains streams and rivers of high scenic and recreational value and a major industry that impacts flow and water chemistry. Such is the case for the St. Louis River in northeastern Minnesota (Fig. 1) which contains a richly forested land dotted with wetlands and lakes, but hosts world-class iron deposits that have been mined for more than a century and extensive, undeveloped, copper-nickel deposits that may be mined in the future. This river, like many others in Minnesota, is considered impaired with respect to mercury concentration in fish (Anderson et al., 2013).

The primary method Minnesota has chosen to address fish mercury impairments is to decrease mercury emissions in the state by 93 percent from 1990 levels and by active and aggressive participation in national and worldwide efforts to cut anthropogenic Hg emissions (MPCA, 2009). This should, in time, lead to a 65

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0301-4797/

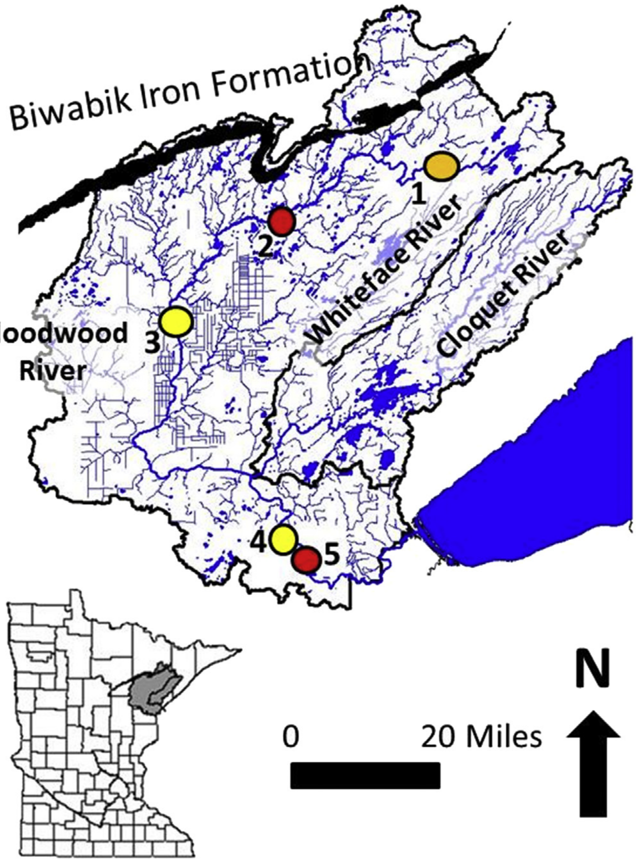

Fig. 1. Location Map showing the St. Louis River watershed and major points of interest to this study. Site 1 is Mile 179 near Skibo, MN, where both flow and chemistry were monitored upstream from the mining region (Biwabik Iron Formation in black). Sites 3 and 4 refer to Miles 94 and 36, respectively, where chemistry was sampled progressively downstream from the mining region. Sites 2 and 5 refer to the Forbes and Scanlon flow monitoring stations.

percent decrease in the amount of mercury in fish throughout the state. However, several rivers, including the St. Louis River, are expected to remain impaired even if these reduction goals are achieved (MPCA, 2014). Thus, the state is interested in determining what other measures might be useful in bringing this and other rivers that will remain impaired into eventual compliance.

One possible management strategy under consideration for such rivers involves decreasing the amount of sulfate released from the mining industry. Sulfate reducing bacteria (SRB) have long been known to participate in mercury methylation processes (Benoit et al., 1999; Gilmour et al., 1992). Sulfate added to water from the agricultural industry is widely debated, for example, as a primary cause for elevated methylmercury levels in certain fish in the Florida Everglades region (Gabriel et al., 2014; Julian et al., 2015). Debate over a possible connection between mining-related sulfate and methylmercury has also ensued for the St. Louis River, and so the State of Minnesota has been urged by environmental and mining advocates alike to study this issue.

Sulfate in Minnesota's mining region is produced when small amounts of pyrite and other less abundant iron sulfide minerals are exposed to air during the mining of taconite iron ore. This sulfate is rinsed into surface and groundwaters when precipitation infiltrates the oxidized portions of rock stockpiles and tailings. The majority of the sulfate currently released from mine wastes in the St. Louis River watershed eventually reaches the bottoms of still active mine pits and is discharged with mine water into nearby surface streams (Berndt and Bavin, 2012a,b). Additionally, some abandoned pits have become filled with high sulfate water (e.g., typically 100–1000 mg/L) that can overflow into nearby streams. The iron mining region, active since the 1890s, also contains other rock stockpiles and tailings piles that can promote oxidation of sulfide minerals that seep into the subsurface and emerge nearby, but this is a much smaller source than the sumps or pits that feed directly into streams in the St. Louis River's northern headwater regions.

Significant chemical and biological sampling efforts were made in this region in 2012 to identify linkages between sulfate release from the mining region and possible influence on MeHg production, transport, and bioaccumulation in the watershed (Berndt et al., 2014; Jeremiason et al., 2016; Johnson et al., in press). The watershed often experiences wet conditions in the spring and early summer that transitions to drier periods in late autumn and this also happened in 2012 (Fig. 2). Comparison of water chemistry for sites located both upstream and downstream from the mining region for this period indicated that sulfate was strongly correlated to magnesium, but not to dissolved organic carbon (DOC) or to methylmercury (MeHg), total mercury (THg), or dissolved iron (Fe) (Berndt et al., 2014). The latter components were, however, strongly correlated to each other. Although sulfate in reduced settings influenced mercury and methylmercury dynamics in sediments, the results suggested that the sulfate from mines may have had relatively little opportunity to interact with reduced sediments in a manner conducive for production and transport of MeHg. This study tests and expands this interpretation by comparing chemical results from the 2012 sampling study to seasonally varying differences in hydrologic flow components as modeled using an HSPF watershed model (Tetratech, 2015).

The HSPF model was selected for this study because it has the ability to provide an independent method to quantify and track the relative amounts of water delivered to the river specifically via surface runoff, interflow, and groundwater recharge. Recharge mechanisms that force hillslope flow paths through riparian zones have received recent attention for use in quantifying DOC, THg, and MeHg delivery to watersheds from similarly forested boreal catchments in Sweden (Bishop et al., 2004; Eklof et al., 2015; Seibert et al., 2009; Winterdahl et al., 2011). According to these models, groundwater that enters a river in its headwater regions attains much of its chemistry by reaction with riparian sediments, the last substrate with which it is in contact prior to becoming part of the surface water flowage. Thus, a comparison of measured chemistry to HSPF modeling results can help to determine the degree to which similar processes might help to account for the chemistry of water in mine-impacted portions of the St. Louis River.

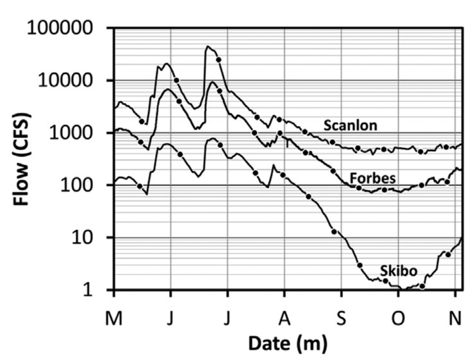

Fig. 2. Measured flow volumes in the St. Louis River during the study period (lines). Solid dots refer to dates when chemical samples were collected at Miles 36, 94, and 179.

2. Methods

HSPF modeling tools provide a well-established means to numerically characterize water recharge and routing in a watershed (Bicknell et al., 2001; Ouyang et al., 2012; Rolle et al., 2012). This model is part of the United States Environment Protection Agency's US-EPA's Better Assessment Science Integrating point and Nonpoint Sources (BASINS) software package (US-EPA, 2013). To the extent possible, HSPF models take into account all available climatological information, land use, topography, and surficial geology. Records from point sources, dams, and gaging stations located along the river or its tributaries are also considered directly in the final hydrologic calibration. The state of Minnesota has invested heavily in the development of HSPF watershed models as a means to improve its understanding of nutrient, sediment, and contaminant loading to rivers and lakes throughout the state. In 2015, a calibrated HSPF model became available for the St. Louis River watershed, with hydrologic calibration extending through the end of 2012 (Tetratech, 2015).

Flow measurements from 11 gaged stations located throughout the watershed were used in the calibration. This included sites at Scanlon (2005–2012 data set, $R^2 = 0.9293$ for monthly average flows), Forbes (2010–2012; $R^2 = 0.8561$), and Skibo (2011–2012, $R^2 = 0.8756$) (Fig. 1). Part of the calibration involved distributing non-point recharge to rivers along three primary flow paths that depend on land characteristics and the intensity and duration of storm events. The HSPF model was used to calculate the percentages of water at each of our sampling locations derived from different recharge sources. Five simulated tracers were defined (n with concentration C_n) each unique to water source types. These tracers were then introduced independently to each water source type as they entered the surface water flow environment as follows:

1. $C_{SR} = 1.0$ mg/L added only to water that enters the surface waters as surface runoff,
2. $C_{IF} = 1.0$ mg/L added only to water that enters the surface waters as interflow,
3. $C_{AG} = 1.0$ mg/L added only to water that enters the surface waters as active groundwater,
4. $C_{P1} = 1.0$ mg/L added only to water that enters the surface waters from mining point sources.
5. $C_{P2} = 1.0$ mg/L added only to water that enters the surface waters from non-mining point sources.

Direct precipitation onto open water was also modeled with a tracer, but its percentage was generally small compared to the others and its contribution is ignored here. The other tracer concentrations were used as proxies for the relative amounts of water derived as a function of time from individual source types.

A second calculation was also conducted for groundwater that involved additional input of a decaying tracer, $^{*}C_{AG}$, also at 1 mg/L concentration to all water entering the watershed as groundwater. This tracer was allowed to decay by a small fraction, k, each day. An indication of actual and relative transit time for dissolved components entering the stream from groundwater could then be computed using $^{*}C_{AG}/C_{AG}$ ratios as follows:

$$\text{Transit time (days)} = -\ln(^{*}C_{AG}/C_{AG})/k \quad (1)$$

where k is a decay rate in units of days^{-1} (e.g., $dC_{AG}/dt = -kC_{AG}$). In reality, some molecules in a watershed could take years to move from source region to sampling site while other molecules sourced nearby a can make the transit in seconds. Thus, transit times defined in this way are not singular or statistically defined values (McDonnell et al., 2010). The transit time in this application is operationally defined by Equation (1). It is used more appropriately in a semiquantitative sense to systematically compare the time that the majority of molecules transported in a stream have spent in the water column since entering the river.

3. Results

Simulated C_{SR}, C_{IF}, C_{AG}, C_{P1}, and C_{P2} concentrations varied by site and by season (Fig. 3). Relative tracer concentrations at all three sites summed very closely to unity in all cases, so the concentration of a particular constituent represents the fraction of water that originated from the tracer's designated source type. C_{AG} values close to 1.0 throughout the region indicate that active groundwater was the overwhelmingly dominant source of water input during most periods from April through July. Overland surface runoff and interflow waters were common immediately following large rain events, but these were flushed quickly downstream by more persistent, longer lasting recharge from active groundwater flow. The simulated tracer concentrations suggest that groundwater also dominated through the winter and dry autumn months at Mile 179, where no significant point sources were present upstream. Modeled mining point sources accounted for over 40 percent of the flow at Mile 94 during winter and at the height of the autumn dry period. Point sources accounted for less than 20 percent of flow in winter at Mile 36 but reached approximately 30 percent in the autumn, 20 percent of which was from the mining industry.

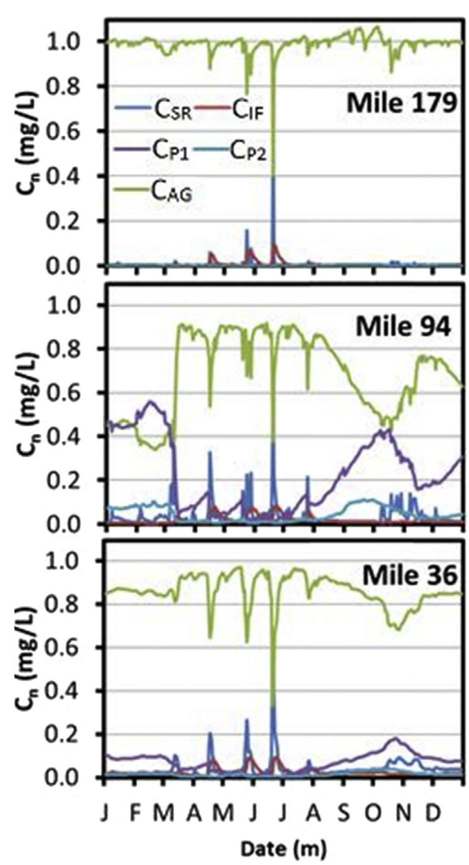

Fig. 3. Computed source type tracer concentrations (C_n) for the three sites sampled in 2012. The model indicates that May through July were dominated by discharge from active groundwater sources (C_{AG}). Mining (C_{P1}) and other (C_{P2}) point sources became progressively more important from August through October downstream from the mining region (Miles 94 and 36) as flow rates declined throughout the watershed.

Sulfate, DOC, THg, MeHg, and Fe concentrations measured at the three sites can be compared with computed mining point source tracer concentrations (Fig. 4) to provide insight on the potential for mine waters to impact these constituents. Dissolved sulfate measured in the water column increased when modeled mine tracer concentrations also increased at Mile 94, but the arrival of the measured sulfate peak at Mile 36 was somewhat delayed compared to that predicted by the minewater tracer. The source of this offset is part of an ongoing investigation to improve the HSPF model's accuracy.

Measured DOC, THg, MeHg, and Fe concentrations declined rapidly as the modeled mine water fraction increased. However, the fraction of mine water present in the watershed at the sampling sites was far too small to explain the declines by simple dilution. While there were peaks for DOC, THg, MeHg, and Fe at all sites, a second large peak in measured concentrations at Mile 179 occurred in August for DOC, THg, Fe, but not MeHg. This later peak followed a relatively small precipitation event near the end of July. The second peak in measured concentrations at Mile 179 was more pronounced for DOC and Fe than for THg and not observed at the downstream sites.

Calculated transit times for groundwater-derived components were generally 10 days or less at all sites from April through July (Fig. 5) but increased significantly, especially at Miles 36 and 94 in the fall and winter months. Transit times were never greater than 8 days at Mile 179, where there must be limited in stream storage between sources and the sampling site. The short computed transit times at Mile 179 suggest that water column demethylation processes were likely not important and, thus, the lack of high MeHg in the autumn is indicative of processes occurring in the source regions. Computed transit times for Mile 94 and Mile 36 increased, respectively, to approximately 25 and 40 days by early October suggesting there was greater opportunity for instream reactions such as DOC photodegration and mercury demethylation during these periods.

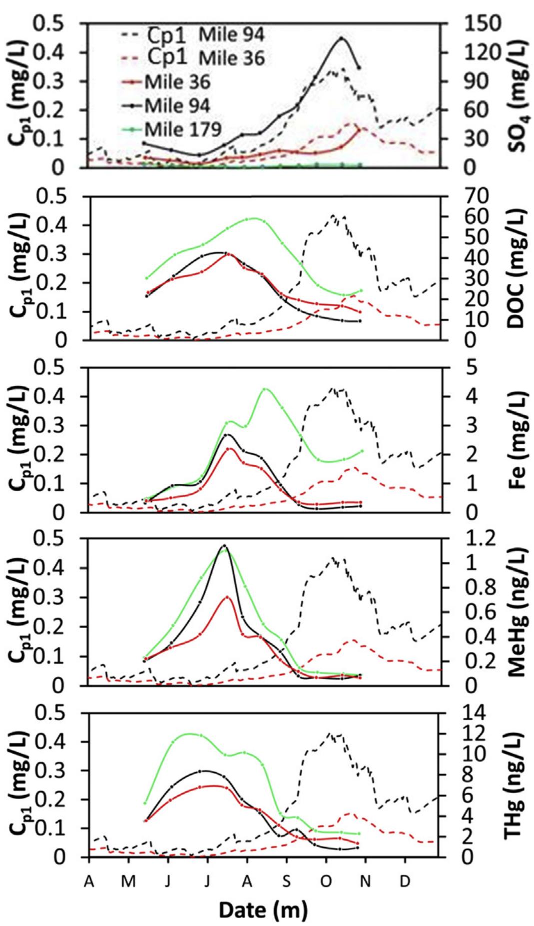

Fig. 4. Relationship between modeled mine water tracer concentration (C_{p1}, dashed lines) and dissolved concentrations of a variety of dissolved constituents (Sulfate, DOC, THg, MeHg, and Fe; solid lines) at Miles 36, 94, and 179.

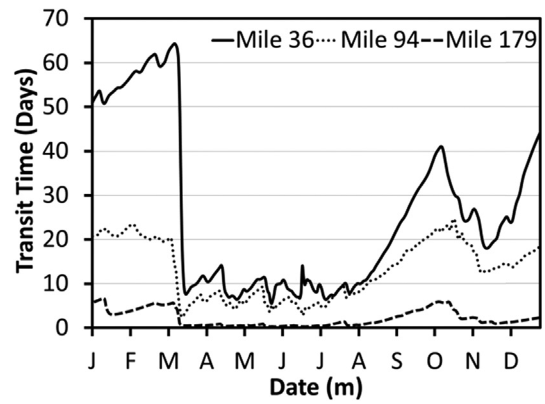

Fig. 5. Calculated transit times at the three sampling sites for components that enter the watershed from active groundwater sources. Transit times become short when flow rates become elevated.

4. Discussion

Landscapes and climate create complicated variables that result in many possible dynamically changing flow paths and mixtures of water in a river. Water from precipitation is added to streams via surface runoff or may be progressively delayed as it flows through and reacts with sediments along interflow and groundwater flow paths. Owing to this complexity, contextual information needed to interpret the chemistry of water draining a large river system can probably best be provided by computer watershed models like HSPF. The model developed here used simulated tracers to provide a mechanism to independently distinguish and track the source and fate of water entering the St. Louis River watershed for a year characterized by periodic sampling at sites located upstream and downstream from the mining region.

Active groundwater tracer concentrations calculated for each of the sampling points approached unity during periods when elevated methylmercury concentrations were found, signifying the importance of groundwater recharge in the MeHg generating process in this river. Although three major rain events early in the growing season led to pronounced but briefly elevated simulated tracer concentrations for interflow and surface water runoff, these components were diluted and washed quickly downstream by groundwater recharge when elevated MeHg concentrations were found in the river (Figs. 3 and 4).

It has long been known that riparian sediments can exert an important influence on the chemistry of stream waters recharged by groundwater (Bishop et al., 2004; Brigham et al., 2009; Vidon et al., 2010). Stream waters in several heavily studied forested boreal watersheds in Sweden, with composition similar to the St. Louis River, are thought to take their chemistry directly from riparian pore waters that obtained their chemistry during reaction with riparian sediments (Eklof et al., 2015; Seibert et al., 2009; Winterdahl et al., 2011). Under conditions of high flow the stream chemistry more closely mimics pore water chemistry that evolves in upper riparian soils. Conversely, stream chemistry under lower flow conditions mimics that of pore fluids that evolve in deeper sediments underlying the riparian soils. The Riparian Profile Flow-Concentration Model (RIM) describes changes in stream chemistry by integrating groundwater flux and concentration profiles for water moving laterally across riparian soils and sediments (Seibert et al., 2009). Based on the above theory, we hypothesize that stream chemistry reflects riparian pore fluid processes during periods of high groundwater input in our region, and use measured stream chemistry (Fig. 6) to infer processes occurring in riparian sediments upstream from the Mile 179 site. This HSPF model indicates water sampled at this site was almost totally from groundwater and had relatively short flow path from stream recharge to the sampling site (Fig. 6).

Sulfate concentration was initially above 5 mg/L when methylmercury and DOC concentrations were low, indicating that constituents in groundwater passing into the stream were not being rapidly metabolized and DOC was not being as actively produced as later in the season. By late July, the growing season was near its peak and sulfate concentrations dropped to approximately 1 mg/L while dissolved MeHg concentration reached its peak. As the summer continued, sulfate continued to remain close to 1 mg/L while iron began to climb to values eventually reaching 4 mg/L. This suggests that iron and sulfate reduction were both occurring within the pore fluid environment in the groundwater source region during these periods. The fact that MeHg concentrations were in decline as iron concentrations began to increase implies that iron reduction may not be the primary process associated with MeHg production and transport during the late summer months. Near the end of August, sulfate levels again began to climb, eventually to approximately 3 mg/L, just as MeHg reached stable low values (e.g., approximately 0.1 ng/L) and iron concentrations declined to approximately 2 mg/L. The gain in sulfate and loss of iron signals the slowing of both iron and sulfate reduction processes and corresponds to a decrease in DOC from almost 60 mg/L to values near 25 mg/L. Water levels in the watershed had declined greatly by this time, meaning that most water entering the streams may have been occurring through long-lasting springs and seeps, involving less contact with labile organic matter or at colder temperatures. For this part of the watershed, however, the attainment of minimum sulfate concentrations coincided with the methylmercury maximum, suggesting a strong role for sulfate reduction in the process that methylates mercury. It is reasonable to expect a similar reaction sequence in the nonmining portions of the mining watersheds where water filters through the landscape and riparian soils.

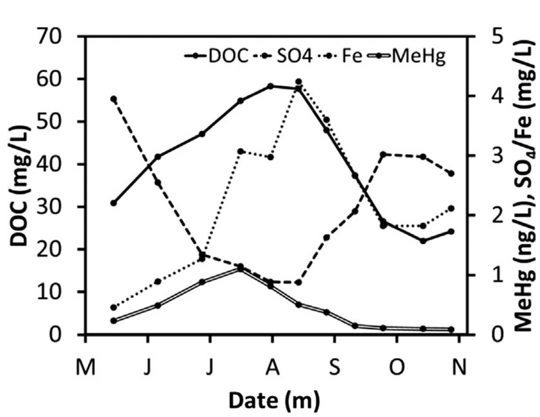

Fig. 6. Dissolved DOC, sulfate, Fe, and MeHg at Mile 179 in 2012. The MeHg peak occurred and Fe concentration quickly increased when sulfate dipped to approximately 1 mg/L. This suggests that DOC, MeHg, and Fe are generated by reactions involving sulfate and iron reduction as groundwater passes through riparian sediments on its way to recharging the river.

The climate impacting the different parts of the watershed appears to be similar based on the similarity of hydrographs for different parts of the river (Fig. 2). The geography and geology of the regions is variable and some differences in chemistry can be expected even without the presence of any mine influences. There are also more lakes and reservoirs that can enhance the importance of in-lake reactions for water collected at Miles 36 and 94, as compared to Mile 179. Despite these differences, the MeHg peaks occurred at the same time in all parts of the watershed, specifically when HSPF modeling suggests there was a very small fraction of mine water flowing in the river at the sampling sites. There was also an extended Fe and DOC peak in the area upstream from Mile 179 compared to at the sites downstream (Fig. 4). Flows at Mile 179 during the late summer become exceedingly small compared to earlier in the summer (Fig. 2). It is possible that a similar high-Fe peak was delivered to the other parts of the watershed, too, but in volumes so small that they were masked by iron-poor water already stored in the watershed. Modeled transit times for components of groundwater recharge increased during this time much more at Mile 36 and Mile 94 than at Mile 179 (Fig. 5), supporting this interpretation.

Two factors make it difficult for sulfate from the mines to impact MeHg in the rivers. First, the sulfate from mines is introduced largely as point sources at the ends of a relatively few tributaries and, thus, is limited geographically from interacting with riparian sediments in the great majority of the region. Second, even in the streams it flows through, it may be hydrologically excluded from reacting with riparian sediments that have the reduced conditions needed to promote methylation. The St. Louis River watershed receives, on average, approximately 8 inches more precipitation than is evaporated or transpired, and thus stream segments along the flow path mostly gain water from the surrounding landscape. The hydraulic gradient, is therefore, well poised to produce and transport chemicals like DOC and MeHg to the river, but water derived from mines is not well poised hydrologically to interact with riparian sediments where DOC and MeHg are likely to be produced.

This does not mean that sulfate introduced as point sources from mines or municipalities will never impact zones of active mercury methylation, but it does imply that instances may be rare in a mining region that receives more rainfall than can evaporate or transpire from the landscape. For example, a wetland rich area may become flooded with mine water containing sulfate during periods of increased pumping rate or from formation of temporary dams (e.g., beavers). Riverine sulfate may also react with materials in its streambed through diffusional exchange and hyporheic flow. Several studies have been conducted in the St. Louis River's mining region to evaluate stream and lake bed processes (Bailey et al., 2014a, 2014b; Berndt and Bavin, 2011). In general, MeHg production was found to be suppressed in sediments when overlying sulfate levels were high, owing likely to the binding of Hg with dissolved sulfide (Johnson et al., in press). This is consistent with findings from other studies which indicate that sulfate availability can lead to reduced sulfur species that can bind with Hg(II), reducing bioavailability (Benoit et al., 1999). A hypereutrophic lake (Lake Manganika) that receives mine water and municipal waste water has also been studied during several seasons. In the first season, when only the outflow for the lake was studied, large amounts of MeHg were found and it was proposed that the lake was producing MeHg in its water column or sediments and mixing on a relatively frequent basis (Berndt and Bavin, 2011). Subsequent years with intensified efforts found that the lake remained stratified during the summer months and while dissolved MeHg concentrations were elevated in the hypolimnion, they remained low in the epilimnion and Lake's outlet (Bailey et al., 2014b).

Instances like these should still be avoided or controlled to limit potential local impacts to MeHg inventories in local streams. However, the great majority of the mining sulfate added to streams apparently has little measureable impact on stream chemistry because opportunities are rare for the sulfate added as a point source to flow onto landscapes, through reduced soils, and back out into openly flowing waters. Elevated MeHg levels at sites located upstream and downstream from the mining region appear linked in time to periods of high summer groundwater recharge and not to periods of elevated minewater influence. Thus, it appears that limiting sulfate from point discharges would be an ineffective strategy for lowering MeHg levels in the St. Louis River.

5. Conclusions

Comparison of measured chemical trends to an HSPF source tracer model for the St. Louis River suggests that MeHg production and transport is associated primarily with the reduction of nonpoint sourced sulfate in groundwater that recharges the river through riparian sediments throughout the watershed. While abundant point sourced sulfate is delivered to the watershed from mines, this type of sulfate is typically delivered to the river in a manner that is isolated geographically and hydrologically from impacting the river's primary MeHg production and transport process. Thus, controlling mine derived sulfate would likely serve as an ineffective means for decreasing MeHg levels in the St. Louis River.

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Lake Superior Manoomin Cultural and Ecosystem Characterization Study

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Table of Contents

1. Introduction

Manoomin (wild rice) is integral to the culture, livelihood, and identity of the Anishinaabe, a group of Indigenous peoples within Canada and the United States. Manoomin grows only in the clean waters of the Gichi-manidoo gitigaan (The Great Spirits Garden). The arrival of the Anishinaabe to the Great Lakes Basin was in fulfillment of the prophecy that guided their migration from the Atlantic Northeast westward toward the Great Lakes to where "food grows on the water." In addition to the vital role of Manoomin in the lives of the Anishinaabe, it is also recognized as being ecologically important. Migrating and resident wildlife feed on Manoomin seeds in wild rice beds, which provide a nursery for many species of fish and serve as nesting and breeding habitats for many waterfowl and muskrat. Many species feed on the plant. Wild rice plants can also help stabilize shorelines (Tribal Wild Rice Task Force, 2018; David et al., 2019).

In this project we aim to describe the importance of Manoomin to help foster community stewardship and education; and to inform Manoomin management, protection, and policy in the Lake Superior Basin and throughout the Great Lakes. Specifically, our objectives were to document and characterize (1) the importance of Manoomin habitat to cultural perspectives and identity, community connections, and cultural and spiritual practices of the Anishinaabe people; and (2) the ecological importance of Manoomin habitat as indicators *of* a high-quality, high-functioning, and biodiverse ecosystem around the Lake Superior Basin.

In this report we provide a brief background on the cultural and ecological importance of Manoomin, and describe current threats (Chapter 2). We then describe the methodology undertaken to characterize the importance of Manoomin in this study (Chapter 3); and provide the study's results, including cultural and ecological metrics developed to characterize cultural (Chapter 4) and ecological functionality of Manoomin and seven case studies (Chapter 5). Based on these results, we offer cross-case findings and lessons learned over the course of this study (Chapter 6), and provide conclusions and discuss potential next steps (Chapter 7).

Project Team members and audience

We, the Project Team members of this study, are a diverse group of Lake Superior Basin Anishinaabe communities, and federal and state agencies (Exhibit 1.1), supported by Abt Associates (Abt). We are self-identified participants in the study, which originated from annual Lake Superior Manoomin Restoration Workshops. The workshops were held in April 2017, April 2018, and December 2019 to discuss the complexity of Manoomin management, its cultural significance, and the challenges and need for coastal wetland restoration where Manoomin is currently and historically harvested (NOAA, 2017, 2018, 2019a). As an outcome of these workshops, the National Oceanic and Atmospheric Administration (NOAA) applied for and received a Great Lakes Restoration Initiative (GLRI) grant, which provided funding to support this current study. A larger group was involved in the initial 2017 and 2018 workshop discussions; the

Exhibit 1.1. Project Team

The Project Team consists of the following entities:

- Fond du Lac Band of Lake Superior Chippewa
- Keweenaw Bay Indian Community
- Lac du Flambeau Band of Lake Superior Chippewa
- Lac Vieux Desert Band of Lake Superior Chippewa
- Grand Portage Band of Lake Superior Chippewa
- 1854 Treaty Authority
- Great Lakes Indian Fish and Wildlife Commission
- Lake Superior National Estuarine Research Reserve
- National Oceanic and Atmospheric Administration
- National Sea Grant College Program
- U.S. Bureau of Indian Affairs
- Wisconsin Department of Administration.

list in Exhibit 1.1 reflects the entities who continued to be engaged in the GLRI-funded project implementation. As Project Team members, we decided upon the design and study methodology on a consensus basis, which Abt, our contractor providing technical support, then applied. We then reviewed and approved all reports and materials developed during this study.

The primary audiences for this report are Indigenous communities, tribal and non-tribal governments, and organizations who are working to actively manage and restore Manoomin across the Great Lakes.

2. Importance of Manoomin

Manoomin is central to the Anishinaabe cultural identity, traditions, and livelihood. It is an important species to the ecology of waters within the Great Lakes region, proving food and habitat to endemic and migratory species. This chapter first provides a brief overview of the cultural and ecological importance of Manoomin, and then describes some of the threats to Manoomin and its associated habitat. For a more detailed understanding of the relationship Manoomin holds with other beings, see Barton (2018) and David et al. (2019).

Cultural importance

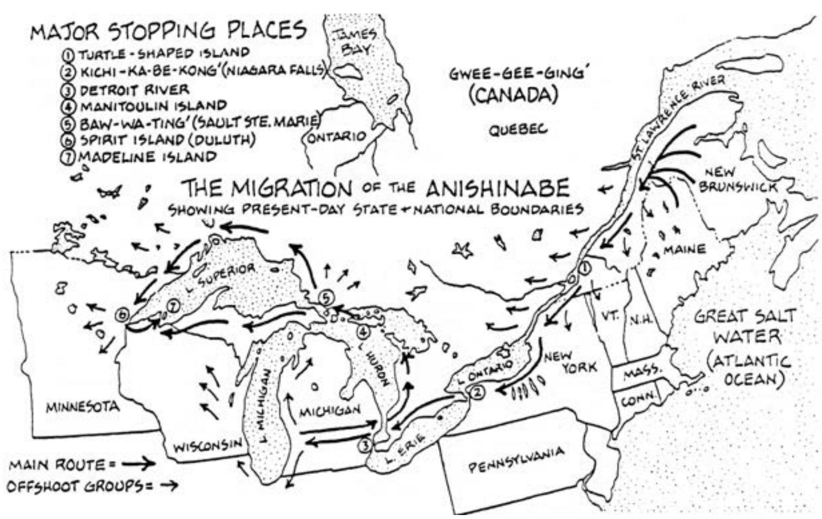
Photo of Kathleen Smith, Habitat Specialist/Plants Program, Keweenaw Bay Indian Community Photo credit: Todd Marsee, Michigan Sea Grant.

Manoomin is a central part of the Anishinaabe migration story: the Anishinaabe people were told to head West to their chosen land by the third of seven prophets, and they would know they were home when they found "the food that grows out of the water" (Exhibit 2.1; Benton-Banai, 1985; David et al., 2019). This food would sustain their families' bodies and souls for generations. As a result, Manoomin holds a critically important place in Anishinaabe culture.

Manoomin is a sacred symbol – it represents the Anishinaabe people's journey, their relationship to the land, and their identity as a culture (Tribal Wild Rice Task Force, 2018). For the Anishinaabe people, Manoomin is considered a sacred, animate, more-than-human being and not an inanimate resource. Manoomin accompanies all ceremonies, celebrations, feasts, funerals, and initiations as a food source and a spiritual presence (David et al., 2019).

The Manoomin harvest is critical to Anishinaabe culture and is part of long-standing traditions. The harvest is a major community activity

Exhibit 2.1. The migration story



Source of map: Benton-Banai, 1985.

Ongow Anishinaabeg ogii-piminizha'aawaan iniw miigisan. Mii iw gaa-izhi-dagoshinowaad eteg wiisiniwin imaa nibiikaang.

The Anishinaabe people were to follow the direction of the Miigis Shell and by doing so would find their final destination; a place identifiable because it was where "food grows on water" [The Migration Story: In Search of Wild Rice. *Ayanjigozing, Manoomin Nandawaabanjigaadeg.* As translated and transcribed by Gimiwan (Dustin Burnette)].

Source of text: David et al., 2019.

that strengthens bonds within the community and within families. Families and friends work together, and children and elders come together to harvest. This tradition is passed down through generations and links the past to the present, providing intergenerational connections and allowing young people to participate in their heritage and history (Kjerland, 2015b). An essential part of harvesting Manoomin is the renewal of ties to the land and spirits (Raster and Hill, 2017). Harvesting by hand reaffirms the nature of Manoomin as a gift from the Creator and that Manoomin should be treated with respect and gratitude (Tribal Wild Rice Task Force, 2018).

Wild rice harvesting

Mii izhichigewaad ingiw Anishinaabeg dibwaa bawa`amowaad akawe asemaakewag biindaakoojigewag. Mii aw asemaa ayaabadizid biindaakoonind a`aw Manidoo. Geget apiitendaagozi asemaa. Mii akina ge izhichigeyangiban gegoo mamooyan imaa zayaaga`kiigin, gidaa-biindaakoojigemin.

The first thing Anishinaabe do is make an offering of tobacco before they harvest wild rice. Tobacco is used when making an offering to the spirit. Tobacco is highly valued. When we take from nature, we should make an offering of tobacco.

Source: GLIFWC, 2010.

Manoomin is a healthy, traditional food source for the Anishinaabe. It remains a dietary staple, nourishing the Anishinaabe and providing spiritual and cultural sustenance. Manoomin is highly nutritious, with a low-glycemic index, and provides benefits in preventing chronic diseases. It is a source of vitamins, minerals, fiber, and protein. Manoomin harvesting can also provide cardiovascular benefits from the physical activity associated with traditional food-gathering (Fond du Lac Band, 2018; David et al., 2019). It provides food sovereignty for the Anishinaabe as well, as it can be stored and consumed year-round (David et al., 2019). Hand-harvested Manoomin is often given as a gift or used for trade. This barter-and-trade system surrounding Manoomin also contributes to Anishinaabe food sovereignty by reducing food costs and improving food security (Tribal Wild Rice Task Force, 2018).

Manoomin is so fundamental to the Anishinaabe identity and culture that Anishinaabe treaties with the U.S. government guarantee access to Manoomin. The Treaties of 1837, 1842, and 1854 reserve gathering rights for Manoomin (among other rights) in lands ceded to the United States. In the Treaty of 1837, Manoomin is the only more-than-human being (i.e., the only biological resource) specifically mentioned. The rights to rice waters explicitly reserved in these treaties have been fundamental to Anishinaabe life historically and currently; and ensure Manoomin's central place in Anishinaabe culture through religious, ceremonial, medicinal, subsistence, and economic uses (David et al., 2019).

Ecological importance


Photo credit: Todd Marsee, Michigan Sea Grant

Manoomin is an essential part of the Great Lakes ecosystem and environment. Natural Manoomin beds are part of complex aquatic ecosystems that support wildlife and waterfowl. Over 17 species of wildlife that use Manoomin habitat for reproduction or foraging are listed in the Minnesota Department of Natural Resources' Comprehensive Wildlife Conservation Strategy as "species of greatest conservation need" (Fond du Lac Band, 2018). Ducks, geese, swans, muskrat, deer, and moose all feed on wild rice. Additionally, insect larvae feed on Manoomin and, in turn, birds feed on these insects.

Decaying Manoomin supports invertebrates that support birds, fish, and amphibians (Raster and Hill, 2017; Tribal Wild Rice Task Force, 2018). Manoomin beds provide breeding and resting grounds for migratory birds, rearing habitat for resident bird species (Raster and Hill, 2017), and nursery areas for young fish and amphibians (Fletcher and Christin, 2015).

Manoomin also plays an important role in maintaining ecosystem quality by sequestering nutrients, enriching soils, and countering nutrient loading and its negative impacts such as algal growth and turbidity (Tribal Wild Rice Task Force, 2018). Manoomin binds loose soils, which slows sedimentation. Additionally, through binding loose soils and acting as a windbreak, Manoomin limits the mixing of soil nutrients into waters, thus improving water clarity and reducing algal blooms (Loew and Thannum, 2011; Fletcher and Christin, 2015; Tribal Wild Rice Task Force, 2018). Manoomin is also an indicator of overall water quality and ecosystem health because it is highly sensitive to changes in water quality (David et al., 2019).

Threats to Manoomin

Manoomin and its associated habitat face many threats, some of which are highlighted below; for a more comprehensive list of threats, see David et al. (2019).

Hydrologic changes. Manoomin depends on shallow waters and both natural and human-based causes can alter lakes and rivers to make them inhospitable to this plant. Manoomin also depends on occasional hydrological disturbances, as long-term stability allows perennial plants to outcompete Manoomin, which is an annual plant. Therefore, occasional high or low water years allow Manoomin to flourish in the long-term. Damming and releasing water can degrade Manoomin habitat. Dams and ditching – created by humans or through natural causes, such as beavers or vegetation – can result in water-level regimes that are not conducive to Manoomin. Manmade dams on some reservoirs impose a large annual variability in water levels that do not allow Manoomin to flourish, while others that control water levels on lakes with lakefront property often impose highly consistent annual water levels that are also unsuitable for Manoomin growth. These managed water-level regimes can further allow other plant species to outcompete Manoomin for habitat. Other human activities that can lead to hydrologic changes that are detrimental to Manoomin include industrial resource extraction, such as mining. Industrial water appropriations and discharges can change water levels in Manoomin waters, preventing Manoomin from growing (David et al., 2019).

Pollution. Manoomin is highly sensitive to changes in water quality and requires unpolluted water to flourish. Sulfate pollution is particularly notable for its harm to Manoomin. Research dating back to the first half of the 20th century demonstrated that wild rice growth is impaired by elevated sulfate in water, but the specific mechanisms were unknown (Plain, 2017). Several recently published studies provide insight into how sulfate in water impairs wild rice: sulfate, which is converted to sulfide by microorganisms in the soil, becomes directly toxic to wild rice (e.g., Myrbo et al., 2017a, 2017b; Pastor et al., 2017; Pollman et al., 2017). Field research and controlled experiments have shown that waters with sulfate levels over 10 parts per million (ppm) are detrimental to Manoomin (Moyle, 1944; Pastor et al., 2017; David et al., 2019; Vogt, 2020b). Sulfate is commonly discharged in wastewater from mining activities, both from tailings basin discharges and process wastewater from ore processing plants (David et al., 2019).

Invasive and native competitive species. Several aquatic invasive species have locally threatened the survival of Manoomin, including milfoil, pondweed, cattail, common reed, flowering rush, and common carp. Plant species such as milfoil, cattail, and pondweed can directly compete with Manoomin for space, nutrients, and habitat. Other species such as purple loosestrife can indirectly compete with Manoomin by reducing suitable habitat if the loosestrife extent expands down-elevation under drought conditions. Common carp can significantly diminish Manoomin survival by feeding on rice seeds and by uprooting plants (David et al., 2019). Some native plants such as ginoozhegoons (or pickerelweed or moose ear) also directly compete with Manoomin for habitat (see Exhibit 2.1).

Exhibit 2.1. Native plant competition

Ginoozhegoons is a native species that occupies the same habitat as Manoomin. As a perennial species, ginoozhegoons continues to grow each year, whereas Manoomin, an annual species, grows from an individual seed each year (Howes, 2010). Although ginoozhegoons is often considered a competitor, in some instances it appears to protect Manoomin beds by absorbing wind and wave action (David et al., 2019).

Photo credit: www.freepik.com.

Land use impacts. Manoomin is sensitive to changes in land use patterns, such as residential development. Lakeside residential development is often associated with motorized boating activity, which can increase wave damage and chop up rice mats. Channel dredging is also more likely to occur in areas with high boating activity, which can lead to changes in hydrology that negatively impact Manoomin. Residential development is also associated with higher levels of ammonium in wetlands, which can limit Manoomin stands (Pillsbury and McGuire, 2009). Shoreline development can also lead to wide-scale vegetation removal, including Manoomin, from property owners desiring an open view (David et al., 2019).

Herbivory. Large populations of birds, especially resident geese and trumpeter swans, can threaten Manoomin. Geese feed on Manoomin, and can have large impacts on small or sparse stands. These populations have been increasing on treaty territories over the past two decades and can have pronounced impacts on smaller rice lakes (Nichols, 2014; David et al., 2019). Other species such as wazhashk (muskrats) and red-winged blackbirds can also heavily utilize or feed on Manoomin, sometimes causing significant impact. However, wazhashk – often classified as “cleaners” or “gardeners” – are also thought to be beneficial to Manoomin, and may play a role in controlling competing vegetation or stirring sediment to the benefit of Manoomin (David et al., 2019).

Climate change. Climate change has begun to negatively impact Manoomin and is projected to have negative impacts on Manoomin in the future. Climate change is expected to lead to more frequent heavy rainfall events, which will lead to flooding that uproots or drowns Manoomin beds. Warmer temperatures resulting from climate change will also negatively impact Manoomin abundancy by favoring outcompeting plants that are better adapted for warmer climates; and being conducive to brown spot disease, which destroys photosynthetic tissues, reduces seed production, and favors high temperature and humidity (Barton et al., 2013; Cozzetto et al., 2013; Grand Portage Band of Lake Superior Chippewa, 2016; David et al., 2019). Warmer temperatures can also change the range of Manoomin and reduce germination. Projections of future climate in the 1854 Ceded Territory indicate substantial warming over the historical baseline that could lead to a shifting of wild rice outside the Great Lakes region and the 1854 Ceded Territory due to the location of Manoomin at the southern edge of its range. These increased temperatures could also lead to decreased germination of Manoomin if the temperatures are too warm for the dormant hardening-off period that northern wild rice requires (Stults et al., 2016). In a climate change vulnerability assessment conducted by the Great Lakes Indian Fish and Wildlife Commission (GLIFWC), Manoomin was found to be the species most vulnerable to the impacts of climate change out of all the species assessed, both because of the numerous climate-related threats and because it is sensitive to different climate effects at all stages of its life cycle (GLIFWC, 2018).

3. Methodology selected to characterize the importance of Manoomin

We evaluated several methodologies for characterizing the cultural and ecological importance of Manoomin and its associated habitat, and ultimately selected an innovative combined Habitat Equivalency Analysis (HEA) approach. This chapter describes how we selected and then applied this combined HEA approach.

Selecting a method

As a team, we identified several methods to characterize the cultural and ecological importance of Manoomin and its associated habitat. We reviewed the cultural and ecological literature, and used our collective knowledge of cultural and ecological characterization methodologies to develop the following list of possible methods:

- **In-person interviews or listening sessions** with tribal community members to gather qualitative information about perspectives, cultural identify, and value systems.
- **A case study analysis** to conduct a systematic and in-depth examination of the cultural and ecological importance of Manoomin across the Lake Superior region.
- **Indigenous metrics** to evaluate Indigenous priorities for cultural, social, and ecological aspects of the community that are understandable to both Indigenous and non-Indigenous ways of thinking (Donatuto et al., 2016), including themes developed by the community (Fond du Lac Band, 2018).
- **An ecosystem service conceptual model** to link changes caused by external stressors or interventions to Manoomin through the ecological system to socioeconomic and well-being outcomes (Olander et al., 2018).
- **A social-ecological keystone concept** to quantify biocultural elements of Manoomin as a keystone species (Winter et al., 2018).
- **An HEA** to determine the amount of restoration needed as a counter-balance for habitat that has lost cultural and ecological functionality (NOAA, 2000, 2019b).
- **A combined HEA approach** to combine several methodologies that overcome individual shortcomings to develop a strong framework to characterize Manoomin and its associated habitat.

We developed and applied a set of criteria to evaluate possible methods for characterizing the cultural and ecological importance of Manoomin (Exhibit 3.1). Using these criteria, we narrowed the possible methodologies to three options – a case study analysis, Indigenous metrics, and an HEA – and a fourth approach that combined these three methods. Ultimately, we selected the combined HEA approach by consensus.

Exhibit 3.1. Criteria for selecting a characterization method

Methods should be:

1. Non-monetary
2. Capable of combining ecological and cultural characterization into a single analysis
3. Implementable using mainly existing data and information (i.e., study should not involve extensive primary data collection efforts)
4. Based, at least in part, on Indigenous methodologies, or research for and by Indigenous people using techniques and methods drawn from their traditions and knowledge.

Applying the combined HEA approach

We applied the combined HEA approach to determine or "scale" the amount of restoration needed to counter-balance habitat with cultural and ecological functionality losses over time. We developed and applied a set of cultural and ecological metrics to characterize (1) the degree of lost functionality at a given location, and (2) the increased functionality provided by restoration actions at that location. We then "scaled" the restoration gains to the losses to quantify the equivalent amount of that same restoration that would be needed to balance the losses. The case studies describe specific locations with degraded Manoomin habitat with reduced cultural and ecological functionality, and actions undertaken in attempts to restore or improve the cultural and ecological functionality. We applied the combined HEA approach to these locations.

The combined HEA approach included (1) identifying case study sites as examples of degraded and restored Manoomin habitat, (2) refining and applying cultural and ecological metrics to characterize the degraded and restored Manoomin and its associated habitat at the case study sites, and (3) using HEA to quantify the amount of restoration need to counter-balance the lost Manoomin habitat functionality (Exhibit 3.2). We describe these steps in more detail below.

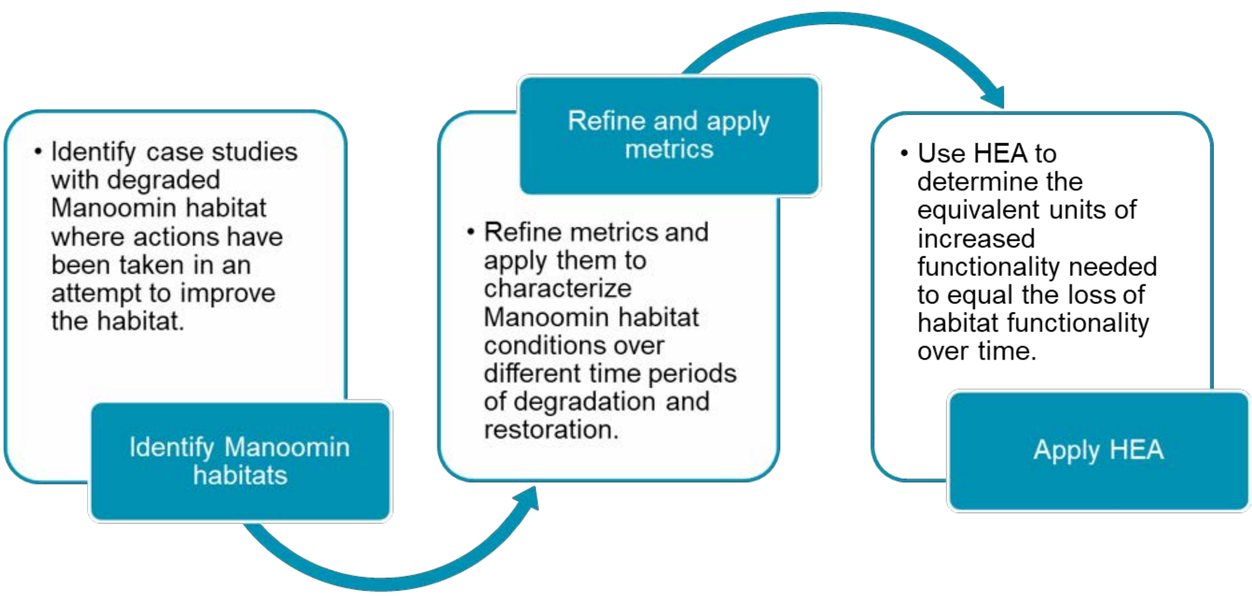


Exhibit 3.2. Steps in the combined HEA approach

Identify Manoomin habitats

We identified areas across the Lake Superior region with current or former Manoomin habitat. Our goal was to identify places that experienced a decline in Manoomin over time, and places where restoration actions have attempted to address the decline. At each site, we aimed to understand:

- The ecological conditions at the site, such as the hydrology, water quality and land use, and climatic conditions
- The cultural and ecological importance of Manoomin at the site, including Manoomin harvest and wildlife dependence on Manoomin
- The cause of Manoomin decline, such as hydrologic changes, invasive species, climate change events, or other threats
- The types of restoration actions undertaken, such as seeding efforts or management of invasive or competitive species
- The success or failure of those restoration actions, including cultural and ecological effects
- The timeline of degradation and restoration actions.

We first selected two pilot case studies to test and refine the approach: Big Rice Lake and Twin Lakes. Once we refined the cultural and ecological metrics and the combined HEA approach, as described below, we then selected five additional case studies. Each Band on our Project Team selected a case study, focusing on places of particular importance to their Band. Case studies could be on reservation lands, in ceded territory, or elsewhere. For each case study, we gathered information about the extent and timeframe of the degradation and restoration. This resulted in a range of types of Manoomin habitat degradation and restoration approaches represented in our case studies, dispersed over a broad geographical area. For each site (or case study), we formed a case study team that assessed the Manoomin habitat degradation and restoration, using cultural and ecological metrics (described below). The case study team included members of our Project Team and other tribal, federal, or state partners with experience managing Manoomin at each case study site.

Refine and apply cultural and ecological metrics

We developed a set of metrics to broadly measure all aspects of community health, with health defined as a coexistence among human beings, nature and natural resources, and spiritual beings (Donatuto et al., 2016). We started with Donatuto et al.'s (2016) indicators of Indigenous health, as well as Fond du Lac Band's (2018) health impact assessment themes and Winter et al.'s (2018) biocultural functional groups; and then adjusted and added to them, to develop a set of cultural and ecological metrics focused on Manoomin and the Great Lakes coastal wetlands.

We refined the descriptive scales used by Donatuto et al. (2016) to rank the relative status of each metric at a specific time period. These rankings provided a baseline from which to compare future rankings of the same metric, and ultimately illustrated health trend data over time. We used the following five-point descriptive scale:

- We're doing great
- We're looking pretty good
- Things are not very good
- Things are very bad
- No use of Manoomin.

We later added numeric scores to the descriptive scales as a scalar for our HEA; our numeric scores ranged from 0% (No use) to 100% (Doing great).

We applied draft metrics to our pilot case study during a workshop in August 2019. We subsequently refined the metrics to incorporate additional considerations, such as incorporating health into the *food sovereignty* metric because eating good foods relates to the mind, body, and spirit. Once we finalized the metrics and agreed to them on a consensus basis, we applied them to our case study sites.

Apply HEA to characterize Manoomin

The HEA tool was developed to determine or "scale" the amount of restoration needed as a counter-balance for habitat that has lost cultural and ecological functionality.

We held a series of webinars for each case study. During these webinars, the case study team defined the case study time periods, and then ranked each metric for each time period. The case study team first identified time periods with distinct or changing Manoomin habitat conditions. This process relied on reviewing historical documents and records, as well as case study team member's specific knowledge of the place. We then stepped through each time period, and formally ranked each metric according to the scale given above. For the Anishinaabe metric, for example, we asked each case study team:

> How would you rank [insert place name] in terms of providing Manoomin, which is sacred to the Anishinaabe and central to the foundations of their culture, sovereignty, and treaty rights? Would you say (a) we're doing great, (b) looking pretty good, (c) not very good, (d) things are bad, or (e) no use?

The case study team members individually ranked each metric, and we took an average of these rankings.

Finally, we used our HEA model to calculate the amount of restoration needed to balance the reduced or lost functions. In other words, given that restoration is challenging and rarely achieves full functionality, and the degradation has often spanned prolonged periods of time, we use the HEA to quantify the additional amount of equivalent restoration that would be needed to counter-balance the lost functionality.

The HEA model includes:

- **Base year** for this economic analysis; we set the base year to the current year, 2020.
- **Intergenerational balancing factor** to account for time preference, where degradation and restoration are put in present-value terms (NOAA, 1999). Because not all communities share this same time preference, we discussed the appropriate factor for this study and decided to apply a constant factor of 3% across all case studies, where things in the past are more valuable than they are today and things in the future are less valuable than they are today. A 3% factor is typical for ecological projects (OMB, 2003).
- **Acres** of Manoomin or Manoomin habitat characterized by the case study team. In some cases, acres included the full area of Manoomin waters and in other cases it was a portion of Manoomin waters.
- **Rankings** of Manoomin habitat over degraded and restored time periods using cultural and ecological metrics.

The amount of restoration in acres needed to counter-balance losses may be significantly larger than the acres of degraded habitat. This may be true because of practical limitations in our ability to produce fully functioning restored habitat. For example, if one acre of restored Manoomin wetland only reaches 50% functionality, then two acres of restored habitat are needed to counter-balance the one acre of lost Manoomin habitat. In addition, the amount of time that the habitat was degraded is counter-balanced with the time the restored habitat takes to reach its maximum functionality. Thus, we can account for habitat degraded for longer periods of time, and restoration actions that take longer to mature.

4. Cultural and ecological metrics

We developed 12 metrics that characterize the cultural and ecological functions of Manoomin and its associated habitat. These metrics describe how Manoomin contributes to maintaining connections with the Anishinaabe culture, how ecological functionality is supported and resilient to changing conditions, and how continued learning and sharing of Anishinaabe values are promoted.

Exhibit 4.1 displays the metrics graphically in the form of a dream catcher. Although many Tribes have adopted dream catchers over time, the Anishinaabe may have originated this tradition. There are many legends and stories behind the origins of dream catchers; in most legends, a dream catcher serves to filter out bad bawedjigewin (dreams) and allow only the good ones to enter (We R Native, 2020). Many indicate that dream catchers were also intended to teach natural wisdom (We R Native, 2020). In this graphical display of the metrics, we group cultural and ecological metrics inside the dream catcher hoop, with the Anishinaabe metric centered as it is critical for all other metrics. The three cultural and ecological education metrics are displayed below the dream catcher, as these educational metrics aim to generate and transmit the cultural and ecological knowledge between generations and communities.

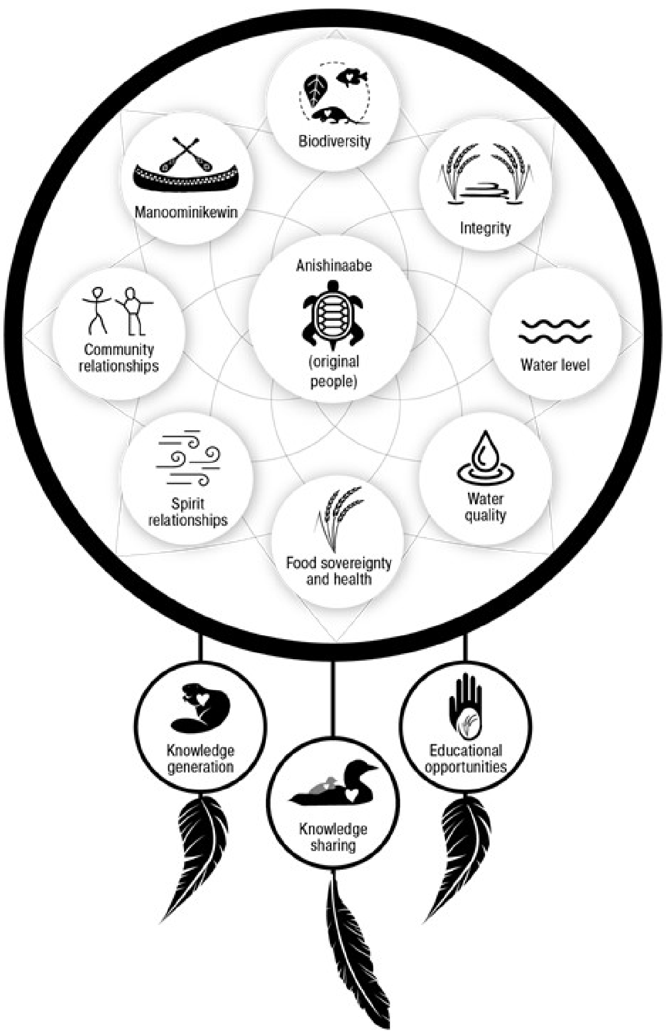


Exhibit 4.1. Dream catcher displaying the 12 metrics developed for this study

Below, we define the cultural, ecological, and cultural and ecological education metrics.

Cultural Metrics

Anishinaabe (original people) – The place provides manoomin, which is sacred to the Anishinaabe and central to the foundations of their culture, sovereignty, and treaty rights.

Community relationships – Manoomin at this place contributes to bonding, traditions, and strengthening family and community connections.

Spirit relationships – Manoomin at this place enables the Anishinaabe to maintain connections and balance with spirit beings (or relatives) from all other orders of creation (first order: rock, water, fire and wind; second order: other plant beings; third order: animal beings; fourth order: human beings).

Manoominikewin – This place allows for the Anishinaabe to harvest, prepare, and share (gifting, healing, and eating) manoomin in the ways practiced by their ancestors for centuries.

Food sovereignty and health – This place provides the capacity to provide for the sustenance, health, and independence of the Anishinaabe.

Ecological Metrics

Biodiversity – Healthy manoomin and appropriate habitat at this place supports diverse biological communities (e.g., free of invasive species) that indicate the capacity of the place to support abundant associated plant and animal species (e.g., other native aquatic vegetation, fish, waterfowl, muskrat), providing for spiritual and subsistence needs.

Integrity – Physical habitat and hydrology, water and sediment chemistry support stands of manoomin that exhibit natural annual variability; viable seed bank ensures that sustainable manoomin populations will persist even after occasional poor production years. Natural genetic diversity is maintained without impact from cultivated strains, or reduced gene flow from the loss of nearby manoomin populations.

Water quality – This place has clean water (e.g., sulfate levels below 10 ppm) and sediments that can support robust stand density and wildlife diversity; is free of contamination or impacts from industrial, agricultural, recreational, or residential influence; and is of sufficient areal extent to sustain a manoomin population.

Water level – This place has a natural or managed hydrologic regime that can maximize resilience under variable or extreme climatic conditions across the growing season (maintaining optimal depth range and flow).

Cultural and Ecological Education Metrics

Knowledge generation – This place allows for continued learning and generation of the Anishinaabe practices, values, beliefs, and language through experience.

Knowledge sharing – This place allows for the continued sharing and transmittal of the Anishinaabe practices, values, beliefs, and language among family members and community.

Educational opportunities – This place provides opportunities for language, land stewardship, and other educational programs, such as educational rice camps.

5. Cultural and ecological characterization case study results

The seven case studies, each of which profiles a story of changes in Manoomin cultural and ecological functionality over time, form the heart of this project. The case studies, grouped around the Lake Superior region, are located in the 1854 Ceded Territory and the 1842 Ceded Territory (Exhibit 5.1). Three of the seven case studies are located on reservation lands.

As described in Chapter 3, these case studies are primarily located in places with current or former Manoomin habitat that have experienced a decline in Manoomin over time, and where restoration actions have been undertaken in an effort to restore Manoomin habitat over different time periods. In a few case studies, documentation of Manoomin presence is not available from historical records; however, their physical or hydrologic features make them conducive to growing Manoomin.

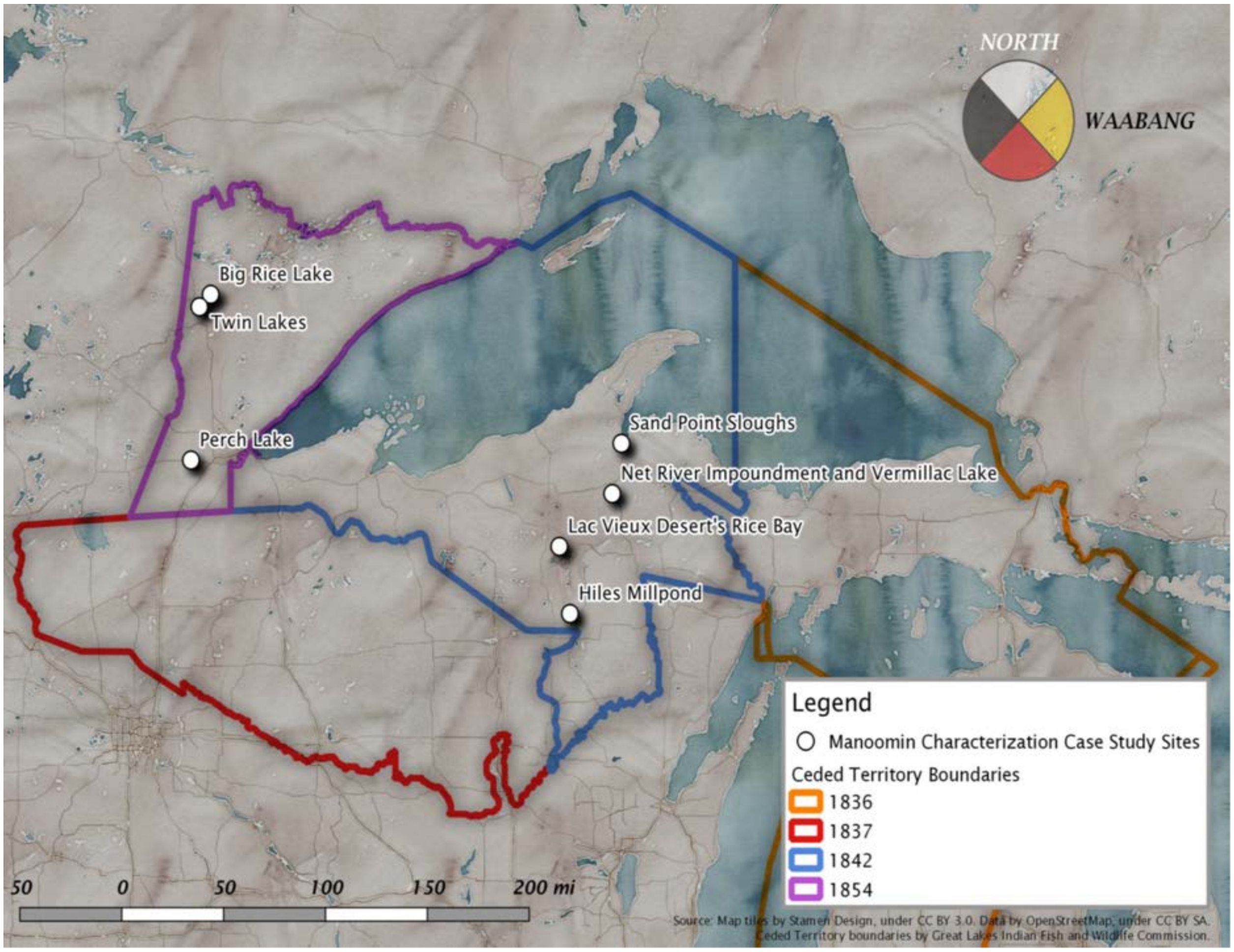


Exhibit 5.1. Map displaying the seven case study locations. The compass is in the form of a medicine wheel, an indigenous symbol used to denote the four directions.

Exhibit 5.2 provides a brief overview of the case studies, including the key threats to Manoomin at these places, some of the actions taken to improve Manoomin habitat, and, if available, the HEA results that indicate how many acres of similar Manoomin restoration habitat are needed to balance lost habitat functionality over time.

Exhibit 5.2. Case study summaries

Case study	Threats to Manoomin	Restoration actions to improve Manoomin	Additional restoration needed
Lac Vieux Desert's Rice Bay *Characterization focused on 243 restoration acres*	• High water levels caused by a concrete and steel dam at the outlet of the lake in the 1930s • High water levels caused by above-average precipitation in the 2010s	• Water level management • Manoomin seeding	**3,034 acres of similar Manoomin restoration** needed to balance the lost habitat functionality over time or **12 equivalent restoration efforts**.
Perch Lake *Characterization focused on 400 restoration acres*	• High water levels caused by agricultural ditching in the 1920s • Competitive vegetation caused by a non-functional dam in the 1960s	• Water level management • Removal of competitive vegetation	**5,204 acres of similar Manoomin restoration** needed to balance the lost habitat functionality over time or **13 equivalent restoration efforts**.
Sand Point Sloughs *Characterization focused on 8 restoration acres*	• Deposited mine tailings from a copper ore processing plant that operated north of the sloughs in the 1920s • High water levels and invasive species after 2005	• Manoomin seeding • Remediation efforts to stabilize the tailings	**175 acres of similar Manoomin restoration** needed to balance the lost habitat functionality over time or **22 equivalent restoration efforts**.
Net River Impoundment and Vermillac Lake *Characterization focused on 97 restoration acres*	Unclear if Manoomin historically grew at site; if it was, land use change likely responsible for Manoomin's depletion	• Manoomin seeding	**1,129 acres of similar Manoomin restoration** needed to balance the lost habitat functionality over time or nearly **12 equivalent restoration efforts**.
Hiles Millpond *Characterization focused on 300 restoration acres*	Unclear if Manoomin historically grew at site; if it was, high water levels caused by dam construction likely responsible for Manoomin's depletion	• Water level management • Manoomin seeding	**864 acres of similar Manoomin restoration** needed to balance the lost habitat functionality over time or **3 equivalent restoration efforts**.
Big Rice Lake *Characterization focused on 1,870 restoration acres*	• Hydrological changes • Competing vegetation	• Water level management • Removal of competitive vegetation	Varies depending on hypothetical improvement scenario.
Twin Lakes *Characterization focused on 210 acres*	• Discharge of mine tailings from an iron ore processing plant upstream of the lakes since the 1960s, which has *increased sulfate levels* and *increased water volume*	• Seepage collection system to collect some of the mine tailings discharge • Manoomin seeding (limited) • Water level management (limited)	Varies depending on hypothetical improvement scenario.

These seven case studies are described in more detail below. For each case study, we briefly describe the cultural and ecological importance of the place, and provide an overview of the threats to Manoomin and the actions taken to restore Manoomin. We then summarize how each case study team characterized the place over time using ecological and cultural metrics; and describe the additional restoration needed, as calculated with the HEA tool.

Lac Vieux Desert's Rice Bay

Exhibit 5.3. Map of Lac Vieux Desert

Lac Vieux Desert, located in Vilas County, Wisconsin, and Gogebic County, Michigan, is over 4,000 acres (Exhibit 5.3). Historically, Manoomin covered many parts of Lac Vieux Desert, including Rice Bay, Thunder Bay, Slaughters Bay, Misery Bay, and along the northwestern shore to the Wisconsin River and parts of the south shore.

Rice Bay is a 243-acre bay on the northeastern portion of Lac Vieux Desert, which historically contained a significant stand of Manoomin that was traditionally managed and harvested by the Lac Vieux Desert Band of Lake Superior Chippewa (LVD Band). West of Rice Bay is Ketegitigaaning, a ricing village used intermittently in the early 18th century by the LVD Band, followed by continuous habitation by 1900. In 2015, Rice Bay was registered as a Traditional Cultural Property on the National Register of Historic Places.

Threats to Manoomin at Rice Bay

Lac Vieux Desert was dammed around 1870 for logging operations. By 1907 the Wisconsin Valley Improvement Company (WVIC) began operating the lake as a storage reservoir and used the dam to create uniform stream flow down the Wisconsin River to reduce flooding events, facilitate hydroelectric power generation, and regulate effluent discharge downstream. In 1937, WVIC replaced the wooden dam with a reinforced concrete and steel structure. The high water levels caused by the dam initiated a decline in Manoomin (Labine, 2017). From 1938 to 1952, Manoomin declined steadily and community members stopped harvesting it during this period (Barton, 2018). During this time period, lakeside property owners became concerned about the erosion caused by rising lake levels.

More recently, heavy rainfall events have negatively affected Manoomin in Lac Vieux Desert (Roger Labine, LVD Band, personal communication, February 15, 2020). In the spring Manoomin is in the floating leaf stage, and can be uprooted by heavy rainfall that raises water levels and uproots Manoomin. In the summer, when Manoomin is in the flowering stage, heavy rainfall can knock Manoomin pollen down from the flower to the water's surface, which prevents pollination and results in "ghost rice" or empty seed hulls that never fill. In addition, the combination of heavy rainfall events and higher air temperatures may also increase the amount of brown spot – a destructive wild rice fungal disease – in Manoomin beds.

Actions taken to improve the abundance of Manoomin at Rice Bay

In 1991, a coalition of tribal, state, and federal governments and governmental agencies determined the operating regime of the dam on Lac Vieux Desert had been detrimental to Manoomin and its associated habitat (Onterra, 2012). By 2001, following a decade of negotiation and litigation, WVIC lowered the maximum operating level by about nine inches and provided financial contribution toward a Manoomin seeding and monitoring program (Barton, 2018). From 2002 to 2005, Lac Vieux Desert was seeded with 14,000 pounds of Manoomin, most of which occurred in Rice Bay (Labine, 2017). From 2007 through 2012, as Manoomin became reestablished on Rice Bay, the LVD Band held traditional ricing camps and workshops, which included traditional practices and activities (Barton et al., 2013).

Exhibit 5.4. Photograph of Lac Vieux Desert Lake's Rice Bay in 2003 (above) and 2010 (below)

Credit: Peter David, Great Lakes Indian Fish & Wildlife Commission (GLIFWC).

From 2000 to 2010, the acreage of Manoomin on Rice Bay significantly increased. In 2000, Rice Bay had just 11 acres of Manoomin coverage (or 5% of Rice Bay). After the first year of seeding, Manoomin coverage increased to over 25 acres (or 10% of Rice Bay). With below-average rainfall conditions in 2010, the extent of Manoomin increased to over 92 acres (or 38% of Rice Bay; Exhibit 5.4). While the extent of Manoomin on Rice Bay was less than its historical coverage, it was considered an improvement over conditions caused by the operating regime of the concrete dam (Barton, 2018).

Since 2011, the acreage of Manoomin on Rice Bay has been declining, with 34 acres in 2019 (GLIFWC, 2019; Exhibit 5.5). Because Manoomin abundance on Rice Bay is generally greatest during low-water years, natural resource managers believe this may be due to above-average precipitation over the past seven years (Peter David, GLIFWC, personal communication, November 12, 2019).

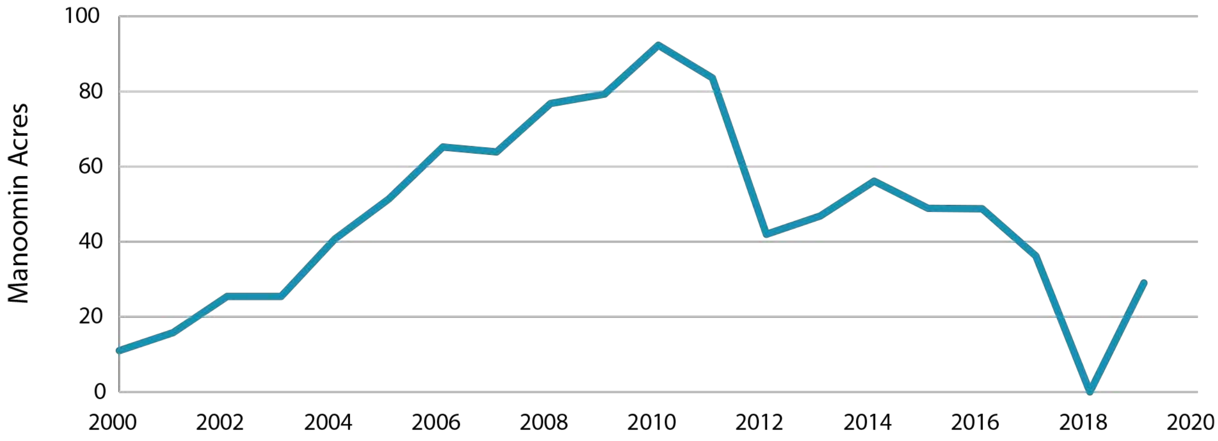


Exhibit 5.5. Manoomin acreage on Rice Bay, 2000 to 2019

Source: GLIFWC, 2019.

Cultural and ecological characterization at Rice Bay

Rice Bay's Manoomin and its associated habitat were characterized over four time periods.

1900 to 1936: With a wooden dam

Based on the combined ranking of cultural and ecological metrics, Rice Bay was characterized as "doing great" during this period. In the early 1900s, Ketegitigaaning was inhabited and the community harvested Manoomin in Rice Bay for gifting, healing, and consumption. The area also boasted a rich biodiversity; and hunting, trapping, fishing, and gathering local resources were common.

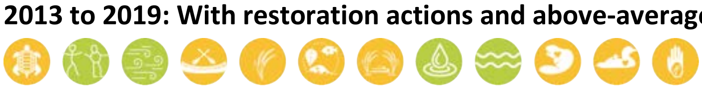
1937 to 1990: With a concrete and steel dam

After the replacement of the wooden dam with a concrete and steel structure, Manoomin declined steadily until the mid-1950s to the point that it was no longer harvestable by community members. During this time period, community members moved away from the lake and into surrounding towns, and stopped harvesting Manoomin in Rice Bay. The "disappearance of Manoomin started the deterioration of the Lac Vieux Desert community," where bonding, traditions, and community connections ceased (Roger Labine, LVD Band, personal communication, November 12, 2019). There was a steady decline in cultural and ecological functionality provided by Manoomin from 1937 to the mid-1950s, when Rice Bay was characterized as "very bad" based on the combined ranking of cultural and ecological metrics.

1991 to 2012: With restoration actions

Once restoration actions began in the 1990s, cultural and ecological functionality provided by Manoomin improved. By 2008, the LVD Band opened Rice Bay for Manoomin harvest and began hosting rice camps in the area for the first time since 1940. Although the community began knowledge sharing and knowledge generation, and educational opportunities increased, it remained difficult to get many community members interested in Manoomin because of its absence over the last 50 years. Even so, restoration actions led to an increase in cultural and ecological functionality. By 2012, Rice Bay ranked as "pretty good" based on the combined ranking of cultural and ecological metrics.

2013 to 2019: With restoration actions and above-average precipitation



With heavy rainfall events negatively affecting Manoomin beds during the growing season, cultural and ecological functionality at Rice Bay have declined. Currently, Rice Bay is ranked as "not very good" based on the combined ranking of cultural and ecological metrics. The decrease in ecological and cultural functionality provided by Manoomin in recent years suggests the need for adaptive management of Manoomin. Actions taken that may have been successful in restoring Manoomin in the past may need to be adjusted to respond to additional threats, such as climate change, to be successful in the future.

Cultural and ecological functionality provided by Manoomin and its associated habitat at Rice Bay have changed over time, both in total and for individual metrics (Exhibit 5.6).

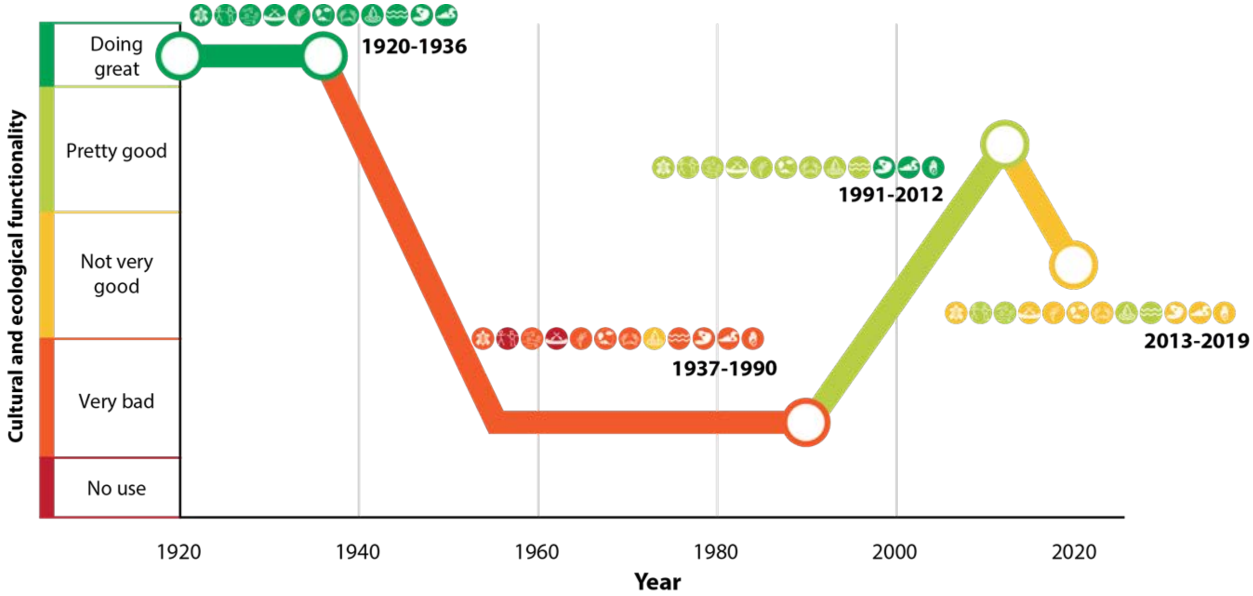


Exhibit 5.6. Characterization of cultural and ecological functionality provided by Manoomin and its associated habitat at Rice Bay

Additional restoration needed

Based on the characterization of the degree of cultural and ecological function over the four time periods, the HEA calculations demonstrate the additional equivalent units of restoration needed to counter-balance the severity and timespan of degradation. Given the success of restoration at the 243-acre Rice Bay, approximately 3,034 acres of similar Manoomin restoration is needed to counter-balance the lost habitat functionality that has occurred over time (Exhibit 5.7). In other words, 12 equivalent restoration efforts at Rice Bay (from 1991 to 2019) are needed to counter-balance the lost cultural and ecological habitat functionality (from 1937 to 1990).

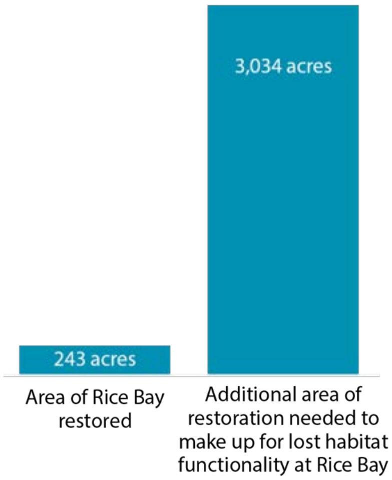


Exhibit 5.7. Additional restoration needed for Lac Vieux Desert Lake's Rice Bay

Case study acknowledgments

The Project Team would like to acknowledge Roger Labine (LVD) and Peter David (GLIFWC) for their valuable input and feedback in the development of this case study, and for participating in the cultural and ecological characterization of Lac Vieux Desert's Rice Bay.

Perch Lake

Perch Lake is located on the Fond du Lac Band of Lake Superior Chippewa Reservation in Minnesota (Exhibit 5.8). It is an approximately 650-acre, double-basin lake. The shallow, southern portion of the lake is approximately 400 acres, and it is the largest Manoomin-containing habitat on the Reservation (Fond du Lac Band, 2008). The northern basin also supports some Manoomin along its fringes.

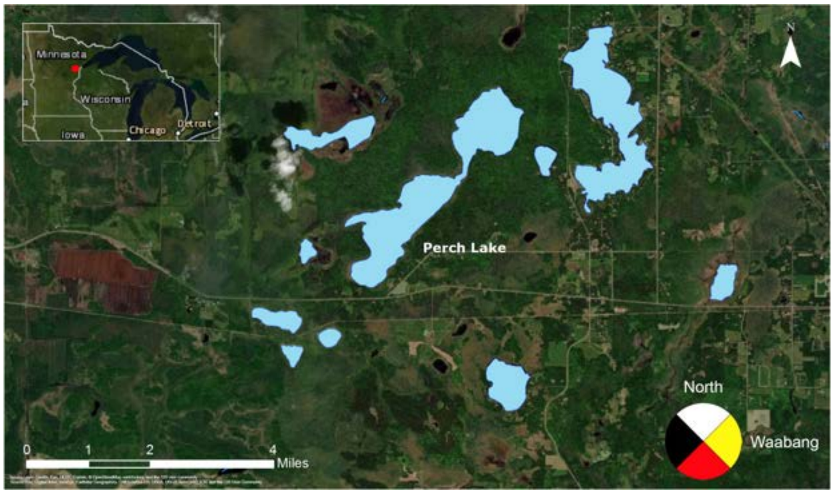


Exhibit 5.8. Map of Perch Lake

Perch Lake is an important traditional cultural property, used as a wild rice lake, a fisheries/spearing and netting site, and hunting grounds (Fond du Lac Band, 2018). Historical evidence suggests that Manoomin has been present at Perch Lake for over 2,000 years, with historical stands on approximately 392 acres (Fond du Lac Band, 2018).

Threats to Manoomin at Perch Lake

Historically, Perch Lake had abundant Manoomin habitat. In the early 1900s, many streams and wetland areas were ditched and drained to accommodate farming. After Perch Lake was ditched for agriculture around 1918 to 1921, the lake experienced a decline in Manoomin (Nancy Schuldt, personal communication, October 7, 2019).

To try to minimize the impacts of ditching, a concrete dam was installed at the lake outlet in 1936. The dam was managed to mimic the natural fluctuation of the water to benefit Manoomin. By the 1960s, the dam fell into disrepair and was non-functional. For the following several decades, lake levels were lower and stagnant, which allowed ginoozhegoons (pickerelweed) to displace Manoomin and become the dominant vegetation in the lake's rice waters (Fond du Lac Band, 2018, 2019).

Actions taken to improve the abundance of Manoomin at Perch Lake

In 1998, a new water control structure was built at the outlet of Perch Lake to manage water levels for Manoomin and improve hydrologic function throughout the watershed (Fond du Lac Band, 2018). In 2001, the Fond du Lac Band began intensive mechanical vegetation removal of ginoozhegoons, a native perennial species that occupies the same habitat as Manoomin and often outcompetes Manoomin (Fond du Lac Band, 2018). Using a sedge mat cutter and aquatic harvesters, the Fond du Lac Band removed ginoozhegoons vegetation at least twice yearly (Exhibit 5.9). This process led to high Manoomin density in restored areas initially. However, three to five years after each removal, ginoozhegoons became dominant again, which called for a rotating schedule for removing this competing plant.

In 2012, Perch Lake experienced a 500-year flood in mid-summer, and the Fond du Lac Band used the water control structure to keep water levels high and eliminate as much ginoozhegoons as possible. The following year, Manoomin stands were so thick that it was difficult to travel through the lake. Learning from the natural flood event, the Fond du Lac Band then developed a management strategy to bring lake levels to flood stage every four years to stress perennial species, such as ginoozhegoons, which compete with Manoomin for habitat. Although this strategy also limits Manoomin production in flood years, it provides Manoomin with a competitive advantage in the years following a flood stage year (Fond du Lac Band, 2018).

With water level management and mechanical removal of competitive vegetation, the Fond du Lac Band has successfully restored Manoomin to over 200 acres on Perch Lake (Fond du Lac Band, 2019).

Exhibit 5.9. Photograph of Sedge mat cutter (above) and aquatic harvester (below)

Credit: Fond du Lac Band, 2018.

Cultural and ecological characterization at Perch Lake

Manoomin and its associated habitat at Perch Lake were characterized over four time periods.

1900 to 1920: Before agricultural ditching

Before it was ditched for agriculture, Perch Lake historically had abundant Manoomin stands. Fond du Lac resource managers estimate that nearly 60% of the lake had extensive Manoomin stands during this time, and it was harvested by the community. Based on the combined ranking of cultural and ecological metrics, Perch Lake was characterized as “doing great” during this first time period.

1921 to 1970: With agricultural ditching

After agricultural ditching of Perch Lake, Manoomin and its associated habitat declined abruptly. Lower and stagnant water levels allowed ginoozhegoons to become the dominant vegetation in the lake, displacing Manoomin, which resulted in a decline in use of the lake by waterfowl and other wildlife. Band members were unable to harvest Manoomin in the ways they did historically, which limited the generation and sharing of Anishinaabe practices, values, and beliefs. During this period of time, Perch Lake was characterized as “not very good” based on the combined ranking of cultural and ecological metrics.

1971 to 1997: Before the new water control structure and restoration actions

During this period, Perch Lake had a significant decline in Manoomin abundance and functionality; approximately 75% of the lake was covered with plant species that occupy the same habitat as and compete with Manoomin. Although Perch Lake's ecological and cultural functionality remained low, Band members continued to try to harvest at the lake; therefore, the lake provided some cultural services during this period. Many elders and wild rice chiefs believe Manoomin is a blessing and is seen as a golden age of their youth. For these reasons, Perch Lake ranked as "pretty good," which was slightly higher than the previous time period.

1998 to 2019: With the new water control structure and restoration actions

The water control structure built at the outlet of Perch Lake in 1998 helped restore the hydrologic conditions of the lake and improve Manoomin and its associated habitat. Active management of the lake started in 2001 and accelerated in 2012, which further restored hydrologic conditions of the lake and removed competing vegetation, all benefiting Manoomin. During this time period, the Fond du Lac Band was fairly successful at restoring Manoomin on Perch Lake. Manoomin covers over 200 acres of Perch Lake, which is about 30% of its historical coverage. Currently, Perch Lake is ranked as "pretty good" based on the combined ranking of cultural and ecological metrics.

The cultural and ecological functionality provided by the Manoomin and its associated habitat at Perch Lake varied over time, both in aggregate and for individual metrics (Exhibit 5.10).

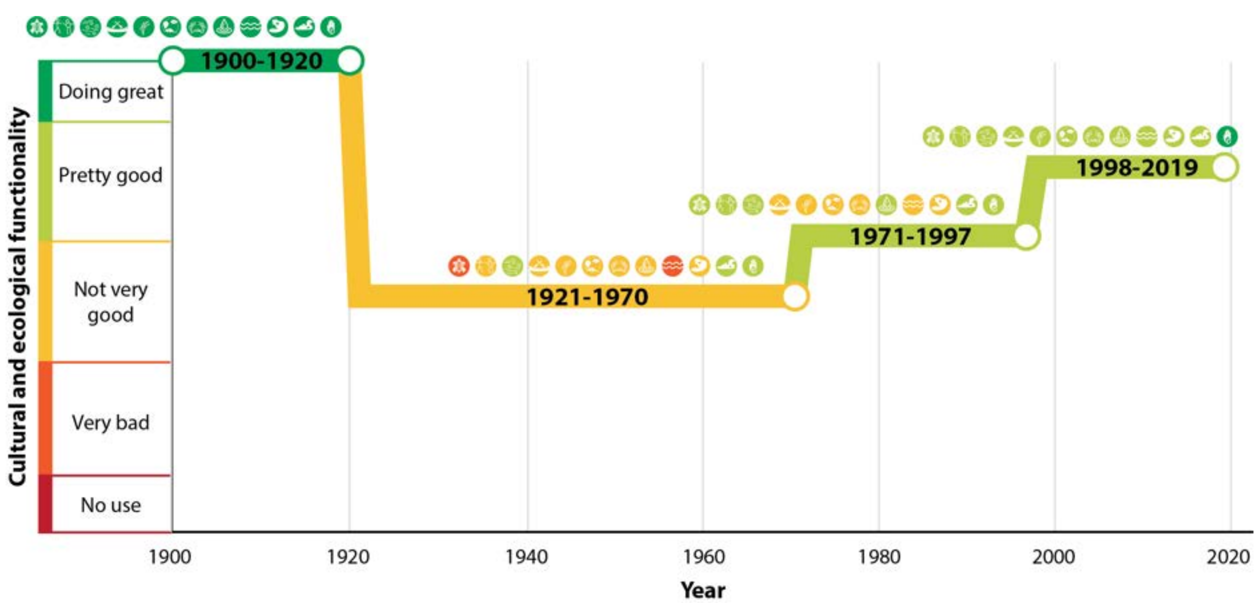


Exhibit 5.10. Characterization of cultural and ecological functionality provided by Manoomin and its associated habitat at Perch Lake

Additional restoration needed

Using the characterization of Perch Lake over the four time periods, an HEA demonstrates the additional equivalent units of restoration needed to counter-balance the severity and timespan of degradation. Given the success of restoration over the shallow, southern 400 acres of Perch Lake, approximately 5,204 acres of similar Manoomin restoration are needed to counter-balance the lost habitat functionality that has occurred over time (Exhibit 5.11). In other words, 13 equivalent restoration efforts at Perch Lake (from 1971 to 2019) are needed to counter-balance the lost cultural and ecological habitat functionality (from 1921 to 1970).

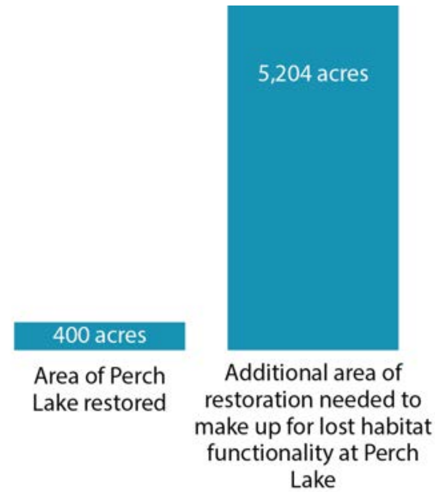


Exhibit 5.11. Additional restoration needed for Perch Lake

Case study acknowledgments

The Project Team would like to acknowledge Nancy Schuldt and Thomas Howes (Fond du Lac Band) for their valuable input and feedback in the development of this case study, and for participating in the cultural and ecological characterization of Perch Lake. We would also like to acknowledge the Fond du Lac Band elders and the wild rice chief who helped us characterize Perch Lake.

Sand Point Sloughs

Sand Point Sloughs are relatively shallow backwater sloughs connected to Lake Superior that are culturally important to the Keweenaw Bay Indian Community (KBIC). Native people used this area for hundreds of years, as indicated by the existence of ancient burial grounds and stories that have been passed on through oral tradition (KBIC, 2003). Manoomin is believed to have been present in Sand Point Sloughs prior to the 1900s (Ravindran et al., 2014). Today, the site contains the KBIC Pow Wow grounds, a traditional healing clinic, extensive wetlands, and Manoomin beds (Exhibit 5.12). A marina, campground, lighthouse, and recreational beaches signify the community’s appreciation of this area. This area also holds ecological value as habitat. It provides for a number of species including medicinal plants, insects, fish, and other non-human relatives.

Exhibit 5.12. Map of Sand Point Sloughs

Threats to Manoomin at Sand Point Sloughs

Connected to Lake Superior, Sand Point Sloughs are part of a dynamic coastal system. In the early 20th century, a copper ore processing plant, Mass Mill, operated on the west side of Keweenaw Bay on the south shore of Lake Superior. During the copper ore processing, approximately six billion pounds of mine tailings, locally known as stamp sands, were disposed into Keweenaw Bay. Lake currents continue to carry these tailings southward and redeposit them onto Sand Point, located just four miles south of the Mass Mill. Sand Point has an extensive beach area with approximately 2.5 miles of lake front and is connected to the sloughs. These tailings contain high concentrations of heavy metals that have the potential to cause environmental harm.

More recently, Sand Point Sloughs have been affected by regional hydrologic conditions – including higher water levels – that are occurring at a regional scale and are beyond local control. As a plant species sensitive to changes in water level, higher water levels have negatively affected the establishment and abundance of Manoomin in Sand Point Sloughs. The sloughs’ connection to Lake Superior also opens the pathway to aquatic invasive species, such as carp and reed canary grass. Carp, for example, are bottom feeders that uproot Manoomin (Premo et al., 2014). Manoomin abundance may also be impeded by competing native vegetation, such as ginoozhegoons (pickerelweed); and by excessive browsing by wildlife on new stands, such as waterfowl.

Actions taken to improve the abundance of Manoomin at Sand Point Sloughs

Sand Point Sloughs are a KBIC Tribal Trust property, wholly owned by KBIC and located entirely within KBIC L'Anse Reservation boundaries. KBIC took over management of the sloughs in the early 1990s, and shortly after began efforts to reintroduce Manoomin. Between 1991 and 1997, KBIC seeded nearly 1,800 pounds of Manoomin across 8 acres of Sand Point Sloughs. By 1999, Manoomin density was sufficient for KBIC to engage in the tradition of ricing. Between 1999 and 2002, community members harvested an estimated 60 to 150 pounds per year (Ravindran et al., 2014). Since 2013, KBIC has seeded Manoomin annually at Sand Point Sloughs (Exhibit 5.13). KBIC continues to tend to this site in an effort to keep Manoomin teachings and traditions vital. However, since 2002, community members have not been able to harvest Manoomin at Sand Point Sloughs, due to decreased abundance of Manoomin related to regional hydrologic conditions.

In addition to seeding efforts, KBIC and partners have undertaken remediation along the Sand Point shoreline, which was listed as a brownfield site. Remediation efforts included capping stamp sands to stabilize the tailings; planting native plants, trees, and shrubs to increase habitat for birds and other wildlife; and installing mounds and boulders to provide relief in the topography, reduce erosion, and protect valuable coastal wetlands, including Manoomin beds (Ravindran et al., 2014).

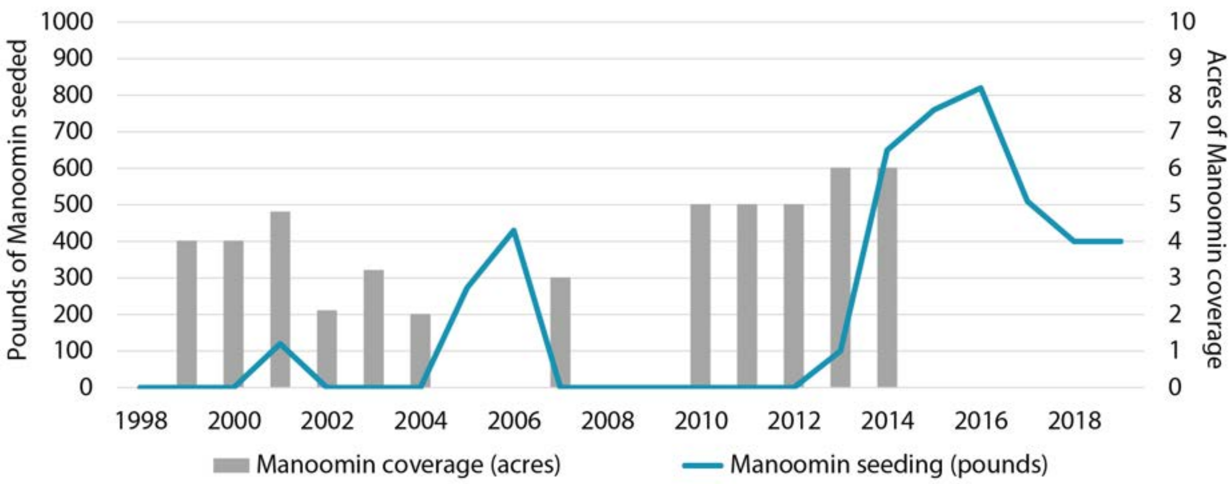


Exhibit 5.13. Manoomin seeding and acres of Manoomin coverage at the Sand Point Sloughs, 1999 to 2019 (data were not collected before 1999, and Manoomin coverage data were not recorded after 2014)

Sources: Ravindran et al., 2014; Karena Schmidt, personal communication, October 31, 2019.

Cultural and ecological characterization at Sand Point Sloughs

Sand Point Sloughs' Manoomin and its associated habitat were characterized over four time periods. This characterization begins after the copper ore processing plant ceased operations around the 1920s.

1920 to 1990: Before KBIC ownership

For each of the four time periods, the water level metric was ranked as "not very good." Due to their location, the Sand Point Sloughs are influenced by regional factors such as Lake Superior water levels, which are beyond local control.

Based on the combined ranking of cultural and ecological metrics, Sand Point Sloughs was characterized as "not very good" during this period. This ranking reflects the absence of Manoomin from the sloughs and the deposition of mine tailings onto Sand Point. Although Manoomin was absent, the sloughs were still a place of cultural and ecological importance: waterfowl and other wildlife foraged at the sloughs; and community members fished, hunted, and gathered there and held Pow Wows on the grounds. Given the intrinsic cultural and ecological values of the sloughs, some cultural metrics – including spirit relationships, knowledge sharing, and food sovereignty – were characterized with a higher ranking.

1991 to 1998: With active management of Manoomin

Once KBIC took over management of Sand Point Sloughs in the early 1990s and began seeding activities, Manoomin grew modestly. Although community members could not yet harvest Manoomin, the presence of Manoomin significantly improved the ranking of most cultural and ecological metrics. During this period, Sand Point Sloughs ranked as "pretty good" based on the combined ranking of cultural and ecological metrics.

1999 to 2005: With active management and harvesting of Manoomin

Once Manoomin was adequately established at Sand Point Sloughs, KBIC was able to open Sand Point Sloughs to their community members for harvesting. Harvesting allowed the recovery and sharing of Anishinaabe practices, values, beliefs, and language at the sloughs in ways that had not been practiced for years. During this period, Sand Point Sloughs ranked as "doing great" based on the combined ranking of improved cultural and ecological metrics.

2006 to 2019: With higher water levels

Sand Point Sloughs is connected to Lake Superior, and is affected by changes in the lake's water level and invasive and competitive species. Invasive species and competing vegetation that have been documented at Sand Point Sloughs may be impacting Manoomin abundance. Water levels have also fluctuated in Sand Point Sloughs, with lower water levels recorded in 2006 and 2007, and higher water levels in recent years (Ravindran et al., 2014). During this period, Sand Point Sloughs' functionality decreased to "pretty good" based on the combined ranking of cultural and ecological metrics. The decrease in ecological and cultural functionality provided by Manoomin in recent years suggests the need for adaptive management of Manoomin. Actions taken that may have been successful in restoring Manoomin in the past may need to be adjusted to respond to additional threats, such as climate change, to be successful in the future.

The cultural and ecological functionality provided by the Manoomin and its associated habitat at Sand Point Sloughs varied over time, both in aggregate and for individual metrics (Exhibit 5.14).

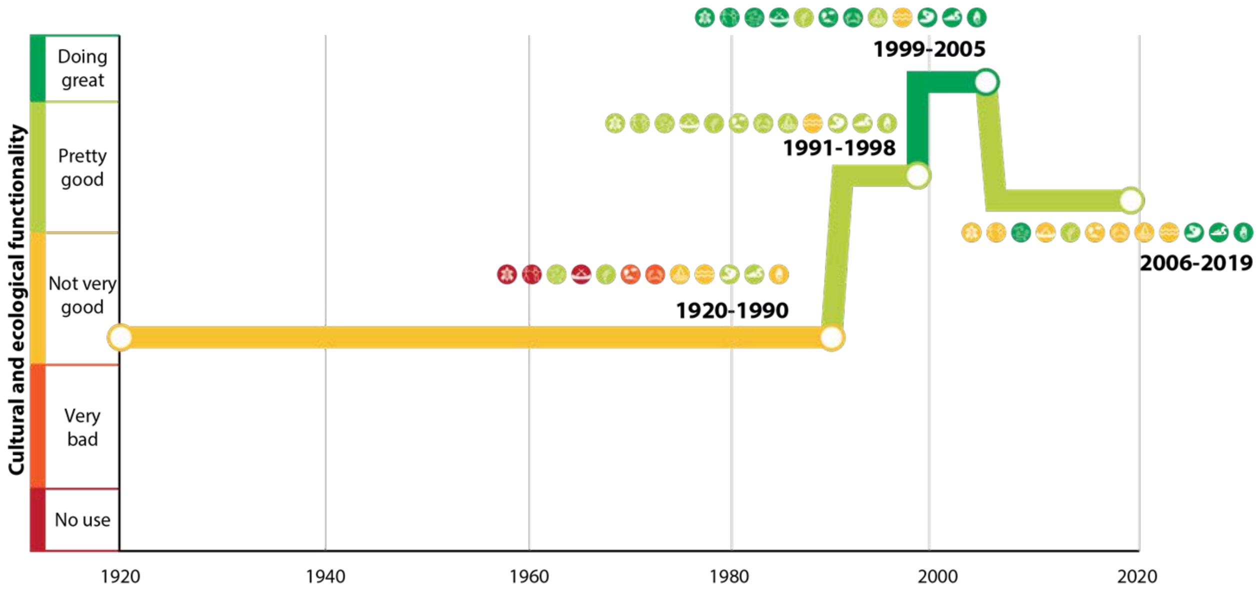


Exhibit 5.14. Characterization of cultural and ecological functionality provided by Manoomin and its associated habitat at Sand Point Sloughs

Additional restoration needed

Based on the characterization of the degree of cultural and ecological function over the four time periods, the HEA calculations demonstrate the additional equivalent units of restoration needed to counter-balance the severity and timespan of degradation. Given the success of restoration on 8 acres of Sand Point Sloughs, 175 acres of similar Manoomin restoration is needed to counter-balance the lost habitat functionality that has occurred over time (Exhibit 5.15). In other words, 22 equivalent restoration efforts at Sand Point Sloughs (from 1991 to 2019) are needed to counter-balance lost cultural and ecological habitat functionality (from 1920 to 1990).

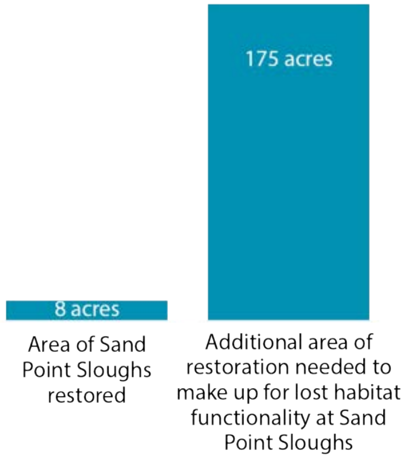


Exhibit 5.15. Additional restoration needed for Sand Point Sloughs

Case study acknowledgments

The Project Team would like to acknowledge Evelyn Ravindran, Karena Schmidt, and Erin Johnston (KBIC) for their valuable input and feedback in the development of this case study, and for participating in the cultural and ecological characterization of KBIC's Sand Point Sloughs.

Net River Impoundment and Vermillac Lake

The Net River is nearly 15 miles long and flows from Baraga County to Iron County, Michigan. Impounded in 1990 as a wetland mitigation site to provide waterfowl benefits, the Net River Impoundment is now 35 acres in size. Vermillac (or Worm) Lake is a 423-acre lake in Baraga County. Both the Net River Impoundment and Vermillac Lake are located outside the L'Anse Indian Reservation, but within Ceded Territory (Exhibit 5.16).

Exhibit 5.16. Map of Net River Impoundment and Vermillac Lake

Threats to Manoomin at Net River Impoundment and Vermillac Lake

Both the Net River Impoundment and Vermillac Lake possibly had Manoomin beds in the past. Many believe that historical trails around the Net River Impoundment indicate traditional use of these places for cultural practices (Evelyn Ravindran, KBIC personal communication, August 20, 2019). Land use changes have altered the local landscape, which may have contributed to the presence or absence of Manoomin at these places.

Actions taken to improve Manoomin at Net River Impoundment and Vermillac Lake

KBIC is receiving more and more teachings from Manoomin and is working to understand which locations on the L'Anse Indian Reservation and within Ceded Territory have conditions that are conducive to grow and sustain Manoomin (BIA, 2019). KBIC is interested in having local sources of Manoomin as seed banks for future restoration activities; as well as places where community members can harvest, prepare, and gift Manoomin. KBIC is currently assessing suitable Manoomin habitat across their territory, and focusing restoration in lakes with the most favorable conditions for Manoomin.

In the early 2010s, KBIC worked with the Michigan Department of Natural Resources to identify additional areas for Manoomin restoration. The Net River Impoundment and Vermillac Lake were selected as lakes with potential for Manoomin beds, and KBIC seeded test plots at both lakes. Given their success, KBIC then seeded the Net River Impoundment and Vermillac Lake with nearly 2,000 pounds of Manoomin seed. Cultural teachings and practices related to Manoomin are beginning to occur at the Net River Impoundment. KBIC continues to seed 97 acres across both lakes with nearly 2,000 pounds of Manoomin each year.

The ultimate goal of the seeding efforts at Net River Impoundment is to produce a Manoomin seed source for Vermillac Lake and other KBIC restoration sites. In keeping with the principles of the honorable harvest, KBIC aims to achieve conditions that will allow the rice to reseed itself to feed wildlife and nourish the people.

Cultural and ecological characterization at Net River Impoundment and Vermillac Lake

Manoomin and its associated habitat at the Net River Impoundment and Vermillac Lake were characterized over two time periods. This characterization begins after the Net River was impounded as a wetland mitigation bank in 1990.

1990 to 2013: Before Manoomin seeding

Based on the combined ranking of cultural and ecological metrics, conditions at the Net River Impoundment and Vermillac Lake were characterized as “not very good” during this period. This ranking reflects the absence of Manoomin from the Net River Impoundment and Vermillac Lake before 2013. Although Manoomin was absent, these areas were culturally and ecological important. Community members used these sites for gathering, fishing, and hunting activities; during these activities, families passed down knowledge to their children or grandchildren about traditional practices and resources. Given the intrinsic cultural and ecological value of these places, some metrics – including spirit relationships, food sovereignty, knowledge generation and sharing, and water level and quality – ranked higher in cultural and ecological characterization.

2014 to 2019: After Manoomin seeding

Once KBIC began seeding the Net River Impoundment and Vermillac Lake, Manoomin grew at these places. Currently, Manoomin supports wildlife and other ecosystem functions. These places have the potential for Manoomin harvesting in the future, although they cannot yet support it. The presence of Manoomin significantly improved the ranking of most of the cultural and ecological metrics. During this period, conditions at the Net River Impoundment and Vermillac Lake ranked as “pretty good” based on cultural and ecological metrics. Although Manoomin provides cultural and ecological functionality, additional management of water levels at the Net River Impoundment could continue to improve the abundance of Manoomin and the long-term sustainability of healthy Manoomin beds.

Cultural and ecological functionality provided by Manoomin and its associated habitat at the Net River Impoundment and Vermillac Lake have increased over time, both in aggregate and for the individual metrics (Exhibit 5.17).

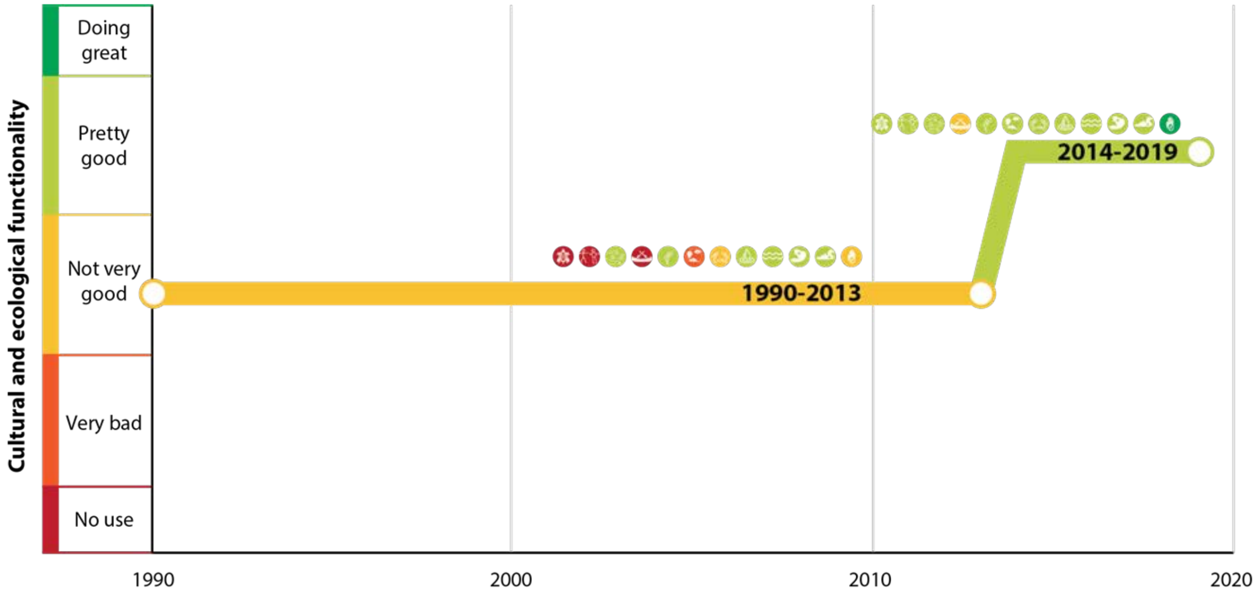


Exhibit 5.17. Characterization of cultural and ecological functionality provided by Manoomin and its associated habitat at Net River Impoundment and Vermillac Lake

Additional restoration needed

Based on the characterization of the degree of cultural and ecological function over the four time periods, the HEA calculations demonstrate the additional equivalent units of restoration needed to counter-balance the severity and timespan of degradation. With seeding, resource managers successfully established Manoomin across the Net River Impoundment and Vermillac Lake. However, given that the period of degradation is much larger (over 20 years) than the period of restoration (around 5 years), an additional 1,129 acres of similar Manoomin restoration is needed to counter-balance the lost habitat functionality that has occurred over time (Exhibit 5.18). In other words, nearly 12 equivalent restoration efforts at the Net River Impoundment and Vermillac Lake (from 2014 to 2019) are needed to counter-balance the lost cultural and ecological habitat functionality (from 1990 to 2013).

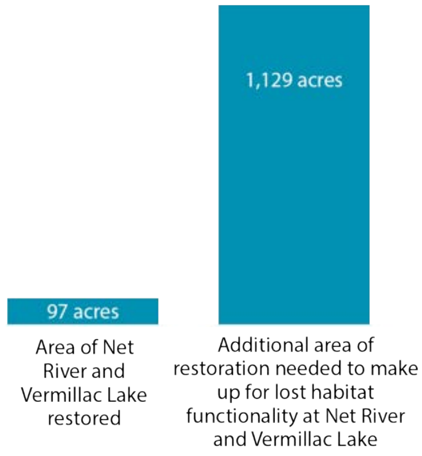


Exhibit 5.18. Additional restoration needed for Net River Impoundment and Vermillac Lake

Case study acknowledgments

The Project Team would like to acknowledge Evelyn Ravindran, Karena Schmidt, and Erin Johnston (KBIC) for their valuable input and feedback in the development of this case study; and for participating in the cultural and ecological characterization of KBIC's Net River Impoundment and Vermillac Lake.

Hiles Millpond

Hiles Millpond is an approximately 300-acre lake located in Forest County, Wisconsin, an 1842 Ceded Territory (Exhibit 5.19).

The millpond provides excellent wildlife habitat, especially for waterfowl, furbearers, eagles, and other wetland-dependent species. The lake also supports a northern pike and panfish fishery.

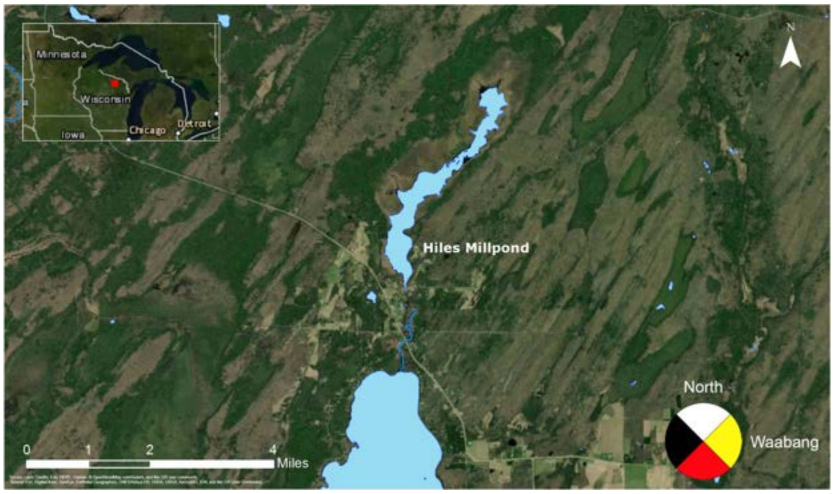


Exhibit 5.19. Map of Hiles Millpond

Threats to Manoomin at Hiles Millpond

Water ponded at Hiles Millpond in the late 1880s, when the Hiles Lumber Company built a dam for logging purposes. Although there is no record of the presence of Manoomin at Hiles Millpond, it may have been there at some point prior to dam construction, since Manoomin is in nearby waters. If Manoomin was present at Hiles Millpond historically, it could have been negatively affected by changes in water levels associated with construction of the dam.

The area and waters around the Town of Hiles were traditionally used by the Lac du Flambeau Band of Lake Superior Chippewa Indians (LDF Band), the Sokaogon Chippewa Community, and other Ojibwe Bands and their ancestors. However, use of the area by Bands for hunting, gathering, fishing, and trapping was limited during much of the last century up until the 1980s. Use of this area increased after this time when relations with the local community in the Town of Hiles improved.

Actions taken to improve the abundance of Manoomin at Hiles Millpond

In 1992, safety inspections found several problems with the dam structure at Hiles Millpond. To meet contemporary safety standards, the Town of Hiles needed to replace the dam structure. Since the town lacked adequate funds, federal, state, tribal, and nongovernmental organizations entered into a cooperative effort. A Memorandum of Understanding included a provision for the town to cooperate with the Forest Service to manage the millpond for productive wildlife and fish habitats, including possible manipulation of water levels, following completion of the project. The dam and water control structure were rebuilt in fall 1993.

Shortly after, biologists realized that the ecological benefits of Hiles Millpond could be significantly enhanced by establishing Manoomin on the millpond. Establishing Manoomin could also help to make up for the loss of Manoomin on other waters in the region, many of which were difficult or impossible to recover due to excessive development, conflicting uses, or other threats to Manoomin (Peter David, GLIFWC, personal communication, November 27, 2019).

In 1998, GLIFWC and the Forest Service cooperatively seeded the Hiles Millpond flowage with a relatively modest amount of Manoomin (329 pounds). Small patches of Manoomin then expanded modestly over the next several years. In 2011, Manoomin expanded significantly under natural drought conditions, which led biologists to believe that Manoomin might increase if the typical summer water level was lowered slightly.-

Although the Town of Hiles was initially concerned that lower water levels might negatively affect the northern pike fishery, it ultimately agreed to manage the water level for Manoomin. Once lowered, Manoomin showed an immediate response. Manoomin abundance increased significantly from 2013, before water levels were lowered, to 2014, following a lowering of water levels (Exhibit 5.20). In recent years, over 125 acres of Manoomin can be found growing across the lake (Peter David, GLIFWC, personal communication, November 27, 2019).

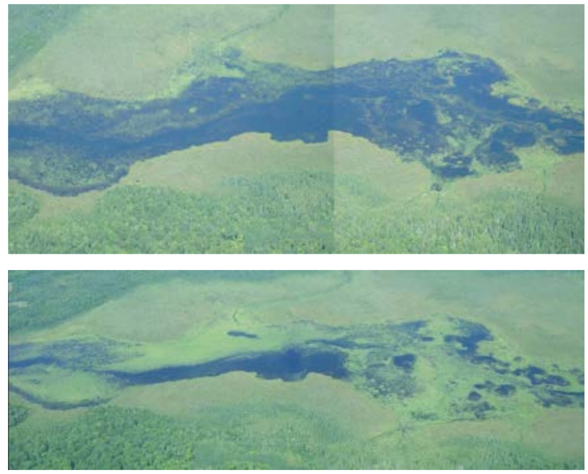


Exhibit 5.20. Manoomin abundance on a portion of the Hiles Millpond in 2013 (above), and in 2014 (below) following a lowering of water levels

Credit: Peter David, GLIFWC.

Cultural and ecological characterization at Hiles Millpond

Manoomin and its associated habitat at Hiles Millpond were characterized over three time periods. The characterization starts in 1980 because prior to that time community members were less likely to travel to Hiles Millpond to harvest Manoomin, and undertake other traditional hunting and gathering practices.

1980 to 1997: Before Manoomin seeding

Based on the combined ranking of cultural and ecological metrics, Hiles Millpond was characterized as “very bad” during this period. Because of the absence of Manoomin in the millpond, most of the metrics – particularly cultural metrics – ranked low on the score range.

1998 to 2013: After Manoomin seeding

Once seeding activities began in 1998, Manoomin began to grow at the millpond. The presence of Manoomin improved the rankings for most cultural and ecological metrics. In particular, the presence of Manoomin at Hiles Millpond allowed for some harvesting, preparation, and sharing of Manoomin by the community. It also improved the Anishinaabe’s connections and balance with spirit beings and relatives, and it supported diverse biological communities. During this period, Hiles Millpond ranked as “not very good” based on the combined ranking of cultural and ecological metrics.

2014 to 2019: With water level management

After resource managers adjusted water levels for Manoomin in 2014, its coverage continued to expand. More Manoomin allowed for harvesting, preparation, and sharing of Manoomin in ways practiced by ancestors. It also allowed for knowledge generation and sharing of Anishinaabe practices, values, beliefs, and language. Although Manoomin provides many cultural and ecological functionality, additional management of water levels could continue to improve Manoomin and its associated habitat at Hiles Millpond. During this period, Hiles Millpond ranked as “pretty good” based on the combined ranking of cultural and ecological metrics.

Cultural and ecological functionality provided by Manoomin and its associated habitat at Hiles Millpond have increased over time, both in aggregate and for individual metrics (Exhibit 5.21).

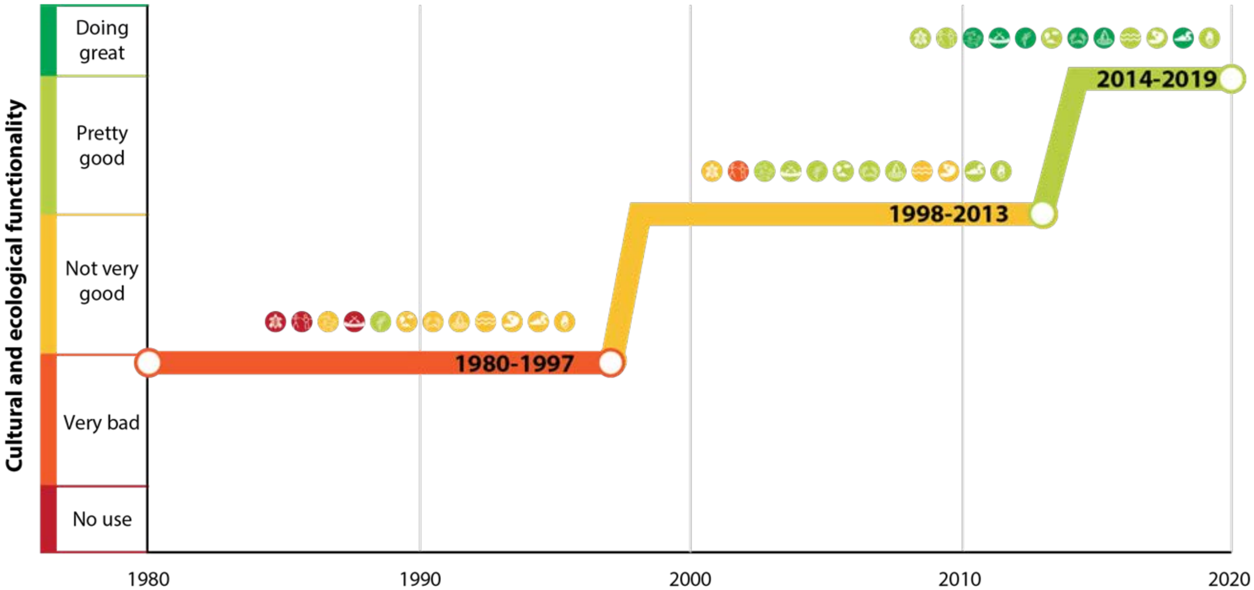


Exhibit 5.21. Characterization of cultural and ecological functionality provided by Manoomin and its associated habitat at Hiles Millpond

Additional restoration needed

Based on the characterization of the degree of cultural and ecological function over the four time periods, the HEA calculations demonstrate the additional equivalent units of restoration needed to counter-balance the severity and timespan of degradation. With modest seeding and slight modifications in water-level management, resource managers successfully established Manoomin across the Hiles Millpond. The analysis indicates that an additional 864 acres of similar Manoomin restoration is needed to counter-balance the lost habitat functionality that has occurred over time (Exhibit 5.22). In other words, nearly three equivalent restoration efforts at Hiles Millpond (from 1998 to 2019) are needed to counter-balance the lost cultural and ecological habitat functionality (from 1980 to 1997).

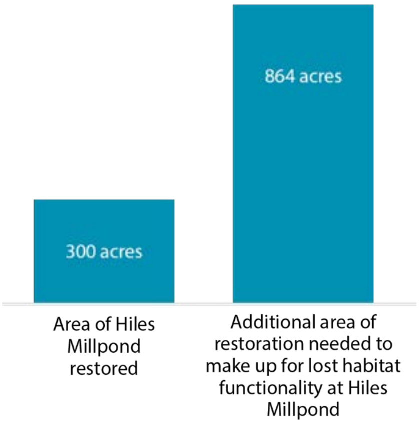


Exhibit 5.22. Additional restoration needed for Hiles Millpond

Case study acknowledgments

The Project Team would like to acknowledge Peter David (GLIFWC), Eric Chapman and Joe Graveen (LDF Band), and Peter McGeshick (Sokaogon Chippewa Community) for their valuable input and feedback in the development of this case study, and for participating in the cultural and ecological characterization of the Hiles Millpond.

Big Rice Lake

Big Rice Lake, located in St. Louis County in northeastern Minnesota, is approximately 1,870 acres (Exhibit 5.23). The area was traditionally used for ricing, sugar bush, and hunting activities; and archeological evidence indicates human use on sites surrounding the lake for hundreds – perhaps thousands – of years.

Exhibit 5.23. Map of Big Rice Lake

The lake is an important feeding and resting area for migrating waterfowl. In years of good Manoomin production, mallards, goldeneyes, wood ducks, blue winged teal, and ring-necked ducks use the lake. In 1992, Big Rice Lake became a Designated Wildlife Lake because of its “outstanding value to wildlife.” Currently, the lake supports a bald eagle nesting territory, as well as muskrats, minks, beaver, otter, great blue herons, and trumpeter swans.

Threats to Manoomin at Big Rice Lake

Hydrologic changes, impacts from competing vegetation, and perhaps climate change have threatened Manoomin at Big Rice Lake. Manoomin is very sensitive to changes in water levels. Low or stable water conditions over long periods can encourage the proliferation of other vegetation, such as ginoozhegoons (pickerelweed), which can outcompete Manoomin for space and resources. Ginoozhegoons has expanded considerably on Big Rice Lake, especially on the eastern half of the lake. In addition to the artificial controls on water levels, climate change could change precipitation patterns, which may increase both the likelihood of drought and the frequency of heavy rain events that can cause high water levels and flooding in Big Rice Lake.

Actions taken to improve Manoomin at Big Rice Lake

Natural resource managers have taken several actions with the goal of increasing Manoomin at Big Rice Lake. In 1995, federal and state agencies built a rock weir at the outlet of the lake to increase the water flow out of the lake and reduce rapid water-level changes that can negatively impact Manoomin growth (MN DNR, 2013). Initially, the installation of the rock weir seemed to improve Manoomin coverage at Big Rice Lake; however, despite adjustments to the weir and varied beaver management, the more stable water level appears to have favored ginoozhegoons over Manoomin (Exhibit 5.24).

Since 2006, a cooperative effort of several federal, state, and tribal partners has taken additional management activities to further support Manoomin (Vogt, 2020b). In addition to allowing water levels to vary naturally, natural resource managers are cutting ginoozhegoons. Natural resource managers use an airboat with chains to disturb the substrate of Big Rice Lake to encourage the germination of Manoomin seed in several test plots (Vogt, 2020b). These efforts control about 100 acres of ginoozhegoons each year, but Manoomin regrowth in cut areas has been minimal (Vogt, 2020b). Over the years, partners have also trapped beavers and removed beaver dams to control water levels.

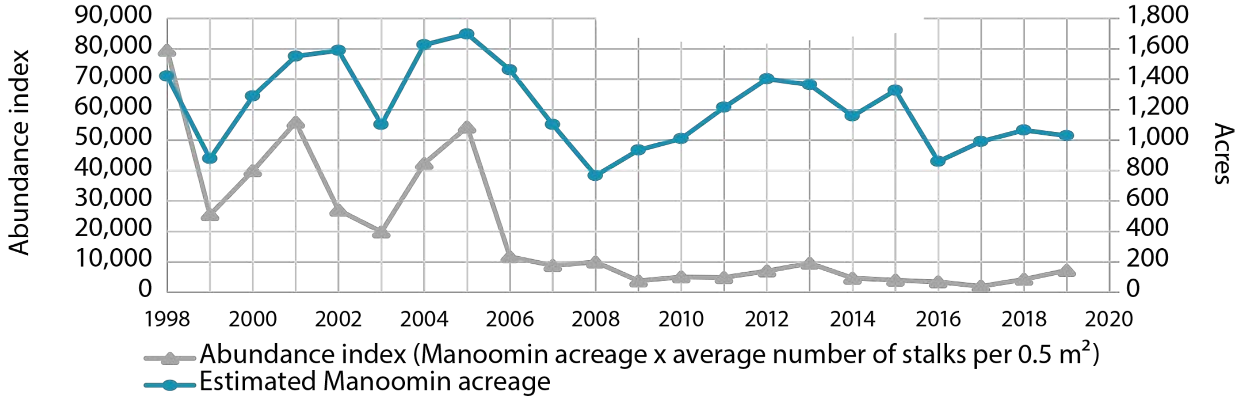


Exhibit 5.24. Manoomin abundance index and acres on Big Rice Lake

Source: Vogt, 2020b.

Cultural and ecological characterization at Big Rice Lake

Big Rice Lake's Manoomin and its associated habitat were characterized over three time periods.

1900 to 1994: Before rock weir construction

Based on the combined ranking of the cultural and ecological metrics, Big Rice Lake was characterized as "pretty good." During this period, Big Rice Lake was dominated by Manoomin with variable production across years, which provided high-quality waterfowl and wildlife habitats, and the opportunity for harvesting. The lake was culturally and historically important to Ojibwe Bands who used the lake during this period and exercised their treaty rights.

1995 to 2005: After rock weir construction

Immediately after the installation of the rock weir in 1995, Manoomin coverage at Big Rice Lake improved in some years. However, over time the more stable water level favored ginoozhegoons over Manoomin, and Manoomin began to decline, although it remained at the "pretty good" ranking score based on the combined ranking of cultural and ecological metrics.

2006 to 2019: With active management of Manoomin

By 2006, Big Rice Lake ranked as "very bad" based on the combined ranking of cultural and ecological metrics. Hydrologic changes, competition from ginoozhegoons, and perhaps other unknown factors led to the dramatic decline of Manoomin. From 2006 to 2019, natural resource managers took active management steps to recover Manoomin at Big Rice Lake; however, it remained sparse in coverage, with only a few small, moderate-to-good density stands found on the lake. As a result, community members were unable to harvest, prepare, and share Manoomin in ways practiced by their ancestors.

This also limited sharing, transmittal, and generation of Anishinaabe practices. The decline in Manoomin may have also negatively affected migratory waterfowl that use the lake.

Cultural and ecological functionality provided by Manoomin and its associated habitat at Big Rice Lake decreased over time, both in total and for individual metrics (Exhibit 5.25).

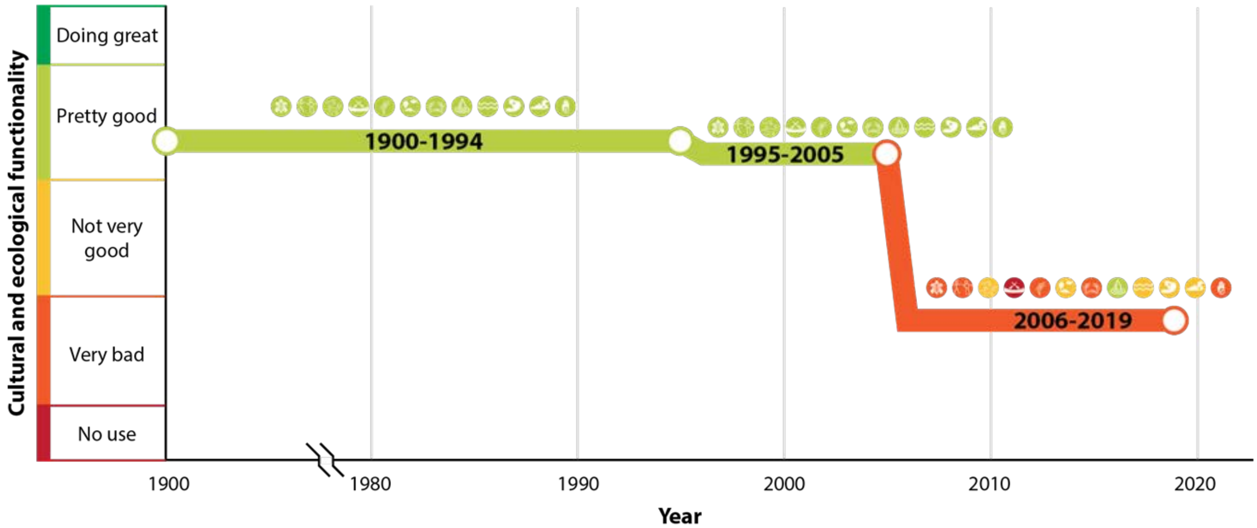


Exhibit 5.25. Characterization of cultural and ecological functionality provided by Manoomin and its associated habitat at Big Rice Lake

Additional restoration needed

Since the 1990s, natural resource managers have tried to improve the conditions of Manoomin and its associated habitat at Big Rice Lake; however, recent actions have not been successful and conditions continue to be diminished.

Restoration funds have recently been awarded to undertake further actions at the lake (Helmberger, 2019). If these actions were to improve functionality, we could use an HEA to demonstrate the additional equivalent units of restoration that would be needed to counter-balance the severity and timespan of degradation. For example, if actions were implemented over the next 20 years (2020 to 2040) to improve habitat functionality by 2.5%, we would need over 400,000 acres of similar Manoomin restoration to counter-balance the lost habitat functionality that has occurred over time (from 1995 to 2019). This is equivalent in size to over 200 Big Rice Lakes. The table below provides the HEA results, assuming several hypothetical scenarios of restoration improving habitat functionality (Exhibit 5.26); it is important to note that we do not know what actions are needed to create these percent improvements or if they are achievable. The main purpose of these scenarios is to highlight that if only minimal restoration is achieved at Big Rice Lake (which may be anticipated, given the long history of attempting restoration, with minimal response), then significant equivalent amounts of this restoration would be needed to balance the prolonged period of degradation at this lake.

Exhibit 5.26. HEA results, assuming several hypothetical scenarios of improvements in habitat functionality

Hypothetical percentage of improvement in habitat functionality from 2020 to 2040	Acres needed to counter-balance historical losses given hypothetical improvement[a]	Number of Big Rice Lakes needed to counter-balance historical losses given hypothetical improvement
2.5%	426,100	228
5.0%	213,100	114
10.0%	106,500	57
20.0%	53,300	29

a. Acres rounded to the nearest hundred.

This case study demonstrates how difficult it is to restore degraded Manoomin and its associated habitat, and how important it is to protect existing Manoomin habitat, as actions taken at Big Rice Lake have not improved its ability to support the various functions of Manoomin. A future characterization of Big Rice Lake could consider the effects of new restoration funding aimed at returning the natural functionality of the lake (Helmberger, 2019). This would refine and improve the current estimate of additional amount of restoration needed. Future restoration actions will include increased efforts to remove ginoozhegoons and return the outlet of the lake to natural rock rapids by removing the rock weir and accumulated sediment (Helmberger, 2019).

Case study acknowledgments

The Project Team would like to acknowledge Darren Vogt (1854 Treaty Authority) and Nancy Schuldt (Fond du Lac Band of Lake Superior Chippewa) for their valuable input and feedback in the development of this case study. In addition, the Project Team would like to thank Thomas Howes (Fond du Lac Band of Lake Superior Chippewa), Tara Geshick (Bois Forte Band of Lake Superior Chippewa), Daniel Ryan (U.S. Forest Service), and Melissa Thompson and Tom Rusch (Minnesota Department of Natural Resources) for participating in the cultural and ecological characterization of Big Rice Lake.

Twin Lakes

Exhibit 5.27. Map of Twin Lakes

The Twin Lakes are located in St. Louis County in northeastern Minnesota. Sandy Lake is approximately 120 acres and Little Sandy Lake is approximately 90 acres (Exhibit 5.27). The Twin Lakes are located immediately downstream of the tailings basin for U.S. Steel's Minntac iron ore operation. Prior to mining operations, the Twin Lakes produced good stands of Manoomin and were important ricing sites for Ojibwe Bands and vital habitat for a range of wildlife species.

Threats to Manoomin at the Twin Lakes

U.S. Steel's Minntac iron ore operation facility includes two mining areas, several processing plants, a heating and utility plant, a water reservoir, and a tailings basin (MWH, 2004). Construction of the tailings basin began in 1966 (MWH, 2004). Part of the seepage from the tailings basin discharges to the east into the Sand River, flows into the Twin Lakes, and into the Sand River watershed. Discharge from the tailings basin has changed the chemical composition and hydrologic condition of the Twin Lakes by increasing sulfate levels and, to a lesser extent, increasing the volume of water in the lakes.

Ongoing sulfate loading renders restoration ineffective at the Twin Lakes

The Twin Lakes are severely degraded by sulfate-laden mine waste from U.S. Steel's tailings basin. Because sulfate concentrations are high, any attempts to restore Manoomin stands that do not address this fundamental issue have proven largely ineffective. For example, multiple attempts by natural resource managers to adjust water levels through beaver management (in the 1970s to 1990s and 2015 to 2018) have not improved Manoomin stands in a measurable way. Modest reseeding efforts (in 1991 and 1992) have also not been effective. Restoration efforts are not successful because sulfate levels at the Twin Lakes are at least 10 times higher than the Manoomin sulfate standard; the current sulfate standard is 10 mg/L (Exhibit 5.20; Tribal Wild Rice Task Force, 2018).

In 2010, U.S. Steel was required to construct a seepage collection system to collect some of the mine wastewater discharging at the base of the tailings basin. While this reduced the total volume of water discharging from the mine site, it did not fully stop it. As a result, mine waste high in sulfate continued to contaminate the Twin Lakes after the collection system was installed. The 1854 Treaty Authority monitored lake conditions before the installation of the seepage collection system (2010) and after (2011 to 2019). Data collected included information on water quality (sulfate and other water quality indicators) and water-depth recordings; as well as data from inlet and outlet field surveys, vegetation surveys, and aerial surveys (Vogt, 2020a). Results showed that sulfate levels remained elevated well above the standard over the nine years of monitoring after the installation of the seepage system, and remained substantially unchanged from conditions prior to the installation (Exhibit 5.28).

During the monitoring study, very limited Manoomin stalks were also observed across the Twin Lakes over the same time period. In 2015, U.S. Steel planted test plots to determine if Manoomin had the potential to grow in the Twin Lakes. In this small-scale test plot, U.S. Steel reseeded with 40 pounds of Manoomin. After seeding, Manoomin success has varied but has been limited across years (Vogt, 2020a). Full-scale reseeding was not attempted.

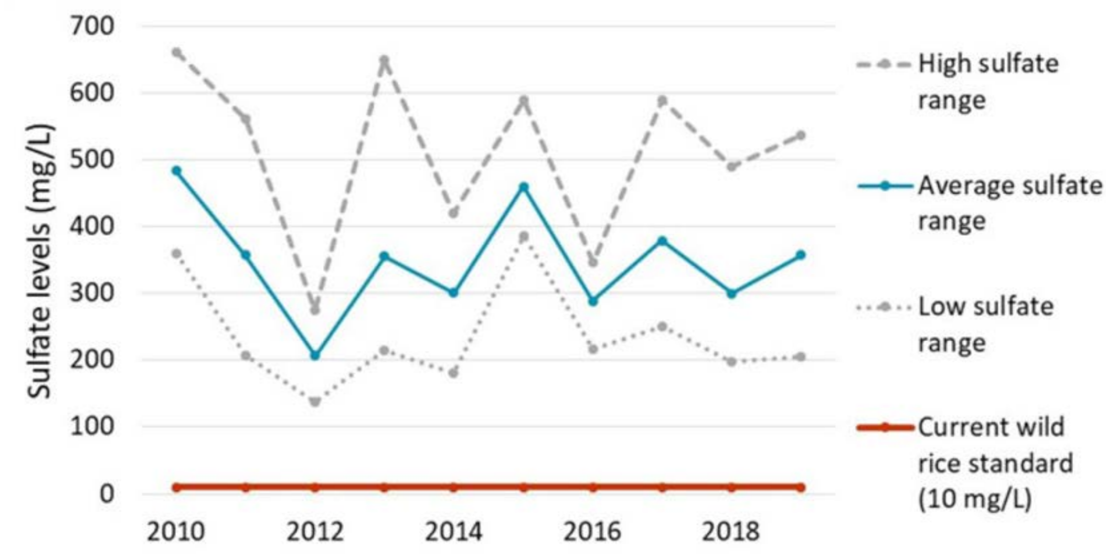


Exhibit 5.28. Sulfate concentrations at the inlet to the Twin Lakes compared to current standard sulfate levels (10 mg/L) for Manoomin, 2010 to 2019

Source: Vogt, 2020a.

Cultural and ecological characterization at the Twin Lakes

The Twin Lakes' Manoomin and its associated habitat were characterized over four time periods.

1950 to 1965: Before construction of the tailings basin

Based on the combined ranking of cultural and ecological metrics, conditions at the Twin Lakes were characterized as "doing great" during this period. Prior to the discharge of mine waste into the Twin Lakes, both lakes had moderately dense to dense stands of Manoomin. The Bois Forte Band of Chippewa, Grand Portage, and other community members historically harvested Manoomin in these lakes. In addition, Manoomin supported waterfowl (e.g., mallard, black ducks, green winged teal, wood ducks), fish such as northern pike, and other wildlife during this period (Minnesota Division of Game and Fish, 1966a, 1966b).

1966 to 1989: After construction of the tailings basin

After the discharge of mine waste started, Manoomin coverage in the Twin lakes steadily declined. Compared to a 1966 vegetation survey of the Twin Lakes (Minnesota Division of Game and Fish, 1966a, 1966b), a 1987 survey found that Manoomin was essentially absent from both lakes, while water levels were considerably higher and water clarity increased dramatically (State of Minnesota, 1987). By 1989, the Twin Lakes ranked as “no use” based on the combined ranking of cultural and ecological metrics.

1990 to 2009: With limited restoration actions

During this period, some actions were undertaken to recover Manoomin, including beaver management and small-scale reseeding efforts. However, these actions did not address the fundamental issue of high levels of sulfate and were largely ineffective at restoring the abundance of Manoomin and its associated habitat at the Twin Lakes. Given the absence of Manoomin on the lakes, community members were unable to harvest, prepare, and share Manoomin in ways practiced by their ancestors. The lost use of the Twin Lakes also limits sharing, transmittal, and generation of Anishinaabe practices at these lakes. During this period, the ranking of the Twin Lakes remained near “no use” based on the combined ranking of cultural and ecological metrics.

2010 to 2019: After construction of the seepage collection system

After U.S. Steel constructed the seepage system, Manoomin remained essentially absent from the Twin Lakes. With the lakes unable to support Manoomin, community members remained unable to harvest, prepare, and share Manoomin in ways practiced by their ancestors. During this period, the ranking of the Twin Lakes remained near “no use” based on the combined ranking of cultural and ecological metrics.

Cultural and ecological functionality provided by Manoomin and its associated habitat at the Twin Lakes declined over time, both in aggregate and for the individual metrics (Exhibit 5.29).

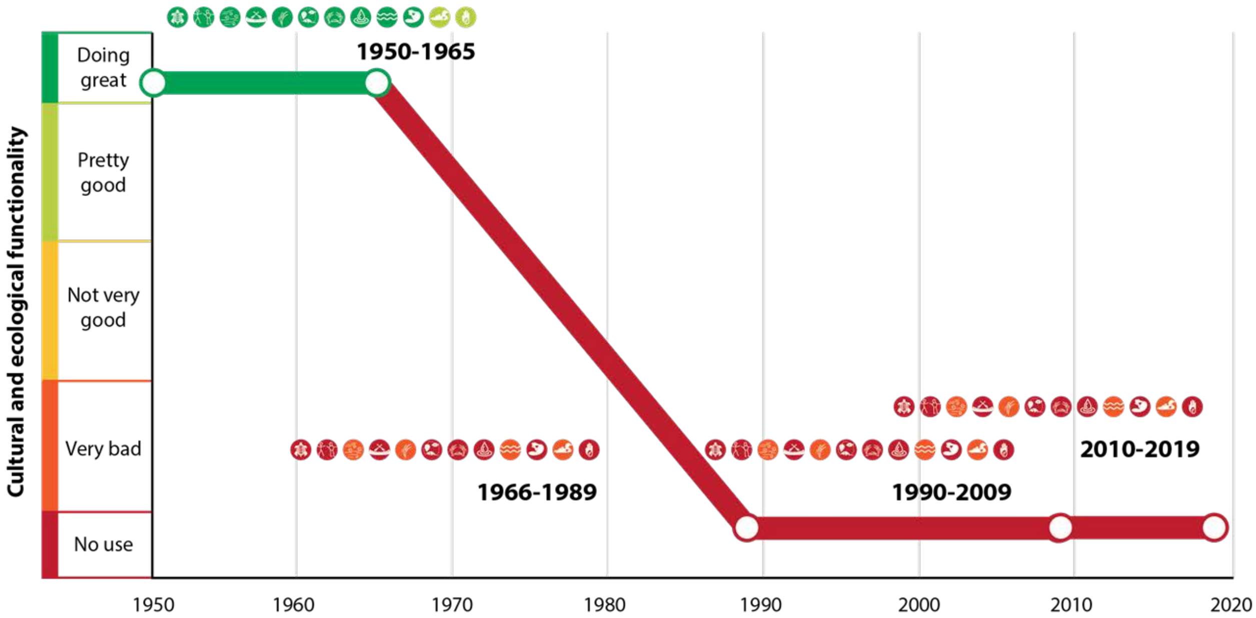


Exhibit 5.29. Characterization of cultural and ecological functionality provided by Manoomin and its associated habitat at the Twin Lakes

Additional restoration needed

Since the installation of a tailings basin for the U.S. Steel's Minntac facility in the mid-1960s, the abundance of Manoomin at the Twin Lakes has steadily declined. Actions taken at the Twin Lakes to improve Manoomin and its associated habitat have been limited and have not addressed the fundamental problem of sulfate loading from the mine. If actions were taken to improve conditions in the future, we could use an HEA to demonstrate the additional equivalent units of restoration needed to counter-balance the severity and timespan of degradation. For example, if actions were implemented over the next 20 years (2020 to 2040) to improve habitat functionality by 2.5%, over 100,000 acres of similar Manoomin restoration would be needed to counter-balance the lost habitat functionality that has occurred over time (from 1966 to 2019). This is equivalent in size to over 550 Twin Lakes.

Exhibit 5.30 provides the HEA results, assuming several hypothetical scenarios of improvements in habitat functionality; it is important to note that we do not know what actions are needed to create these percent improvements, but they would likely require addressing the fundamental problem of sulfate loading from the mine. The main purpose of these scenarios is to highlight that if only minimal restoration is achieved at Twin Lakes (which may be anticipated, given the long history of attempting restoration, with minimal response), then significant equivalent amounts of this restoration would be needed to balance the prolonged period of degradation at these lakes.

Exhibit 5.30. HEA results, assuming several hypothetical scenarios of improvements in habitat functionality

Hypothetical percentage of improvement in habitat functionality from 2020 to 2040	Acres needed to counter-balance historical losses given hypothetical improvement[a]	Number of Twin Lakes needed to counter-balance historical losses given hypothetical improvement
2.5%	116,700	556
5.0%	58,400	278
10.0%	29,200	139
20.0%	14,600	69

a. Acres rounded to the nearest hundred.

This case study demonstrates the difficulty in restoring Manoomin and its associated habitat when the root cause of the degradation – in this case, sulfate discharge – is not addressed. Given the difficulty of restoring degraded habitat, it is important to protect and preserve existing Manoomin habitat to ensure a future with Manoomin.

Case study acknowledgments

The Project Team would like to acknowledge Darren Vogt (1854 Treaty Authority) and Nancy Schuldt (Fond du Lac Band of Lake Superior Chippewa) for their valuable input and feedback in the development of this case study. The Project Team would also like to thank Wayne Dupuis (Fond du Lac Band of Lake Superior Chippewa), Tara Geshick (Bois Forte), John Coleman and Esteban Chiriboga (Great Lakes Indian Fish & Wildlife Commission), and Amy Myrbo for participating in the cultural and ecological characterization of the Twin Lakes.

6. Cross-case findings and lessons learned

In this chapter, we detail the cross-case findings and lessons learned developed through this study. The cross-case findings represent the collective wisdom of our project team on these seven unique case studies. While each case study is unique, with distinct attributes, here we focus on some common themes that emerged across the studies.

The Anishinaabe have long history of careful tending to Gichi-manidoo gitigaan through Manoomin stewardship; however, restoring Manoomin and its associated habitat remains a significant challenge under current conditions.

The Anishinaabe have a long relationship of careful tending to Manoomin to enhance its health and productivity (David et al., 2019). This stewardship is both spiritual and ecological in nature. Wild rice chiefs, for example, conduct ceremonies honoring Manoomin to help protect the crop and ensure its abundance (David et al., 2019). With tribal and other partners, wild rice chiefs also regulate water levels, remove competitive vegetation, and seed new areas. The contemporary restoration undertaken throughout the seven case studies described in this study reflect these stewardship practices.

> The older term for rice beds, *Gichi-manidoo gitigaan* or the Great Spirit's Garden, "captures (among other concepts) the perspective that while Manoomin is a natural part of the landscape, careful tending to the crop can enhance its health and productivity, in the same way a dedicated gardener benefits her plants."
>
> – David et al., 2019

- *Manoomin seeding* efforts have expanded since the reaffirmation of treaty rights in the Great Lakes region (David et al., 2019). Considerable resources have been expended to increase the abundance of Manoomin through seeding efforts. Most of our case studies include some Manoomin seeding efforts (see Exhibit 5.2). The level of effort varies from modest reseeding efforts in the Twin lakes to more extensive reseeding efforts at Lac Vieux Desert's Rice Bay.
- *Water-level management* can help regulate water levels to benefit Manoomin; these management actions can include traditional water-level management actions (e.g., removing beaver dams), as well as more complex water-level management activities. Most of the restoration efforts in our case studies include water-level management of some form (see Exhibit 5.2). Changing the operating regime of a dam on Lac Vieux Desert to lower water levels, for example, combined with Manoomin seeding efforts, helped to reestablish Manoomin on Lac Vieux Desert's Rice Bay.
- *Removal of competitive vegetation* on a rotational schedule can restore Manoomin density. In several case studies, the native plant ginoozhegoons is outcompeting Manoomin (Exhibit 2.1). Fond du Lac Band of Lake Superior Chippewa, for example, is undertaking mechanical removal of ginoozhegoons at *Perch Lake* and Big Rice Lake to restore Manoomin habitat (Fond du Lac Band, 2018).

Success of these restoration actions has been incremental and at times challenging. Restoration actions taken at historically high-producing Manoomin waters – including Big Rice Lake, Twin Lakes, Lac Vieux Desert's Rice Bay, and *Perch Lake* – have not returned Manoomin and its associated habitat to historical cultural and ecological functionality. And, in some cases, restoration actions have been largely ineffective with Manoomin abundance and density continuing to decline. For example, natural resource managers have tried to improve the conditions of Manoomin and its associated habitat at Big Rice Lake since the 1990s; however, actions have had limited success and Manoomin conditions continue to be diminished.

Several case studies also highlight the need to return to the concept of traditional stewardship and carefully tend to Manoomin through sustained, long-term resource management At Perch Lake, the Fond du Lac Band of Lake Superior Chippewa developed a management strategy that brings lake levels to flood stage every four years in order to stress perennial species, such as ginoozhegoons that otherwise outcompete Manoomin. This long-term restoration approach provides Manoomin with a competitive advantage in the immediate years following the flood stage (Fond de Lac Band, 2018).

Even in places where Manoomin restoration has shown success, more restoration is often needed given the significant historical losses in Manoomin cultural and ecological functionality.

The combined HEA approach applied in this study accounts for the amount of time that Manoomin habitat has been degraded and the time required for restored Manoomin habitat to recover or reach improved functionality. For several case studies, water level modifications through dams and agricultural diching or mining activities led to a decline in Manoomin habitat over 100 years ago. For example, Lac Vieux Desert was first dammed around 1870 for logging operations, and by 1907 the WVIC began operating the lake as a storage reservoir. In 1937, WVIC replaced the wooden dam with a reinforced concrete and steel structure. Changes in water levels caused by the dam initiated a decline in Manoomin and, from 1938 to 1952, Manoomin declined steadily and community members stopped harvesting it during this period (Barton, 2018; Labine, 2017). In addition, mine tailings were carried from a copper ore processing plant that operated from 1902 to 1919 around Keweenaw Bay. Connected to Keweenaw Bay, Sand Point Sloughs, a culturally important site for KBIC, and its natural resources have been exposed to high concentrations of heavy metals for many years.

Even with successful restoration, Manoomin habitat at many of our case study sites has had significant cultural and ecological losses over a long period of time, which often means that many more acres of restoration are needed to counter-balance the lost habitat functionality than the case study footprint. At Lac Vieux Desert's Rice Bay, the equivalent of 12 restoration efforts (from 1991 to 2019) are needed to counter-balance the lost cultural and ecological habitat functionality (from 1900 to 1990), while at Sand Point Sloughs, 22 equivalent restoration efforts (from 1991 to 2019) are needed to counter-balance the lost cultural and ecological habitat functionality (from 1920 to 1990).

At some locations, restoration actions may never fully recover all cultural and ecological functionality given that long time period of loss. At Twin Lakes, for example, actions taken to improve Manoomin and its associated habitat have been limited and have not addressed the fundamental problem of sulfate loading from the mine. Given the significant cultural and ecological losses that have occurred since the installation of a tailings basin for the U.S. Steel's Minntac facility in the mid-1960s, it is challenging to foresee a scenario where restoration actions could fully recover all lost functionality. In these cases, protection and/or restoration of Manoomin habitat at additional locations may be one approach to compensate for all the losses that occurred over time.

Seeding to enhance existing Manoomin stands and to introduce it to new locations can be worthwhile and necessary; places with favorable habitat features and conditions seem conducive to growing Manoomin.

Manoomin seeding in waters with favorable physical or hydrologic features can be an effective and inexpensive way to restore Manoomin (David et al., 2019). In addition, seeding at both sites where Manoomin is known to have historically occurred, and sites where there are no records, but hydrologic conditions seem suitable, can be worthwhile and necessary – "worthwhile because of the many ecological and cultural benefits rice provides and because rice abundance in the state remains lower than it was prior to European contact, and necessary because rice seed has a very limited natural ability to disperse" (David et al., 2019, p. 68). Natural resource managers around the Lake Superior region have had some success in identifying good Manoomin habitat, based on physical or hydrologic features, and seeding Manoomin. In two of our seven case studies, natural resource managers selected areas that were not known to have any Manoomin, but were thought to have favorable conditions for Manoomin growth – suitable soils, clean water, and modifications in water-level management. The following two case studies are showing preliminary success in their seeding efforts. At Hiles Millpond, biologists realized that the ecological benefits of this place could be significantly enhanced by establishing Manoomin. With modest seeding and slight modifications in water-level management, resource managers successfully established Manoomin across the Hiles Millpond. At Net River Impoundment and Vermillac Lake, KBIC worked with the Michigan Department of Natural Resources to identify areas for Manoomin restoration, and the Net River Impoundment and Vermillac Lake were selected as lakes with potential for Manoomin beds. After successful seeded test plots at both lakes, KBIC has expanded seeding efforts and has seen successful establishment of Manoomin across these locations. In addition, cultural teachings and practices related to Manoomin are beginning to occur at the Net River Impoundment.

Although the results of seeding efforts are encouraging, more study is needed to confirm whether seeding can lead to culturally and ecologically high-quality Manoomin habitat. In addition, given that the period of degradation is often longer than the period of restoration, additional Manoomin restoration may be needed to counter-balance the lost habitat functionality that has occurred over time. At Net River Impoundment and Vermillac Lake, for example, nearly 12 equivalent restoration efforts (from 2014 to 2019) are needed to counter-balance the lost cultural and ecological habitat functionality (from 1990 to 2013).

Restoration must be adaptive; what may have worked in the past may not be successful in the future, given additional threats.

Many tribal, state, and federal agencies have been involved in Manoomin restoration around the Lake Superior region for decades and, in the case of tribal communities, for much longer. However, in some cases, actions taken in the past that have had some success at restoring Manoomin are no longer successful. For example, more frequent heavy rainfall events in the spring and summer have negatively affected Manoomin in Lac Vieux Desert's Rice Bay. These above-average precipitation events, which have led to "ghost rice" or empty seed hulls that never fill and brown spot disease in Manoomin beds, are likely driving the decline of Manoomin abundance on Rice Bay. In addition, Sand Point Sloughs is connected to Lake Superior, and affected by changes in the lake's water level and invasive and competitive species. These regional threats to the sloughs may be affecting Manoomin abundance and are largely beyond local control. The decrease in ecological and cultural functionality provided by Manoomin in recent years at several of our case study sites suggests the need for adaptive management of Manoomin habitats. Actions taken that may have been successful in restoring Manoomin in the past may need to be adjusted to respond to additional threats, such as climate change, to be successful in the future.

As conditions change and as we face uncertainty in future environmental conditions, it will be critical to collect monitoring data, evaluate the degree of success of restoration actions based on the interpretation of those data, and then make adaptations, or changes, as needed to future restoration actions to adapt to changing environmental conditions. Adaptive management could include taking initial restoration actions, and then using new information for future decisions. Or it can include exploring a range of options during all phases of restoration to select the best path forward to achieving restoration objectives. Long-term adaptive management of Manoomin and its associated habitat will rely on monitoring and make adjustments in the future based on monitoring results.

Monitoring should be incorporated into all future restoration projects.

Monitoring can help wild rice chiefs and other natural resource managers assess the health of existing Manoomin habitats, evaluate the success of different restoration actions, and make informed resource management decisions. Monitoring can provide information about ecological trends, including Manoomin productivity and biomass, as well as information about other components of Manoomin waters, such as water quality and use of waters by muskrats, beaver, geese, swans, and other beings. It can also provide information about cultural trends, such as harvest levels by tribal members and exercise of treaty-reserved harvesting rights. Monitoring can also evaluate the effectiveness of restoration or inform adaptive management actions. Because of the high variability in the productivity and biomass of Manoomin from year-to-year, monitoring is most useful when undertaken over several years (Kjerland, 2015b). Monitoring should be completed using methods that are both scientifically robust and culturally respectful (Kjerland, 2015a, 2015b).

This project illustrates the critical importance of monitoring data. The seven case studies in this project would not have been possible, if not for existing monitoring data. Around the Lake Superior region, several agencies have undertaken long-term monitoring studies. Since the 1980s, GLIFWC has conducted Manoomin harvest surveys for tribal (off-reservation) and state (statewide) licensed ricers in Wisconsin (David et al., 2019). Nearly all of this harvest comes from the ceded territory. GLIFWC also uses aerial surveys to approximate rice abundance information for over 200 waterbodies each year (David et al., 2019). NOAA is using hyperspectral imaging to delineate aquatic vegetation, with Manoomin as the primary species. In 1998, the 1854 Treaty Authority initiated a Manoomin monitoring program on lakes and rivers within the 1854 Ceded Territory in northern Minnesota (Vogt, 2020b).

This study relies upon the long-term monitoring data from these efforts to understand the cultural and ecological conditions of Manoomin. Where available, case study teams incorporated monitoring data into their cultural and ecological characterization of Manoomin and its associated habitat. For example, the Lac Vieux Desert Band and GLIFWC mapped Manoomin acreage on Lac Vieux Desert's Rice Bay from 2000 to 2019 as part of the 10-year trial Lac Vieux Desert Wild Rice Restoration Plan with the Wisconsin Valley Improvement Company (WVIC; Exhibit 6.1). These data provided background on the condition of Manoomin with restoration actions (the 1991 to 2012 time period) and during the decline in Manoomin abundance with above-average precipitation (2013 to 2019 time period). Our study underscores the importance of long-term monitoring. There should be a concerted effort to inventory all Manoomin waters across the Great Lakes.

Traditional ecological knowledge can help understand habitat functionality across the Lake Superior region.

Cultural leaders, community members, wild rice chiefs, Manoomin harvesters, and elders have essential knowledge and perspectives that can inform the characterization of cultural and ecological functionality provided by Manoomin over long time periods. Our Project Team was composed of many cultural leaders, community members, harvesters, and wild rice chiefs who shaped the development of our cultural and ecological metrics; and informed the characterization of Manoomin at specific sites. In a few instances, our Project Team relied on their wild rice chiefs and elders to provide cultural and traditional ecological knowledge about a place. For example, the Fond du Lac Band of Lake Superior

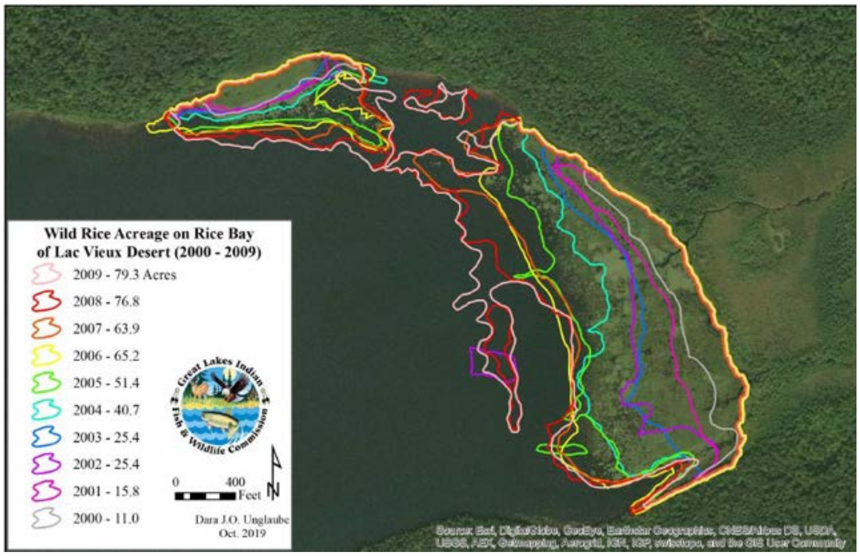


Exhibit 6.1. Manoomin distribution and acreage on Rice Bay on Lac Vieux Desert, 2000–2009

Credit: GLIFWC, 2019.

Chippewa case study team received input from an elder and wild rice chief to characterize a time period for Perch Lake where the case study team had limited knowledge and limited ecological monitoring data.

Educating tribal and nontribal community members can ensure successful Manoomin restoration.

While Manoomin is one of the most valuable aquatic plants in the Lake Superior region, the benefits and values of Manoomin are often unknown or underappreciated by the general public (David et al., 2019). Education and information about the importance of Manoomin can encourage the stewardship of Manoomin and improve restoration outcomes. On Lac Vieux Desert, for example, some lakeshore owners and boaters viewed Manoomin as a nuisance. After taking the time to educate the non-tribal community about the importance of Manoomin and why it is worth protecting, the LVD Band now works closely with them to ensure the existence of Manoomin in Rice Bay and other parts of the lake.

Preserving existing Manoomin habitat is critical to ensuring a future with Manoomin.

Given the significant challenges in restoring Manoomin that has become degraded, a key management strategy for Manoomin is to protect and preserve existing Manoomin stands and the clean water resources and habitats in which it thrives. In many places, dramatic changes to wetland and lake systems – including hydrologic changes from dams and agricultural ditching and mining activities – has had unforeseen consequences. Protecting areas with Manoomin habitat could reduce some stressors to Manoomin, and allow the plant to adapt to climate change and other changing conditions. Manoomin habitats may be protected through a number of different actions, including first ensuring there is a comprehensive characterization (mapping) of the habitat across the Great Lakes Region, such as the use of hyperspectral imaging to delineate Manoomin habitat. Acquisitions and conservation easements may also be part of the strategy to protect Manoomin habitat. In addition, instituting best management practices to protect existing high-quality habitat from existing stressors should also be considered. This may include controlling invasive species; limiting activities with adverse consequences in sensitive habitats, such as discharging mine waste; and developing climate monitoring and adaptive management plans. Finally, educational outreach could be an important aspect of preserving Manoomin habitat, including outreach to lakeshore landowners with Manoomin stands about the value of this habitat, and to the general public with respect to the ecological and cultural value of Manoomin.

7. Conclusion and next steps

This report documents and characterizes the importance and functions of Manoomin and its associated habitat to cultural perspectives and identity, community connections, and cultural and spiritual practices of the Anishinaabe people; as well as to biodiversity and ecosystem integrity. Using a set of cultural and ecological metrics and a combined HEA approach, we characterized a range of degraded Manoomin waters where restoration actions have been undertaken, with locations dispersed over the Lake Superior region. We quantified lost cultural and ecological functionality in terms of the additional amount of equivalent restoration that would be needed to counter-balance the losses.

We find that restoration is worthwhile, with demonstrable improvements documented in our case studies. However, our case studies also highlight the challenges to return degraded Manoomin stands to full functionality. Many restoration actions have improved cultural and ecological functionality, but have not been successful at fully returning Manoomin to historical conditions or to the potential capacity implied by conditions at the site. In places where Manoomin restoration has shown some success, we find that additional restoration is often needed, given historical losses in cultural and ecological functionality. The challenges in restoring Manoomin habitat after it is degraded serve to highlight the critical importance of protecting existing Manoomin stands.

To provide a path forward for Indigenous communities, tribal and non-tribal governments, organizations, and staff who are working to actively manage and restore Manoomin across the Great Lakes, we would like to offer several possible next steps to further assess the cultural and ecological importance of Manoomin.

Expand the geographic scope of this study

This study focuses on seven case studies around the Lake Superior region. We selected the case studies in places that were of particular importance to our team and had adequate data and information to inform the characterization. As we were only able to delve deep into a limited number of the case studies, it is difficult to generalize our case study findings from these seven places to the Lake Superior region or the Great Lakes basin more broadly.

A cumulative sample of case studies could allow us to aggregate information from places around the Great Lakes – including the full Lake Superior region and across lakes Michigan, Huron, Erie, and Ontario – to allow for greater generalization. With a more representative sample of case studies, we could provide additional insights into threats to Manoomin and different restoration approaches used across the Great Lakes, and better understand the cultural and ecological losses (or gains) in Manoomin and its associated habitat throughout the region. This could help target critical resources to protect the remaining populations of Manoomin and restore Manoomin habitat across the Great Lakes region.

Incorporate cultural and ecological characterizations into annual monitoring efforts

Many of the sites are newly restored, such as Hiles Millpond and the Net River Impoundment, or have recently acquired additional resources to complete more restoration, such as Big Rice Lake and Lac Vieux Desert's Rice Bay. Characterizing future restoration conditions at these places could allow for a continued understanding of how well restoration returns the cultural and ecological functionality of the place and, in some cases, could refine the output from the HEA approach. For example, Big Rice Lake could be characterized after additional restoration efforts are implemented to determine how well those actions return the lake's natural functionality.

Cultural metrics could also inform annual monitoring efforts. Combined with ecological monitoring metrics (e.g., water quality, water level, and Manoomin biomass and stalk density), cultural metrics incorporate Indigenous knowledge, cultural values, beliefs, and practices into the monitoring process; and provide a more holistic understanding of determining if restoration actions are achieving target goals or returning conditions to historical or baseline conditions. Without Indigenous metrics, the cultural values, beliefs, and practices are unseen or invisible and, therefore, the restoration is not adequately characterized. The characterization must be driven and refined by the people in the community. In particular, cultural metrics will need to reflect the unique history of the community or the place, as well as the place-based use of Manoomin or other natural resources.

In the Great Lakes, continuous efforts are needed to protect, restore, and monitor Manoomin and its associated habitat. Understanding the success (or failure) of restoration actions in counterbalancing historical losses in cultural and ecological functionality can help determine how to target future resources toward restoring and protecting Manoomin. We hope that the information and knowledge gained through this study will help Indigenous communities, tribal and non-tribal governments, organizations, and staff in the Great Lakes region ensure a future with healthy Manoomin waters.

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Appendix

In this appendix, we provide the standalone communications materials developed for each case study. In each case study, we provide a brief overview of the place, and describe the threats to Manoomin at the place and the actions taken to improve the abundance of Manoomin at the place. We then describe the case study results, including the metrics used to characterize the cultural and ecological importance of the place, the characterized conditions of Manoomin habitat over time, and the results of the HEA model that calculates the amount of restoration needed to balance the reduced or lost functions. Case studies include:

- Restoration of **Lac Vieux Desert's Rice Bay** increases cultural and ecological functionality: Significant progress made but additional restoration could counter-balance losses
- Restoration of **Perch Lake** increases cultural and ecological services: Efforts by the Fond du Lac Band show some improvement in Manoomin coverage
- Restoration of Keweenaw Bay Indian Community's **Sand Point Sloughs** increases cultural and ecological functionality: Significant progress made but additional restoration could counter-balance losses
- Introduction of Manoomin at **Net River Impoundment and Vermillac Lake** provides cultural and ecological functionality: With favorable conditions, restoration can enhance Gichi-manidoo gitigaan
- Introduction of Manoomin at **Hiles Millpond** provides cultural and ecological functionality: With favorable conditions, restoration can enhance Manoomin habitat
- Efforts to manage **Big Rice Lake** have not improved Manoomin functionality: Manoomin continues to be affected by hydrologic conditions and other threats
- Low ecological and cultural functionality characterized at the **Twin Lakes**: Manoomin is unable to rebound due to ongoing sulfate loading from mine discharges.

Restoration of Lac Vieux Desert's Rice Bay increases cultural and ecological functionality

Significant progress made but additional restoration could counter-balance losses

Recent restoration efforts at Lac Vieux Desert's Rice Bay have improved the cultural and ecological functionality of the bay's Manoomin (wild rice) and its associated habitat. However, given the significant losses, much more restoration is needed. Based on the methods applied in this study, it would take an additional 3,034 acres of similar Manoomin restoration to counter-balance the lost cultural and ecological functionality that has occurred over time. This is equivalent in scale to 12 times the current restoration efforts at Rice Bay. In addition, future restoration actions will need to be adaptive to respond to changing precipitation patterns.

Credit: Todd Marsee, Michigan Sea Grant

Threats to Manoomin at Rice Bay

Lac Vieux Desert was dammed around 1870 for logging operations. By 1907 the Wisconsin Valley Improvement Company (WVIC) began operating the lake as a storage reservoir and used the dam to create uniform stream flow down the Wisconsin River to reduce flooding events, facilitate hydroelectric power generation, and regulate effluent discharge downstream. In 1937, WVIC replaced the wooden dam with a reinforced concrete and steel structure. The high water levels caused by the dam initiated a decline in Manoomin (Labine, 2017). From 1938 to 1952, Manoomin declined steadily and community members stopped harvesting it during this period (Barton, 2018). During this period, lakeside property owners became concerned about the erosion caused by rising lake levels.

More recently, heavy rainfall events have negatively affected Manoomin in Lac Vieux Desert [Roger Labine, Lac Vieux Desert Band of Lake Superior Chippewa (LVD Band), personal communication, February 15, 2020]. In the spring, Manoomin is in the floating leaf stage, and can be uprooted by heavy rainfall that raises water levels. In the summer, when Manoomin is in the flowering stage, heavy rainfall can knock Manoomin pollen down from the flower to the water's surface, which prevents pollination and results in "ghost rice" or empty hulls that never fill. In addition, the combination of heavy rainfall events and higher air temperatures may also increase the amount of brown spot – a destructive wild rice fungal disease – in Manoomin beds.

About Lac Vieux Desert's Rice Bay

Lac Vieux Desert, located in Vilas County, Wisconsin, and Gogebic County, Michigan, is over 4,000 acres. Historically, Manoomin covered many parts of Lac Vieux Desert, including Rice Bay, Thunder Bay, Slaughters Bay, Misery Bay, and along the northwestern shore to the Wisconsin River and parts of the south shore.

Rice Bay is a 243-acre bay on the northeastern portion of Lac Vieux Desert, which historically contained a significant stand of Manoomin that was traditionally managed and harvested by the LVD Band. West of Rice Bay is Ketegitigaaning, a ricing village used intermittently in the early 18th century by the LVD Band, followed by continuous habitation by 1900. In 2015, Rice Bay was registered as a Traditional Cultural Property on the National Register of Historic Places.

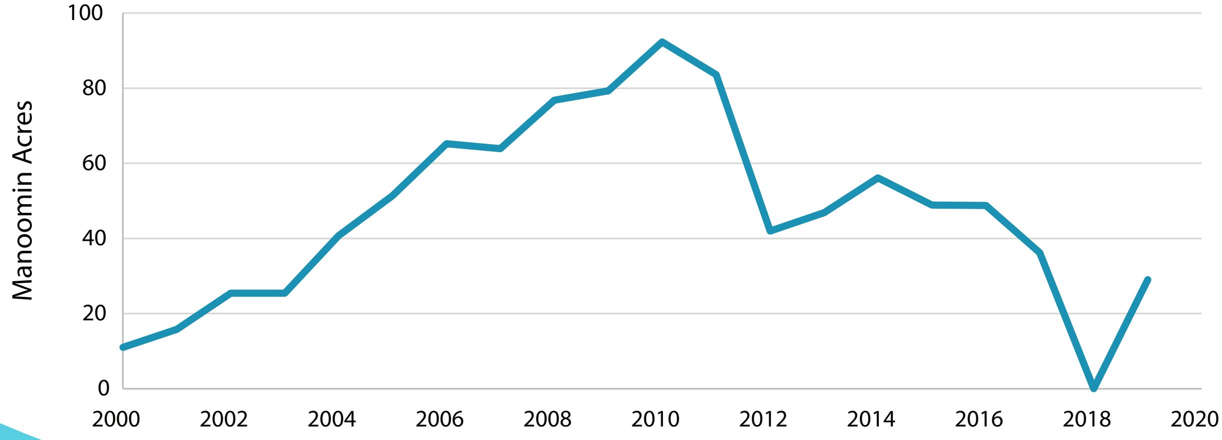
Actions taken to improve the abundance of Manoomin at Rice Bay

In 1991, a coalition of tribal, state, and federal governments and governmental agencies determined the operating regime of the dam on Lac Vieux Desert had been detrimental to Manoomin and its associated habitat (Onterra, 2012). By 2001, following a decade of negotiation and litigation, WVIC lowered the maximum operating level by about nine inches and provided financial contribution toward a Manoomin seeding and monitoring program (Barton, 2018). From 2002 to 2005, Lac Vieux Desert was seeded with 14,000 pounds of Manoomin, most of which occurred in Rice Bay (Labine, 2017). From 2007 through 2012, as Manoomin became reestablished on Rice Bay, the LVD Band held traditional ricing camps and workshops, which included traditional practices and activities (Barton and Labine, 2013).

From 2000 to 2010, the acreage of Manoomin on Rice Bay significantly increased. In 2000, Rice Bay had just 11 acres of Manoomin coverage (or 5% of Rice Bay). After the first year of seeding, Manoomin coverage increased to over 25 acres (or 10% of Rice Bay; top aerial photograph). With below-average rainfall conditions in 2010, the extent of Manoomin increased to over 92 acres (or 38% of Rice Bay; bottom aerial photograph). While the extent of Manoomin on Rice Bay was less than its historical coverage, it was considered an improvement over conditions caused by the operating regime of the concrete dam (Barton, 2018).

Since 2011, the acreage of Manoomin on Rice Bay has been declining, with 34 acres in 2019 (GLIFWC, 2019). Because Manoomin abundance on Rice Bay is generally greatest during low-water years, natural resource managers believe this may be due to above-average precipitation over the past seven years (Peter David, GLIFWC, personal communication, November 12, 2019).

Manoomin abundance on Lac Vieux Desert Lake's Rice Bay in 2003 (above) and 2010 (below). Credit: Peter David, Great Lakes Indian Fish & Wildlife Commission (GLIFWC).



Manoomin acreage on Rice Bay, 2000 to 2019

Credit: GLIFWC, 2019.

Approach to characterizing Manoomin at Rice Bay

Twelve metrics characterize the cultural and ecological functions of Rice Bay's Manoomin and its associated habitat. These metrics describe how Manoomin at Rice Bay contributes to maintaining connections with the Anishinaabe culture, how ecological functionality is supported and resilient to changing conditions, and how continued learning and sharing of Anishinaabe values are promoted.

Cultural Metrics

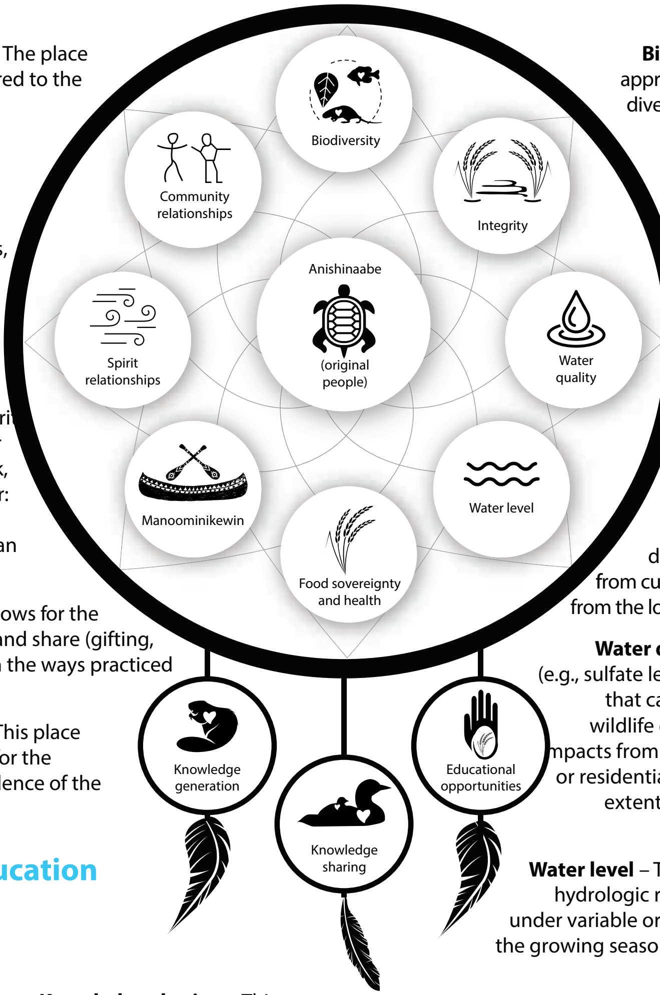
Anishinaabe (original people) – The place provides Manoomin, which is sacred to the Anishinaabe and central to the foundations of their culture, sovereignty, and treaty rights.

Community relationships – Manoomin at this place contributes to bonding, traditions, and strengthening family and community connections.

Spirit relationships – Manoomin at this place enables the Anishinaabe to maintain connections and balance with spiri beings (or relatives) from all other orders of creation (first order: rock, water, fire and wind; second order: other plant beings; third order: animal beings; fourth order: human beings).

Manoominikewin – This place allows for the Anishinaabe to harvest, prepare, and share (gifting, healing, and eating) Manoomin in the ways practiced by their ancestors for centuries.

Food sovereignty and health – This place provides the capacity to provide for the sustenance, health, and independence of the Anishinaabe.



Ecological Metrics

Biodiversity – Healthy Manoomin and appropriate habitat at this place supports diverse biological communities (e.g., free of invasive species) that indicate the capacity of the place to support abundant associated plant and animal species (e.g., other native aquatic vegetation, fish, waterfowl, muskrat), providing for spiritual and subsistence needs.

Integrity – Physical habitat and hydrology, and water and sediment chemistry support stands of Manoomin that exhibit natural annual variability; viable seed bank ensures that sustainable Manoomin populations will persist even after occasional poor production years. Natural genetic diversity is maintained without impact from cultivated strains, or reduced gene flow from the loss of nearby Manoomin populations.

Water quality – This place has clean water (e.g., sulfate levels below 10 ppm) and sediments that can support robust stand density and wildlife diversity; is free of contamination or mpacts from industrial, agricultural, recreational, or residential influence; and is of sufficient areal extent to sustain a Manoomin population.

Water level – This place has a natural or managed hydrologic regime that can maximize resilience under variable or extreme climatic conditions across the growing season (maintaining optimal depth range and flow).

Cultural and Ecological Education Metrics

Knowledge generation – This place allows for continued learning and generation of the Anishinaabe practices, values, beliefs, and language through experience.

Knowledge sharing – This place allows for the continued sharing and transmittal of the Anishinaabe practices, values, beliefs, and language among family members and community.

Educational opportunities – This place provides opportunities for language, land stewardship, and other educational programs, such as educational rice camps.

Cultural and ecological characterization at Rice Bay

Rice Bay's Manoomin and its associated habitat were characterized over four time periods. Each metric was ranked using the following five-point descriptive scale: No use, Very bad, Not very good, Pretty good, Doing great

1900 to 1936: With a wooden dam

Based on the combined ranking of cultural and ecological metrics, Rice Bay was characterized as "doing great" during this period. In the early 1900s, Ketegitigaaning was inhabited and the community harvested Manoomin in Rice Bay for gifting, healing, and consumption. The area also boasted a rich biodiversity; and hunting, trapping, fishing, and gathering local resources were common.

1937 to 1990: With a concrete and steel dam

After the replacement of the wooden dam with a concrete and steel structure, Manoomin declined steadily until the mid-1950s to the point that it was no longer harvestable by community members. During this time period, community members moved away from the lake and into surrounding towns, and stopped harvesting Manoomin in Rice Bay. The "disappearance of Manoomin started the deterioration of the Lac Vieux Desert community," where bonding, traditions, and community connections ceased (Roger Labine, LVD Band, personal communication, November 12, 2019). There was a steady decline in cultural and ecological functionality provided by Manoomin from 1937 to the mid-1950s, when Rice Bay was characterized as "very bad" based on the combined ranking of cultural and ecological metrics.

1991 to 2012: With restoration actions

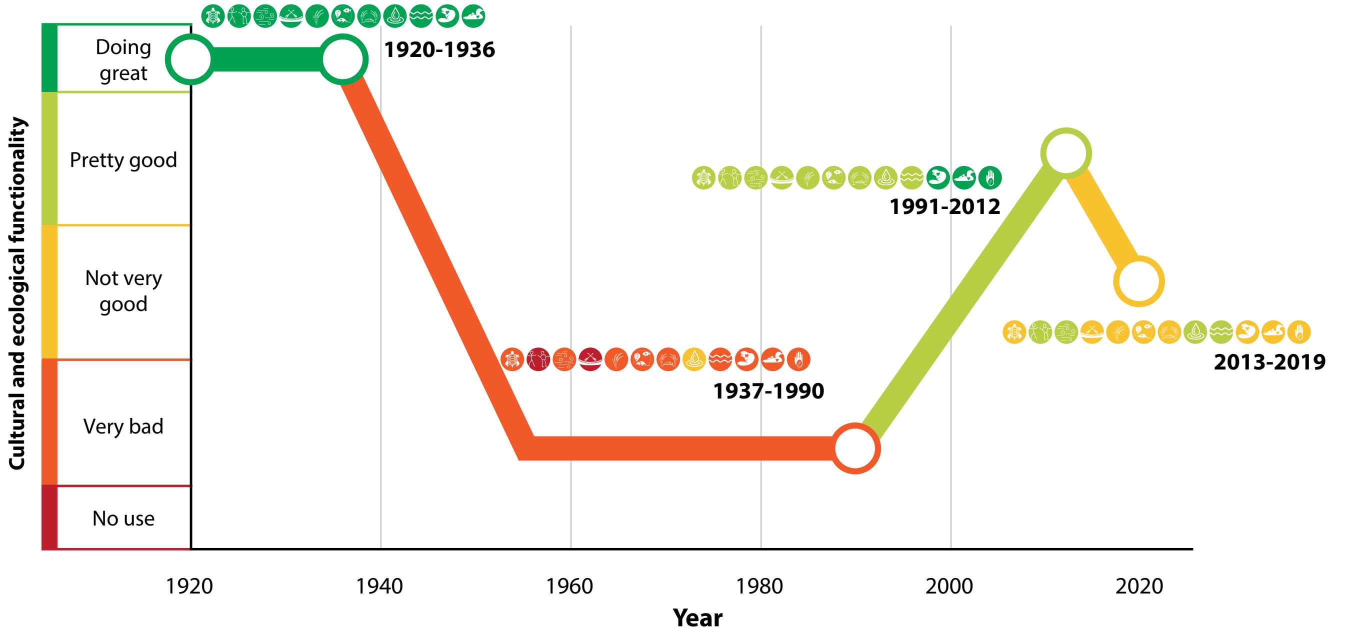
Once restoration actions began in the 1990s, cultural and ecological functionality provided by Manoomin improved. By 2008, the LVD Band opened Rice Bay for Manoomin harvest and began hosting rice camps in the area for the first time since 1940. Although the community began knowledge sharing, knowledge generation, and educational opportunities increased, it remained difficult to get many community members interested in Manoomin because of its absence over the last 50 years. Even so, restoration actions led to an increase in cultural and ecological functionality. By 2012, Rice Bay ranked as "pretty good" based on the combined ranking of cultural and ecological metrics.

2013 to 2019: With restoration actions and above-average precipitation

With heavy rainfall events negatively affecting Manoomin beds during the growing season, cultural and ecological functionality at Rice Bay have declined. Currently, Rice Bay is ranked as "not very good" based on the combined ranking of cultural and ecological metrics. The decrease in ecological and cultural functionality provided by Manoomin in recent years suggests the need for adaptive management of Manoomin. Actions taken that may have been successful in restoring Manoomin in the past may need to be adjusted to respond to additional threats, such as climate change, to be successful in the future.

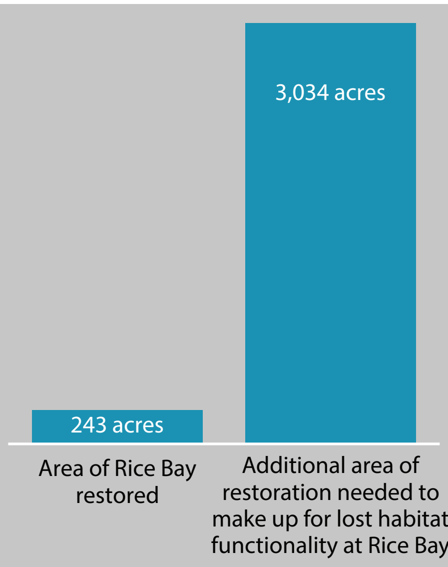
Cultural and ecological characterization at Rice Bay

Cultural and ecological functionality provided by Manoomin and its associated habitat at Rice Bay have changed over time, both in total and for individual metrics.



Additional Restoration Needed

Based on the characterization of the degree of cultural and ecological function over the four time periods, a Habitat Equivalency Analysis demonstrates the additional equivalent units of restoration needed to counter-balance the severity and timespan of degradation. Given the success of restoration at the 243-acre Rice Bay, 3,034 acres of similar Manoomin restoration is needed to counter-balance the lost habitat functionality that has occurred over time. In other words, 12 equivalent restoration efforts at Rice Bay (from 1991 to 2019) are needed to counter-balance the lost cultural and ecological habitat functionality (from 1937 to 1990).



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About this effort

This case study is part of the Lake Superior Manoomin Cultural and Ecosystem Characterization Study. The project was initiated by a team of Lake Superior Basin Anishinaabe communities, and federal and state agencies, with technical support from Abt Associates. This project aims to describe the importance of Manoomin to help foster community stewardship and education; and to inform Manoomin management, protection, and policy in the Lake Superior region and throughout the Great Lakes. Funding for this project was received via Great Lakes Restoration Initiative. For more information on the Initiative and Action Plan go to https://www.glri.us/.

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The Project Team would like to acknowledge Roger Labine (LVD) and Peter David (GLIFWC) for their valuable input and feedback in the development of this case study, and for participating in the cultural and ecological characterization of Lac Vieux Desert's Rice Bay.

Restoration of Perch Lake increases cultural and ecological services

Efforts by the Fond du Lac Band show some improvement in Manoomin coverage

Recent restoration efforts at Perch Lake, or Aatawemegokokaaning, have improved the cultural and ecological services of the lake's Manoomin (wild rice) and its associated habitat. However, given the significant historical losses, much more restoration is needed. Based on methods applied in this study, it would take an additional 5,204 acres of similar Manoomin restoration to counter-balance the lost cultural and ecological services that have occurred over time. This is equivalent in scale to 13 times the current restoration efforts at Perch Lake.

Credit: Lake Superior National Estuarine Research Reserve education intern Riley Oliver

Threats to Manoomin at Perch Lake

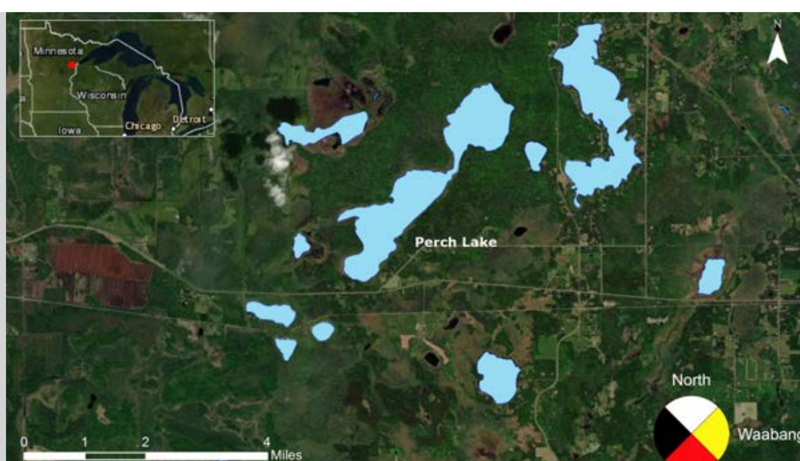
Historically, Perch Lake had abundant Manoomin habitat. In the early 1900s, many streams and wetland areas were ditched and drained to accommodate farming. After Perch Lake was ditched for agriculture around 1918 to 1921, the lake experienced a decline in Manoomin (Nancy Schuldt, personal communication, October 7, 2019).

To try to minimize the impacts of ditching, a concrete dam was installed at the lake outlet in 1936. The dam was managed to mimic the natural fluctuation of the water to benefit Manoomin. By the 1960s, the dam fell into disrepair and was non-functional. For the following several decades, lake levels were lower and stagnant, which allowed ginoozhegoons (pickerelweed) to displace Manoomin and become the dominant vegetation in the lake's rice waters (Fond du Lac Band, 2018, 2019).

About Perch Lake

Perch Lake is located on the Fond du Lac Band of Lake Superior Chippewa Reservation in Minnesota. It is an approximately 650-acre, double-basin lake. The shallow, southern portion of the lake is approximately 400 acres, and it is the largest Manoomin-containing habitat on the Reservation (Fond du Lac Band, 2008). The northern basin also supports some Manoomin along its fringes.

Perch Lake is an important traditional cultural property, used as a wild rice lake, a fisheries/spearing and netting site, and hunting grounds (Fond du Lac Band, 2018). Historical evidence suggests that Manoomin has been present at Perch Lake for over 2,000 years, with historical stands on approximately 392 acres (Fond du Lac Band, 2018).



Actions taken to improve the abundance of Manoomin at Perch Lake

In 1998, a new water control structure was built at the outlet of Perch Lake to manage water levels for Manoomin and improve hydrologic function throughout the watershed (Fond du Lac Band, 2018). In 2001, the Fond du Lac Band began intensive mechanical vegetation removal of ginoozhegoons, a native perennial species that occupies the same habitat as Manoomin and often outcompetes Manoomin (Fond du Lac Band, 2018). Using a sedge mat cutter and aquatic harvesters, the Fond du Lac Band removed ginoozhegoons vegetation at least twice yearly. This process led to high Manoomin density in restored areas initially. However, three to five years after each removal, ginoozhegoons became dominant again, which called for a rotating schedule for removing this competing plant.

In 2012, Perch Lake experienced a 500-year flood in mid-summer, and the Fond du Lac Band used the water control structure to keep water levels high and eliminate as much ginoozhegoons as possible. The following year, Manoomin stands were so thick that it was difficult to travel through the lake. Learning from the natural flood event, the Fond du Lac Band then developed a management strategy to bring lake levels to flood stage every four years to stress perennial species, such as ginoozhegoons, which compete with Manoomin for habitat. Although this strategy also limits Manoomin production in flood years, it provides Manoomin with a competitive advantage in the years following a flood stage year (Fond du Lac Band, 2018).

With water level management and mechanical removal of competitive vegetation, the Fond du Lac Band has successfully restored Manoomin to over 200 acres on Perch Lake (Fond du Lac Band, 2019).

Sedge mat cutter. Credit: Fond du Lac Band, 2018.

Aquatic harvester. Credit: Fond du Lac Band, 2018.

Perch Lake. Credit: Lake Superior National Estuarine Research Reserve education intern Riley Oliver.

Approach to characterizing Manoomin at Perch Lake

Twelve metrics characterize the cultural and ecological functions of Perch Lake's Manoomin and its associated habitat. These metrics describe how Manoomin at Perch Lake contributes to maintaining connections with the Anishinaabe culture, how it supports ecological functionality and is resilient to changing conditions, and how it allows for continued learning and sharing of Anishinaabe values.

Cultural Metrics

Anishinaabe (original people) – The place provides Manoomin, which is sacred to the Anishinaabe and central to the foundations of their culture, sovereignty, and treaty rights.

Community relationships – Manoomin at this place contributes to bonding, traditions, and strengthening family and community connections.

Spirit relationships – Manoomin at this place enables the Anishinaabe to maintain connections and balance with spirit beings (or relatives) from all other orders of creation (first order: rock, water, fire and wind; second order: other plant beings; third order: animal beings; fourth order: human beings).

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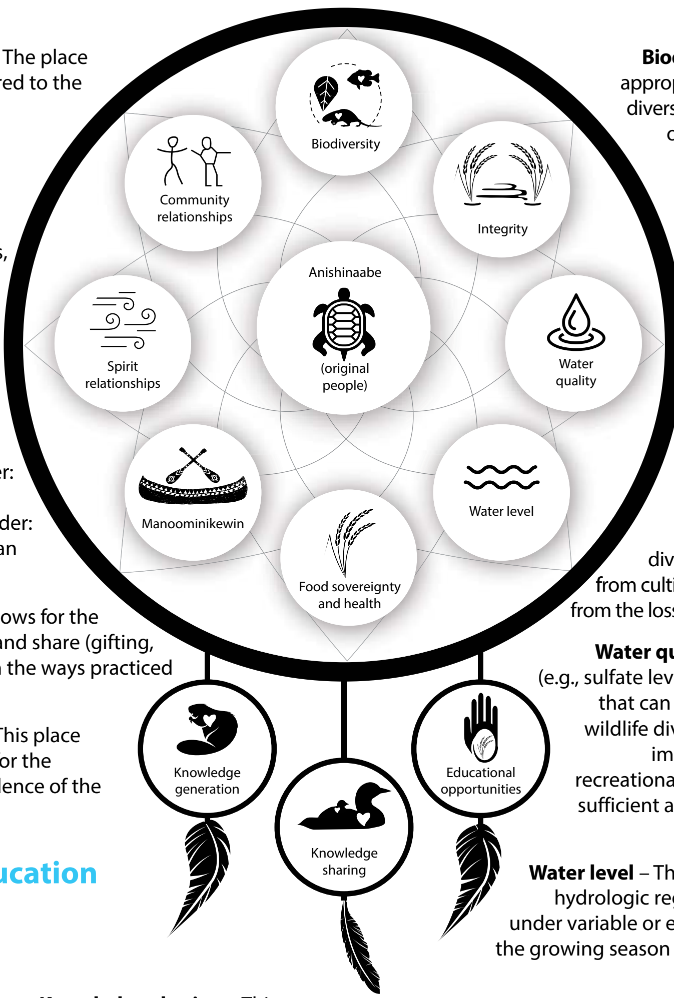
Food sovereignty and health – This place provides the capacity to provide for the sustenance, health, and independence of the Anishinaabe.



Ecological Metrics

Biodiversity – Healthy Manoomin and appropriate habitat at this place supports diverse biological communities (e.g., free of invasive species) that indicate the capacity of the place to support abundant associated plant and animal species (e.g., other native aquatic vegetation, fish, waterfowl, muskrat), providing for spiritual and subsistence needs.

Integrity – Physical habitat and hydrology, and water and sediment chemistry support stands of Manoomin that exhibit natural annual variability; viable seed bank ensures that sustainable Manoomin populations will persist even after occasional poor production years. Natural genetic diversity is maintained without impact from cultivated strains, or reduced gene flow from the loss of nearby Manoomin populations.

Water quality – This place has clean water (e.g., sulfate levels below 10 ppm) and sediments that can support robust stand density and wildlife diversity; is free of contamination or impacts from industrial, agricultural, recreational, or residential influence; and is of sufficient areal extent to sustain a Manoomin population.

Water level – This place has a natural or managed hydrologic regime that can maximize resilience under variable or extreme climatic conditions across the growing season (maintaining optimal depth range and flow).

Cultural and Ecological Education Metrics

Knowledge generation – This place allows for continued learning and generation of the Anishinaabe practices, values, beliefs, and language through experience.

Knowledge sharing – This place allows for the continued sharing and transmittal of the Anishinaabe practices, values, beliefs, and language among family members and community.

Educational opportunities – This place provides opportunities for language, land stewardship, and other educational programs, such as educational rice camps.

Cultural and ecological characterization at Perch Lake

Manoomin and its associated habitat at Perch Lake were characterized over four time periods. Each metric was ranked using the following five-point descriptive scale: No use, Very bad, Not very good, Pretty good, Doing great

1900 to 1920: Before agricultural ditching

Before it was ditched for agriculture, Perch Lake historically had abundant Manoomin stands. Fond du Lac resource managers estimate that nearly 60% of the lake had extensive Manoomin stands during this time, and it was harvested by the community. Based on the combined ranking of cultural and ecological metrics, Perch Lake was characterized as "doing great" during this first time period.

1921 to 1970: With agricultural ditching

After agricultural ditching of Perch Lake, Manoomin and its associated habitat declined abruptly. Lower and stagnant water levels allowed ginoozhegoons to become the dominant vegetation in the lake, displacing Manoomin, which resulted in a decline in use of the lake by waterfowl and other wildlife. Band members were unable to harvest Manoomin in the ways they did historically, which limited the generation and sharing of Anishinaabe practices, values, and beliefs. During this period of time, Perch Lake was characterized as "not very good" based on the combined ranking of cultural and ecological metrics.

1971 to 1997: Before the new water control structure and restoration actions

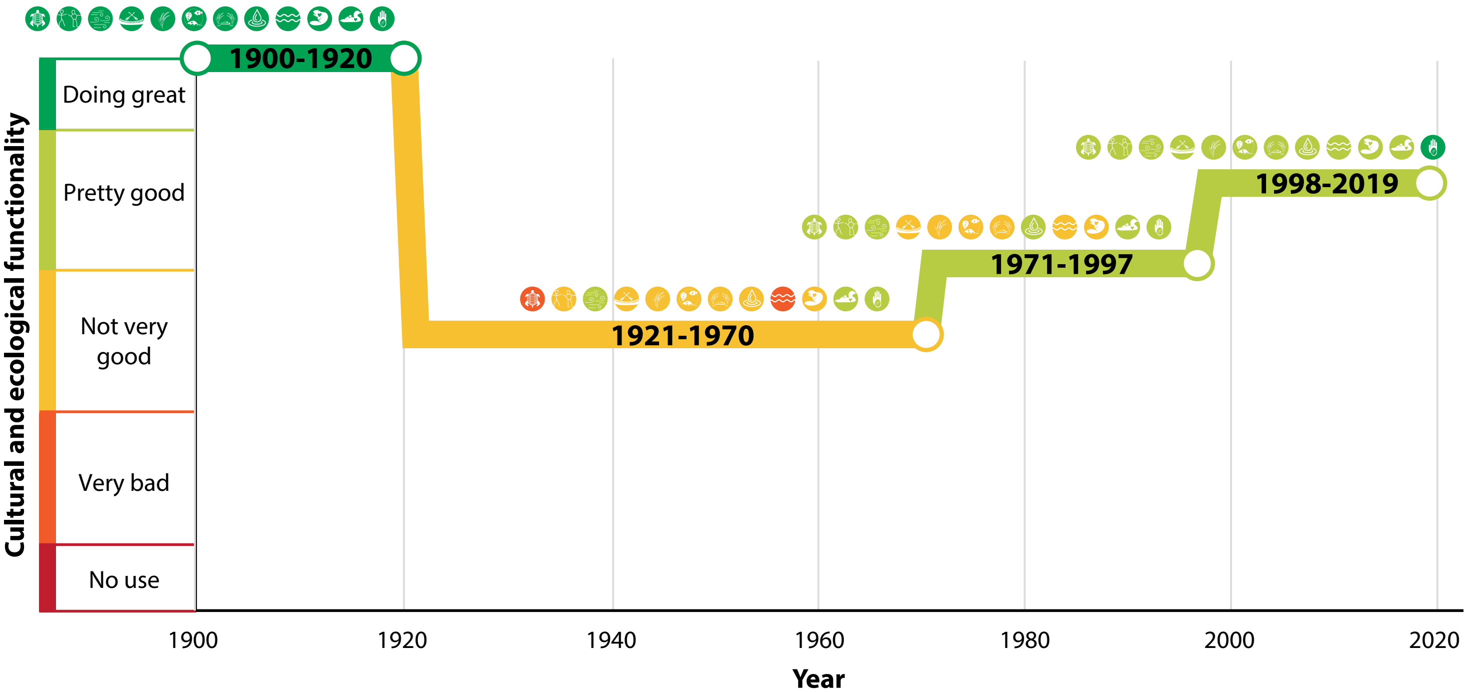
During this period, Perch Lake had a significant decline in Manoomin abundance and functionality; approximately 75% of the lake was covered with plant species that occupy the same habitat as and compete with Manoomin. Although Perch Lake's ecological and cultural functionality remained low, Band members continued to try to harvest at the lake; therefore, the lake provided some cultural services during this period. Many elders and wild rice chiefs believe Manoomin is a blessing and is seen as a golden age of their youth. For these reasons, Perch Lake ranked as "pretty good," which was slightly higher than the previous time period.

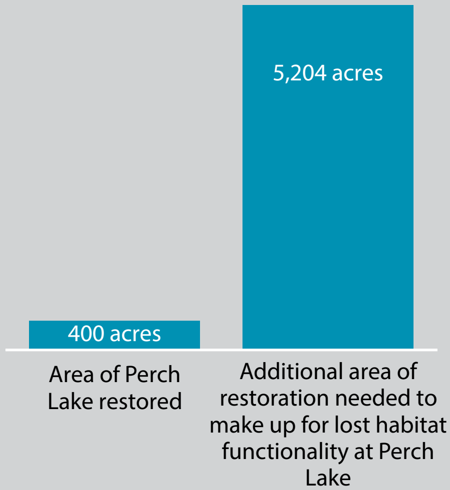
1998 to 2019: With the new water control structure and restoration actions

The water control structure built at the outlet of Perch Lake in 1998 helped restore the hydrologic conditions of the lake and improve Manoomin and its associated habitat. Active management of the lake started in 2001 and accelerated in 2012, which further restored hydrologic conditions of the lake and removed competing vegetation, all benefiting Manoomin. During this time period, the Fond du Lac Band was fairly successful at restoring Manoomin on Perch Lake. Manoomin covers over 200 acres of Perch Lake, which is about 30% of its historical coverage. Currently, Perch Lake is ranked as "pretty good" based on the combined ranking of cultural and ecological metrics.

Cultural and ecological characterization at Perch Lake

The cultural and ecological functionality provided by the Manoomin and its associated habitat at Perch Lake varied over time, both in aggregate and for individual metrics.





Additional restoration needed

Using the characterization of Perch Lake over the four time periods, a habitat equivalency analysis demonstrates the additional equivalent units of restoration needed to counter-balance the severity and timespan of degradation. Given the success of restoration over the shallow, southern 400 acres of Perch Lake, approximately 5,204 acres of similar Manoomin restoration are needed to counter-balance the lost habitat functionality that has occurred over time. In other words, 13 equivalent restoration efforts at Perch Lake (from 1971 to 2019) are needed to counter-balance the lost cultural and ecological habitat functionality (from 1921 to 1970).

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About this effort

This case study is part of the Lake Superior Manoomin Cultural and Ecosystem Characterization Study. The project was initiated by a team of Lake Superior Basin Anishinaabe communities, and federal and state agencies, with technical support from Abt Associates. This project aims to describe the importance of Manoomin to help foster community stewardship and education; and to inform Manoomin management, protection, and policy in the Lake Superior region and throughout the Great Lakes. Funding for this project was received via Great Lakes Restoration Initiative. For more information on the Initiative and Action Plan go to https://www.glri.us/.

Acknowledgments

The Project Team would like to acknowledge Nancy Schuldt and Thomas Howes (Fond du Lac Band) for their valuable input and feedback in the development of this case study, and for participating in the cultural and ecological characterization of Perch Lake. We would also like to acknowledge the Fond du Lac Band elders and the wild rice chief who helped us characterize Perch Lake.

Restoration of Keweenaw Bay Indian Community's Sand Point Sloughs increases cultural and ecological functionality

Significant progress made but additional restoration could counter-balance losses

Recent restoration efforts on eight acres at Keweenaw Bay Indian Community's (KBIC's) Sand Point Sloughs have improved the cultural and ecological functionality of the sloughs' Gichi-manidoo gitigaan (The Great Spirit's Garden); however, given the significant historical losses, much more restoration is needed. Based on methods applied in this study, it would take an additional 175 acres of similar Manoomin (wild rice) restoration to counter-balance the lost cultural and ecological functionality that have occurred over time. This is equivalent in scale to 22 times the current restoration efforts at the sloughs. In addition, future restoration actions will need to be adaptive to respond to changing climate conditions.

Threats to Manoomin at Sand Point Sloughs

Connected to Lake Superior, Sand Point Sloughs is part of a dynamic coastal system. In the early 20th century, a copper ore processing plant, Mass Mill, operated on the west side of Keweenaw Bay on the south shore of Lake Superior. During the copper ore processing, approximately six billion pounds of mine tailings, locally known as stamp sands, were disposed into Keweenaw Bay. Lake currents continue to carry these tailings southward and redeposit them onto Sand Point, located just four miles south of the Mass Mill. Sand Point has an extensive beach area with approximately 2.5 miles of lake front and is connected to the sloughs. These tailings contain high concentrations of heavy metals that have the potential to cause environmental harm.

More recently, Sand Point Sloughs has been affected by regional hydrologic conditions – including higher water levels – that are occurring at a regional scale and are beyond local control. As a plant species sensitive to changes in water level, higher water levels have negatively affected the establishment and abundance of Manoomin in Sand Point Sloughs. The sloughs' connection to Lake Superior also opens the pathway to aquatic invasive species, such as carp and reed canary grass. Carp, for example, are bottom feeders that uproot Manoomin (Premo et al., 2014). Manoomin abundance may be impeded by competing native vegetation, such as ginoozhegoons (pickerelweed); and by excessive browsing by wildlife on new stands, such as waterfowl.

About Sand Point Sloughs

Sand Point Sloughs are relatively shallow backwater sloughs connected to Lake Superior that are culturally important to the KBIC. Native people used this area for hundreds of years, as indicated by the existence of ancient burial grounds and stories that have been passed on through oral tradition (KBIC, 2003). Manoomin is believed to have been present in Sand Point Sloughs prior to the 1900s (Ravindran et al., 2014). Today, the site contains the KBIC Pow Wow grounds, a traditional healing clinic, extensive wetlands, and Manoomin beds. A marina, campground, lighthouse, and recreational beaches signify the community's appreciation of this area.

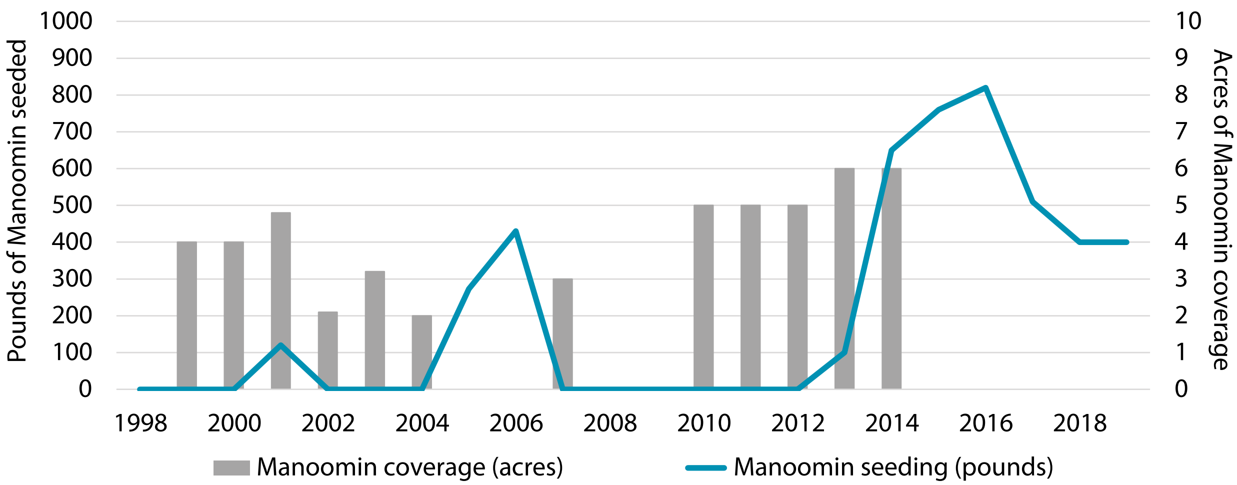
This area also holds ecological value as habitat. It provides for a number of species including medicinal plants, insects, fish, and other non-human relatives.

Actions taken to improve the abundance of Manoomin at Sand Point Sloughs

Sand Point Sloughs are a KBIC Tribal Trust property, wholly owned by KBIC and located entirely within KBIC L'Anse Reservation boundaries. KBIC took over management of the sloughs in the early 1990s, and shortly after began efforts to reintroduce Manoomin. Between 1991 and 1997, KBIC seeded nearly 1,800 pounds of Manoomin across 8 acres of Sand Point Sloughs. By 1999, Manoomin density was sufficient for KBIC to engage in the tradition of ricing. Between 1999 and 2002, community members harvested an estimated 60 to 150 pounds per year (Ravindran et al., 2014). Since 2013, KBIC has seeded annually at Sand Point Sloughs. KBIC continues to tend to this site in an effort to keep Manoomin teachings and traditions vital. However, since 2002, community members have not been able to harvest Manoomin at Sand Point Sloughs due to decreased abundance of Manoomin related to regional hydrologic conditions.

Floating wild rice. Credit: KBIC NRD

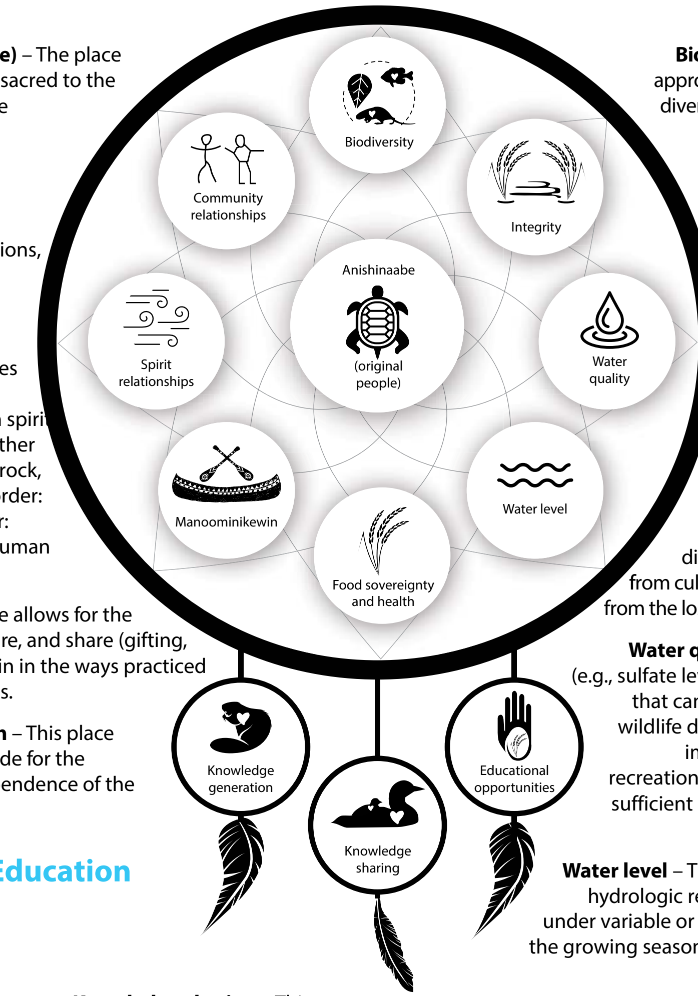
In addition to seeding efforts, KBIC and partners have undertaken remediation along the Sand Point shoreline, which was listed as a brownfield site. Remediation efforts included capping stamp sands to stabilize the tailings; planting native plants, trees, and shrubs to increase habitat for birds and other wildlife; and installing mounds and boulders to provide relief in the topography, reduce erosion, and protect valuable coastal wetlands, including Manoomin beds (Ravindran et al., 2014).



Manoomin seeding and acres of Manoomin coverage at the Sand Point Sloughs, 1999 to 2019 (data were not collected before 1999, and Manoomin coverage data were not recorded after 2014). Sources: Ravindran et al., 2014; Karena Schmidt, personal communication, October 31, 2019.

Approach to characterizing Manoomin at Sand Point Sloughs

Twelve metrics characterize the cultural and ecological functions of Sand Point Sloughs' Manoomin and its associated habitat. These metrics describe how Manoomin at the Sloughs contributes to maintaining connections with the Anishinaabe culture, how it supports ecological functionality and is resilient to changing conditions, and how it allows for continued learning and sharing of Anishinaabe values.



Cultural Metrics

Anishinaabe (original people) – The place provides Manoomin, which is sacred to the Anishinaabe and central to the foundations of their culture, sovereignty, and treaty rights.

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Ecological Metrics

Biodiversity – Healthy Manoomin and appropriate habitat at this place supports diverse biological communities (e.g., free of invasive species) that indicate the capacity of the place to support abundant associated plant and animal species (e.g., other native aquatic vegetation, fish, waterfowl, muskrat), providing for spiritual and subsistence needs.

Integrity – Physical habitat and hydrology, and water and sediment chemistry support stands of Manoomin that exhibit natural annual variability; viable seed bank ensures that sustainable Manoomin populations will persist even after occasional poor production years. Natural genetic diversity is maintained without impact from cultivated strains, or reduced gene flow from the loss of nearby Manoomin populations.

Water quality – This place has clean water (e.g., sulfate levels below 10 ppm) and sediments that can support robust stand density and wildlife diversity; is free of contamination or impacts from industrial, agricultural, recreational, or residential influence; and is of sufficient areal extent to sustain a Manoomin population.

Water level – This place has a natural or managed hydrologic regime that can maximize resilience under variable or extreme climatic conditions across the growing season (maintaining optimal depth range and flow).

Cultural and Ecological Education Metrics

Knowledge generation – This place allows for continued learning and generation of the Anishinaabe practices, values, beliefs, and language through experience.

Knowledge sharing – This place allows for the continued sharing and transmittal of the Anishinaabe practices, values, beliefs, and language among family members and community.

Educational opportunities – This place provides opportunities for language, land stewardship, and other educational programs, such as educational rice camps.

Cultural and ecological characterization at Sand Point Sloughs

Sand Point Sloughs' Manoomin and its associated habitat were characterized over four time periods. Each metric was ranked using the following five-point descriptive scale: No use, Very bad, Not very good, Pretty good, Doing great

This characterization begins after the copper ore processing plant ceased operations around the 1920s.

1920 to 1990: Before KBIC ownership

Based on the combined ranking of cultural and ecological metrics, Sand Point Sloughs was characterized as "not very good" during this period. This ranking reflects the absence of Manoomin from the sloughs and the deposition of mine tailings onto Sand Point. Although Manoomin was absent, the sloughs were still a place of cultural and ecological importance: waterfowl and other wildlife foraged at the sloughs; and community members fished, hunted, and gathered there and held Pow Wows on the grounds. Given the intrinsic cultural and ecological values of the sloughs, some cultural metrics – including spirit relationships, knowledge sharing, and food sovereignty – were characterized with a higher ranking.

1991 to 1998: With active management of Manoomin

Once KBIC took over management of Sand Point Sloughs in the early 1990s and began seeding activities, Manoomin grew modestly. Although community members could not yet harvest Manoomin, the presence of Manoomin significantly improved the ranking of most cultural and ecological metrics. During this period, Sand Point Sloughs ranked as "pretty good" based on the combined ranking of cultural and ecological metrics.

For each of the four time periods, the water level metric was ranked as "not very good." Due to their location, the Sand Point Sloughs are influenced by regional factors such as Lake Superior water levels, which are beyond local control.

1999 to 2005: With active management and harvesting of Manoomin

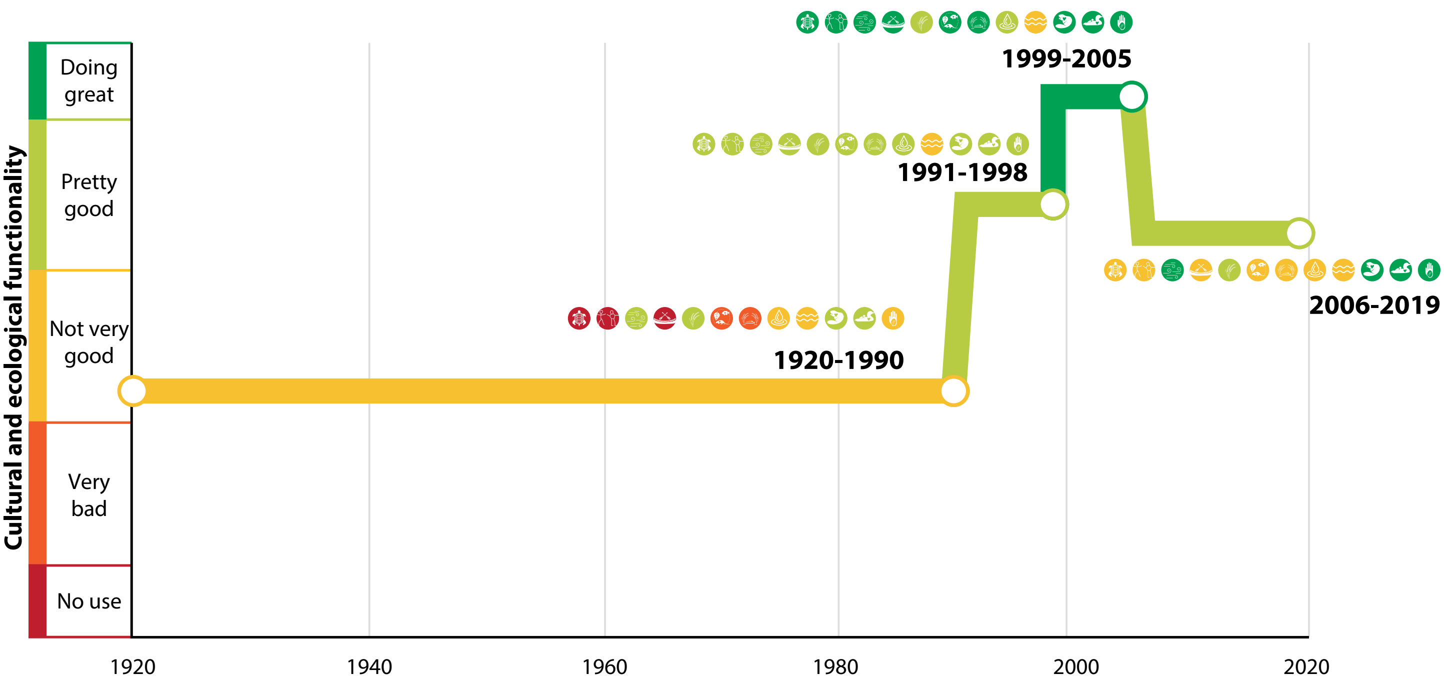
Once Manoomin was adequately established at Sand Point Sloughs, KBIC was able to open Sand Point Sloughs to their community members for harvesting. Harvesting allowed the recovery and sharing of Anishinaabe practices, values, beliefs, and language at the sloughs in ways that had not been practiced for years. During this period, Sand Point Sloughs ranked as "doing great" based on the combined ranking of improved cultural and ecological metrics.

2006 to 2019: With higher water levels

Sand Point Sloughs is connected to Lake Superior, and is affected by changes in the lake's water level and invasive and competitive species. Invasive species and competing vegetation that have been documented at Sand Point Sloughs may be impacting Manoomin abundance. Water levels have also fluctuated in Sand Point Sloughs, with lower water levels recorded in 2006 and 2007, and higher water levels in recent years (Ravindran et al., 2014). During this period, Sand Point Sloughs' functionality decreased to "pretty good" based on the combined ranking of cultural and ecological metrics. The decrease in ecological and cultural functionality provided by Manoomin in recent years suggests the need for adaptive management of Manoomin. Actions taken that may have been successful in restoring Manoomin in the past may need to be adjusted to respond to additional threats, such as climate change, to be successful in the future.

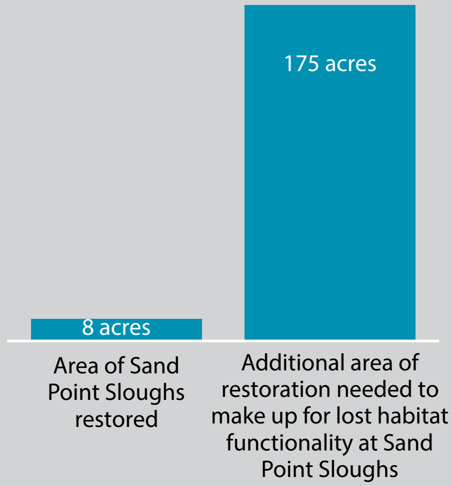
Cultural and ecological characterization at Sand Point Sloughs

The cultural and ecological functionality provided by the Manoomin and its associated habitat at Sand Point Sloughs varied over time, both in aggregate and for individual metrics.



Additional restoration needed

Based on the characterization of the degree of cultural and ecological function over the four time periods, a Habitat Equivalency Analysis demonstrates the additional equivalent units of restoration needed to counter-balance the severity and timespan of degradation. Given the success of restoration on 8 acres of Sand Point Sloughs, 175 acres of similar Manoomin restoration is needed to counter-balance the lost habitat functionality that has occurred over time. In other words, 22 equivalent restoration efforts at Sand Point Sloughs (from 1991 to 2019) are needed to counter-balance lost cultural and ecological habitat functionality (from 1920 to 1990).



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Acknowledgments

The Project Team would like to acknowledge Evelyn Ravindran, Karena Schmidt, and Erin Johnston (KBIC) for their valuable input and feedback in the development of this case study, and for participating in the cultural and ecological characterization of KBIC's Sand Point Sloughs.

Introduction of Manoomin at Net River Impoundment and Vermillac Lake provides cultural and ecological functionality

With favorable conditions, restoration can enhance Gichi-manidoo gitigaan

Tending to Gichi-manidoo gitigaan (The Great Spirit's Garden) through Manoomin (wild rice) seeding efforts at Net River Impoundment and Vermillac Lake has benefited natural resources at these locations. Seeding the Net River Impoundment also has the potential to create a Manoomin seed bank for other lakes in the area, including Vermillac Lake.

Efforts to introduce Manoomin in these waterbodies have shown preliminary success. Therefore, additional seeding could help counter-balance the lost ecological functionality and inspire cultural practices to occur at these locations. Based on methods applied in this study, it would take an additional 1,129 acres of similar Manoomin seeding to counter-balance the lost ecological functionality that have occurred over time, which is equivalent in scale to nearly 12 times the current restoration efforts at the Net River Impoundment and Vermillac Lake.

Threats to Manoomin at Net River Impoundment and Vermillac Lake

Both the Net River Impoundment and Vermillac Lake possibly had Manoomin beds in the past. Many believe that historical trails around the Net River Impoundment indicate traditional use of these places for cultural practices (Evelyn Ravindran, KBIC personal communication, August 20, 2019). Land use changes have altered the local landscape, which may have contributed to the presence or absence of Manoomin at these places.

Credit: KBIC NRD.

About Net River impoundment and Vermillac Lake

The Net River is nearly 15 miles long and flows from Baraga County to Iron County, Michigan. Impounded in 1990 as a wetland mitigation site to provide waterfowl benefits, the Net River Impoundment is now 35 acres in size. Vermillac (or Worm) Lake is a 423-acre lake in Baraga County. Both the Net River Impoundment and Vermillac Lake are located outside the L'Anse Indian Reservation, but within Ceded Territory.

Actions taken to improve Manoomin at Net River Impoundment and Vermillac Lake

KBIC is receiving more and more teachings from Manoomin and is working to understand which locations on the L'Anse Indian Reservation and within Ceded Territory have conditions that are conducive to grow and sustain Manoomin (BIA, 2019). KBIC is interested in having local sources of Manoomin as seed banks for future restoration activities; as well as places where community members can harvest, prepare, and gift Manoomin. KBIC is currently assessing suitable Manoomin habitat across their territory, and focusing restoration in lakes with the most favorable conditions for Manoomin.

In the early 2010s, KBIC worked with the Michigan Department of Natural Resources to identify additional areas for Manoomin restoration. The Net River Impoundment and Vermillac Lake were selected as lakes with potential for Manoomin beds, and KBIC seeded test plots at both lakes. Given their success, KBIC then seeded the Net River Impoundment and Vermillac Lake with nearly 2,000 pounds of Manoomin seed. Cultural teachings and practices related to Manoomin are beginning to occur at the Net River Impoundment. KBIC continues to seed 97 acres across both lakes with nearly 2,000 pounds of Manoomin each year.

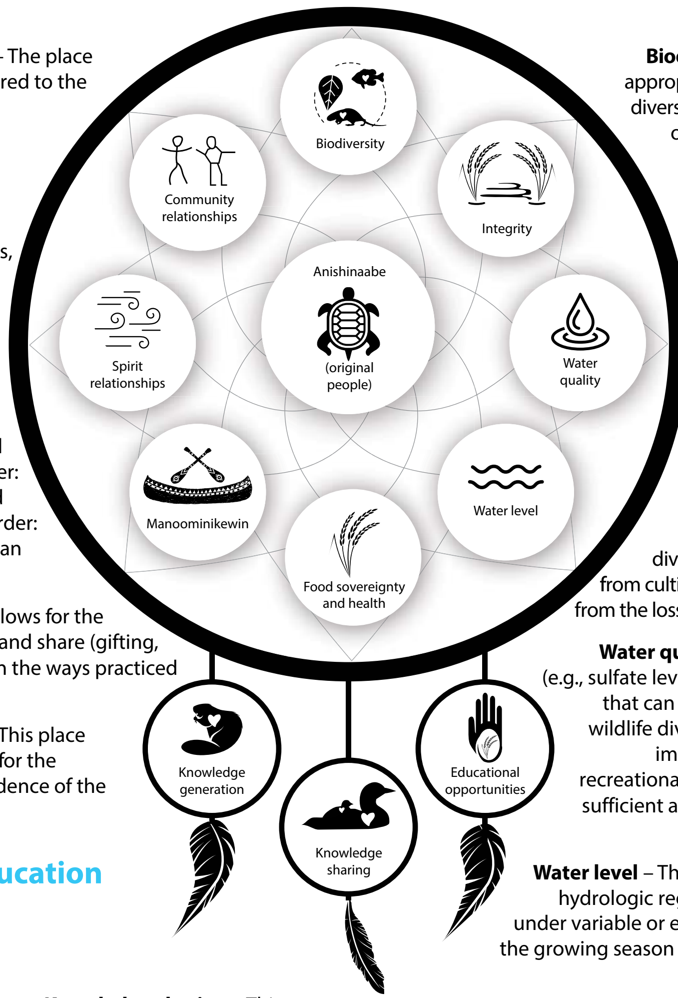
The ultimate goal of seeding efforts at the Net River Impoundment is to produce a Manoomin seed source for Vermillac Lake and other KBIC restoration sites. In keeping with the principles of the honorable harvest, KBIC aims to achieve conditions that will allow the rice to reseed itself to feed wildlife and nourish the people.

Survey point. Credit: KBIC NRD.

Rice stand. Credit: KBIC NRD.

Approach to characterizing Manoomin at Net River Impoundment and Vermillac Lake

Twelve metrics characterize the cultural and ecological functions of the Net River Impoundment's and Vermillac Lake's Manoomin and associated habitats. These metrics describe how Manoomin at these areas contributes to maintaining connections with the Anishinaabe culture, how ecological functionality is supported and resilient to changing conditions, and how continued learning and sharing of Anishinaabe values are promoted.



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Ecological Metrics

Biodiversity – Healthy Manoomin and appropriate habitat at this place supports diverse biological communities (e.g., free of invasive species) that indicate the capacity of the place to support abundant associated plant and animal species (e.g., other native aquatic vegetation, fish, waterfowl, muskrat), providing for spiritual and subsistence needs.

Integrity – Physical habitat and hydrology, and water and sediment chemistry support stands of Manoomin that exhibit natural annual variability; viable seed bank ensures that sustainable Manoomin populations will persist even after occasional poor production years. Natural genetic diversity is maintained without impact from cultivated strains, or reduced gene flow from the loss of nearby Manoomin populations.

Water quality – This place has clean water (e.g., sulfate levels below 10 ppm) and sediments that can support robust stand density and wildlife diversity; is free of contamination or impacts from industrial, agricultural, recreational, or residential influence; and is of sufficient areal extent to sustain a Manoomin population.

Water level – This place has a natural or managed hydrologic regime that can maximize resilience under variable or extreme climatic conditions across the growing season (maintaining optimal depth range and flow).

Cultural and Ecological Education Metrics

Knowledge generation – This place allows for continued learning and generation of the Anishinaabe practices, values, beliefs, and language through experience.

Knowledge sharing – This place allows for the continued sharing and transmittal of the Anishinaabe practices, values, beliefs, and language among family members and community.

Educational opportunities – This place provides opportunities for language, land stewardship, and other educational programs, such as educational rice camps.

Cultural and ecological characterization at Net River Impoundment and Vermillac Lake

Manoomin and its associated habitat at the Net River Impoundment and Vermillac Lake were characterized over two time periods. Each metric was ranked using the following five-point descriptive scale:

No use · Very bad · Not very good · Pretty good · Doing great

This characterization begins after the Net River was impounded as a wetland mitigation bank in 1990.

1990 to 2013: Before Manoomin seeding

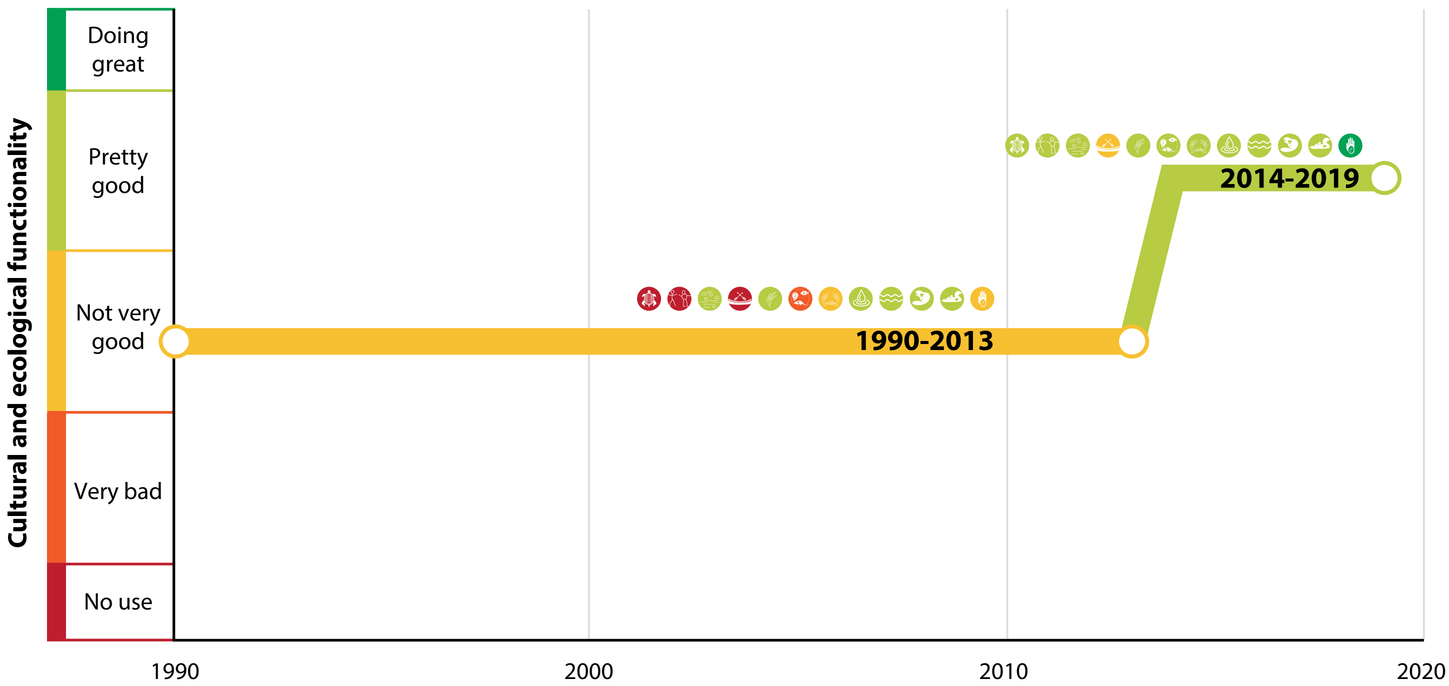
Based on the combined ranking of cultural and ecological metrics, conditions at the Net River Impoundment and Vermillac Lake were characterized as "not very good" during this period. This ranking reflects the absence of Manoomin from the Net River Impoundment and Vermillac Lake before 2013. Although Manoomin was absent, these areas were culturally and ecological important. Community members used these sites for gathering, fishing, and hunting activities; during these activities, families passed down knowledge to their children or grandchildren about traditional practices and resources. Given the intrinsic cultural and ecological value of these places, some metrics – including spirit relationships, food sovereignty, knowledge generation and sharing, and water level and quality – ranked higher in cultural and ecological characterization.

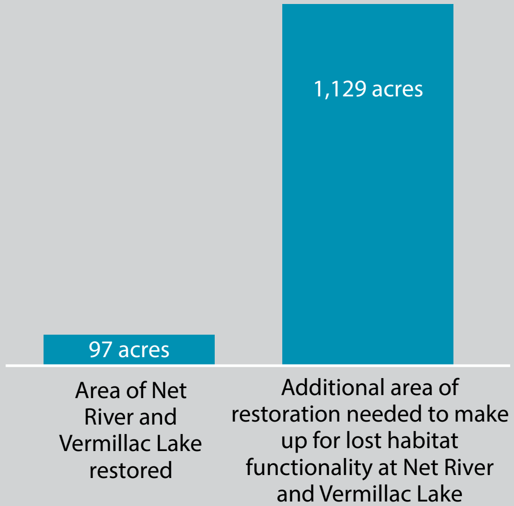
2014 to 2019: After Manoomin seeding

Once KBIC began seeding the Net River Impoundment and Vermillac Lake, Manoomin grew at these places. Currently, Manoomin supports wildlife and other ecosystem functions. These places have the potential for Manoomin harvesting in the future, although they cannot yet support it. The presence of Manoomin significantly improved the ranking of most of the cultural and ecological metrics. During this period, conditions at the Net River Impoundment and Vermillac Lake ranked as "pretty good" based on cultural and ecological metrics. Although Manoomin provides cultural and ecological functionality, additional management of water levels at the Net River Impoundment could continue to improve the abundance of Manoomin and the long-term sustainability of healthy Manoomin beds.

Cultural and ecological characterization at Net River Impoundment and Vermillac Lake

Cultural and ecological functionality provided by Manoomin and its associated habitat at the Net River Impoundment and Vermillac Lake have increased over time, both in aggregate and for the individual metrics.





Additional restoration needed

Based on the characterization of the degree of cultural and ecological function over the two time periods, a Habitat Equivalency Analysis can demonstrate the additional equivalent units of restoration needed to counter-balance the severity and timespan of degradation. With seeding, resource managers successfully established Manoomin across the Net River Impoundment and Vermillac Lake. However, given that the period of degradation is much larger (over 20 years) than the period of restoration (around 5 years), an additional 1,129 acres of similar Manoomin restoration is needed to counter-balance the lost habitat functionality that has occurred over time. In other words, nearly 12 equivalent restoration efforts at the Net River Impoundment and Vermillac Lake (from 2014 to 2019) are needed to counter-balance the lost cultural and ecological habitat functionality (from 1990 to 2013).

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About this effort

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Acknowledgments

The Project Team would like to acknowledge Evelyn Ravindran, Karena Schmidt, and Erin Johnston (KBIC) for their valuable input and feedback in the development of this case study; and for participating in the cultural and ecological characterization of KBIC's Net River Impoundment and Vermillac Lake.

Introduction of Manoomin at Hiles Millpond provides cultural and ecological functionality

With favorable conditions, restoration can enhance Manoomin habitat

Establishing Manoomin (wild rice) at Hiles Millpond significantly enhances its cultural and ecological functionality. It also helps to make up for the loss of Manoomin on other waters throughout the region. Although recent restoration efforts have shown preliminary success, Manoomin has been absent from Hiles Millpond for a long time. Therefore, additional restoration could help counter-balance lost cultural and ecological functionality. Based on the methods applied in this study, 864 additional acres of similar Manoomin restoration would counter-balance the lost cultural and ecological functionality that have occurred over time. This is equivalent in scale to nearly three times the current restoration efforts at Hiles Millpond. The successful introduction of Manoomin at Hiles Millpond suggests that naturally suitable soils, combined with seeding and modifications in water-level management, can yield high-quality Manoomin and habitat.

Threats to Manoomin at Hiles Millpond

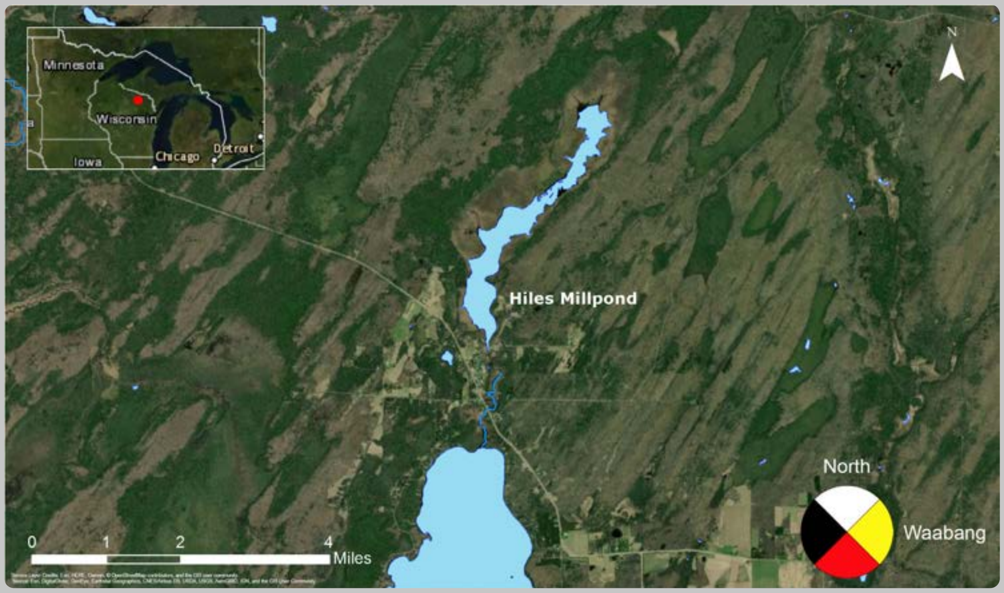
Water became ponded at Hiles Millpond in the late 1880s when the Hiles Lumber Company built a dam for logging purposes. Although there is no record of the presence of Manoomin at Hiles Millpond, it may have been there prior to dam construction since Manoomin is in nearby waters. If Manoomin was present at Hiles Millpond historically, it could have been negatively affected by changes in water levels associated with construction of the dam.

The area and waters around the Town of Hiles were traditionally used by the Lac du Flambeau Band of Lake Superior Chippewa Indians (LDF Band), the Sokaogon Chippewa Community, and other Ojibwe Bands and their ancestors. However, use of the area by Bands for hunting, gathering, fishing, and trapping was limited during much of the last century up until the 1980s. Use of this area increased after this time when relations with the local community in the Town of Hiles improved.

About Hiles Millpond

Hiles Millpond is an approximately 300-acre lake located in Forest County, Wisconsin, an 1842 Ceded Territory.

The millpond provides excellent wildlife habitat, especially for waterfowl, furbearers, eagles, and other wetland-dependent species. The lake also supports a northern pike and panfish fishery.



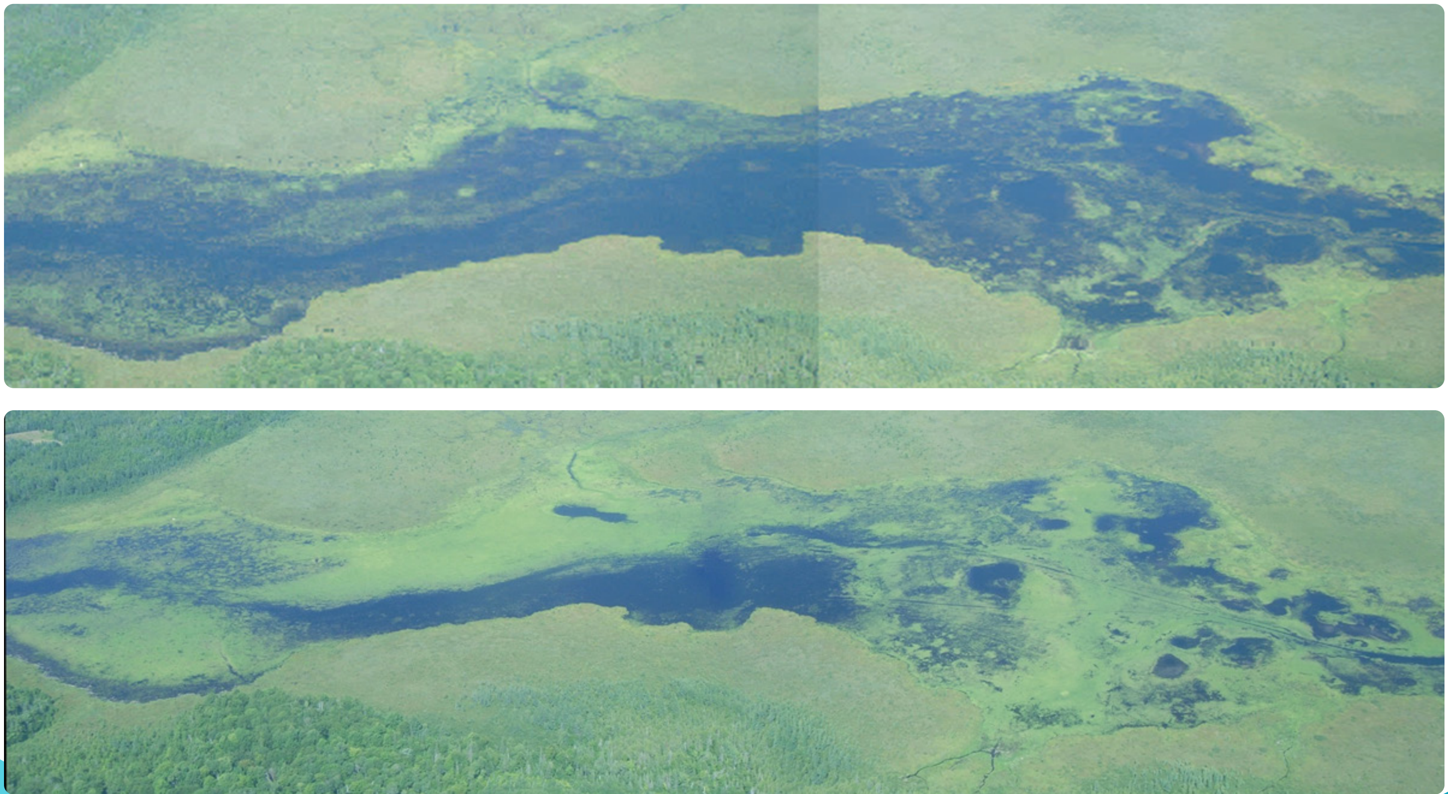
Actions taken to improve the abundance of Manoomin at the Hiles Millpond

In 1992, safety inspections found several problems with the dam structure at Hiles Millpond. To meet contemporary safety standards, the Town of Hiles needed to replace the dam structure. Since the town lacked adequate funds, federal, state, tribal, and nongovernmental organizations entered into a cooperative effort. A Memorandum of Understanding included a provision for the town to cooperate with the Forest Service to manage the millpond for productive wildlife and fish habitats, including possible manipulation of water levels, following completion of the project. The dam and water control structure were rebuilt in fall 1993.

Shortly after, biologists realized that the ecological benefits of Hiles Millpond could be significantly enhanced by establishing Manoomin on the millpond. Establishing Manoomin could also help to make up for the loss of Manoomin on other waters in the region, many of which were difficult or impossible to recover due to excessive development, conflicting uses, or other threats to Manoomin (Peter David, GLIFWC, personal communication, November 27, 2019).

In 1998, GLIFWC and the Forest Service cooperatively seeded the Hiles Millpond flowage with a relatively modest amount of Manoomin (329 pounds). Small patches of Manoomin then expanded modestly over the next several years. In 2011, Manoomin expanded significantly under natural drought conditions, which led biologists to believe that Manoomin might increase if the typical summer water level was lowered slightly.

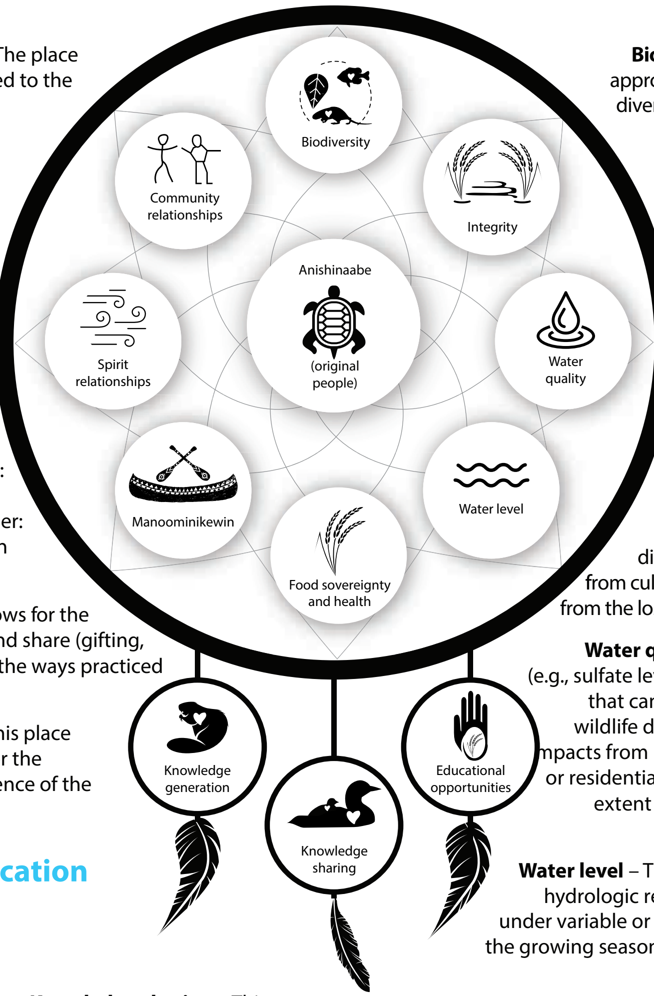
Although the Town of Hiles was initially concerned that lower water levels might negatively affect the northern pike fishery, it ultimately agreed to manage the water level for Manoomin. Once lowered, Manoomin showed an immediate response. Manoomin abundance increased significantly from 2013, before water levels were lowered, to 2014, following a lowering of water levels. In recent years, over 125 acres of Manoomin can be found growing across the lake (Peter David, GLIFWC, personal communication, November 27, 2019).



Manoomin abundance on a portion of the Hiles Millpond, 2013 above, and 2014 below, following a lowering of water levels. Credit: Peter David, GLIFWC

Approach to characterizing Manoomin at Hiles Millpond

Twelve metrics characterize the cultural and ecological functions of Hiles Millpond Manoomin and its associated habitat. These metrics describe how Manoomin at Hiles Millpond contributes to maintaining connections with the Anishinaabe culture, how ecological functionality is supported and resilient to changing conditions, and how continued learning and sharing of Anishinaabe values are promoted.



Cultural Metrics

Anishinaabe (original people) – The place provides Manoomin, which is sacred to the Anishinaabe and central to the foundations of their culture, sovereignty, and treaty rights.

Community relationships – Manoomin at this place contributes to bonding, traditions, and strengthening family and community connections.

Spirit relationships – Manoomin at this place enables the Anishinaabe to maintain connections and balance with spirit beings (or relatives) from all other orders of creation (first order: rock, water, fire and wind; second order: other plant beings; third order: animal beings; fourth order: human beings).

Manoominikewin – This place allows for the Anishinaabe to harvest, prepare, and share (gifting, healing, and eating) Manoomin in the ways practiced by their ancestors for centuries.

Food sovereignty and health – This place provides the capacity to provide for the sustenance, health, and independence of the Anishinaabe.

Ecological Metrics

Biodiversity – Healthy Manoomin and appropriate habitat at this place supports diverse biological communities (e.g., free of invasive species) that indicate the capacity of the place to support abundant associated plant and animal species (e.g., other native aquatic vegetation, fish, waterfowl, muskrat), providing for spiritual and subsistence needs.

Integrity – Physical habitat and hydrology, and water and sediment chemistry support stands of Manoomin that exhibit natural annual variability; viable seed bank ensures that sustainable Manoomin populations will persist even after occasional poor production years. Natural genetic diversity is maintained without impact from cultivated strains, or reduced gene flow from the loss of nearby Manoomin populations.

Water quality – This place has clean water (e.g., sulfate levels below 10 ppm) and sediments that can support robust stand density and wildlife diversity; is free of contamination or impacts from industrial, agricultural, recreational, or residential influence; and is of sufficient areal extent to sustain a Manoomin population.

Water level – This place has a natural or managed hydrologic regime that can maximize resilience under variable or extreme climatic conditions across the growing season (maintaining optimal depth range and flow).

Cultural and Ecological Education Metrics

Knowledge generation – This place allows for continued learning and generation of the Anishinaabe practices, values, beliefs, and language through experience.

Knowledge sharing – This place allows for the continued sharing and transmittal of the Anishinaabe practices, values, beliefs, and language among family members and community.

Educational opportunities – This place provides opportunities for language, land stewardship, and other educational programs, such as educational rice camps.

Cultural and ecological characterization at Hiles Millpond

Manoomin and its associated habitat at Hiles Millpond were characterized over three time periods. Each metric was ranked using the following five-point descriptive scale: No use, Very bad, Not very good, Pretty good, Doing great

The characterization starts in 1980 because prior to that time community members were less likely to travel to Hiles Millpond to harvest Manoomin, and undertake other traditional hunting and gathering practices.

1980 to 1997: Before Manoomin seeding

Based on the combined ranking of cultural and ecological metrics, Hiles Millpond was characterized as "very bad" during this period. Because of the absence of Manoomin in the millpond, most of the metrics – particularly cultural metrics – ranked low on the score range.

1998 to 2013: After Manoomin seeding

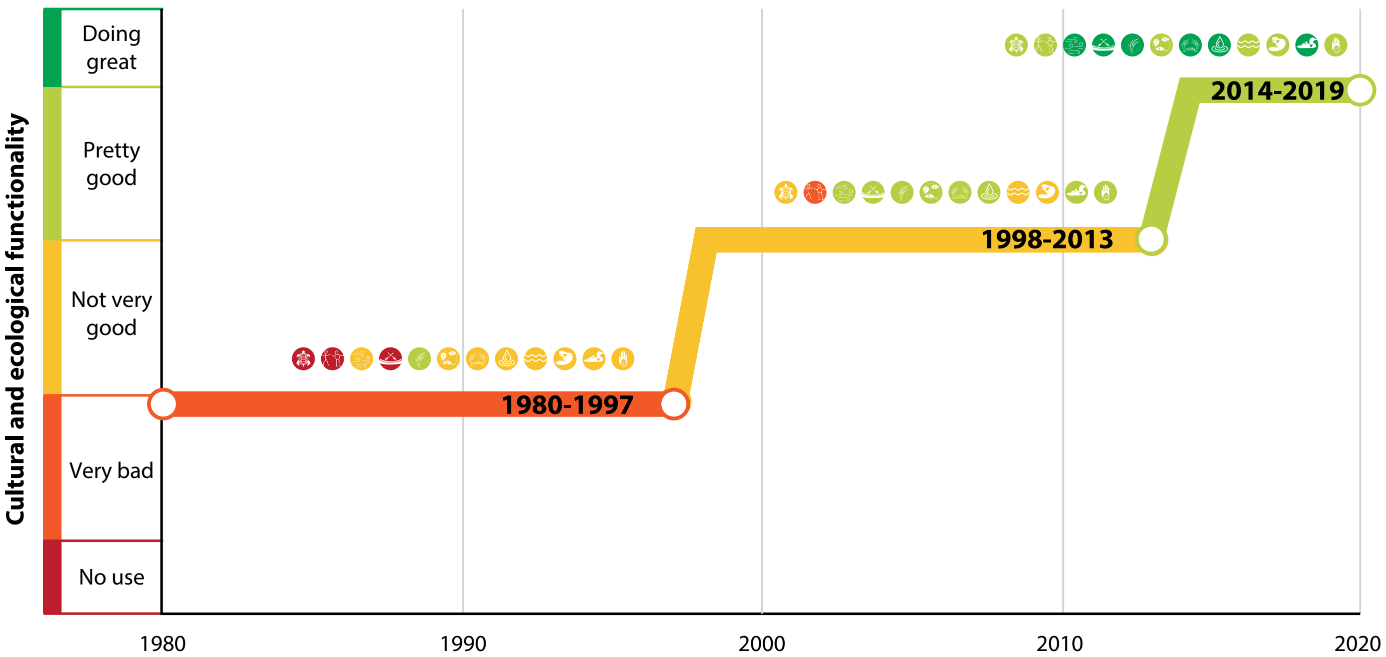
Once seeding activities began in 1998, Manoomin began to grow at the Millpond. The presence of Manoomin improved the rankings for most of the cultural and ecological metrics. In particular, the presence of Manoomin at Hiles Millpond allowed for some harvesting, preparation, and sharing of Manoomin by the community. It also improved the Anishinabee's connections and balance with spirit beings and relatives, and it supported diverse biological communities. During this period, Hiles Millpond ranked as "not very good" based on the combined ranking of the cultural and ecological metrics.

2014 to 2019: With water level management

After resource managers adjusted water levels for Manoomin in 2014, its coverage continued to expand. More Manoomin allowed for harvesting, preparation, and sharing of Manoomin in ways practiced by ancestors. It also allowed for knowledge generation and sharing of Anishinaabe practices, values, beliefs, and language. Although Manoomin provides many cultural and ecological functionality, additional management of water levels could continue to improve Manoomin and its associated habitat at Hiles Millpond. During this period, Hiles Millpond ranked as "pretty good" based on the combined ranking of cultural and ecological metrics.

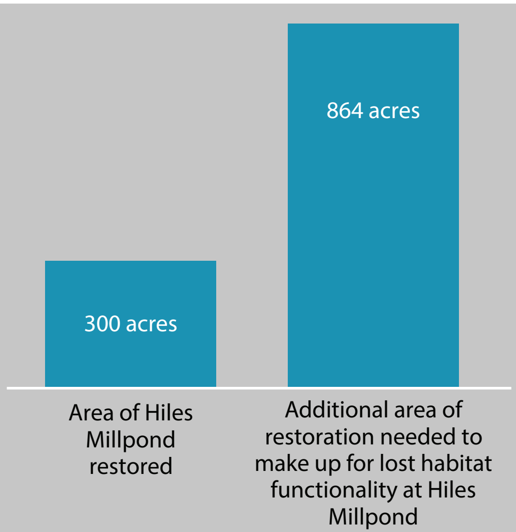
Cultural and ecological characterization at Hiles Millpond

Cultural and ecological functionality provided by Manoomin and its associated habitat at Hiles Millpond have increased over time, both in aggregate and for individual metrics.



Additional restoration needed

Based on the characterization of the degree of cultural and ecological function over the three time periods, a Habitat Equivalency Analysis demonstrates the additional equivalent units of restoration needed to counter-balance the severity and timespan of degradation. With modest seeding and slight modifications in water-level management, resource managers successfully established Manoomin across the Hiles Millpond. The analysis indicates that an additional 864 acres of similar Manoomin restoration is needed to counter-balance the lost habitat functionality that has occurred over time. In other words, nearly three equivalent restoration efforts at Hiles Millpond (from 1998 to 2019) are needed to counter-balance the lost cultural and ecological habitat functionality (from 1980 to 1997).



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Acknowledgments

The Project Team would like to acknowledge Peter David (GLIFWC), Eric Chapman and Joe Graveen (LDF Band), and Peter McGeshick (Sokaogon Chippewa Community) for their valuable input and feedback in the development of this case study, and for participating in the cultural and ecological characterization of the Hiles Millpond.

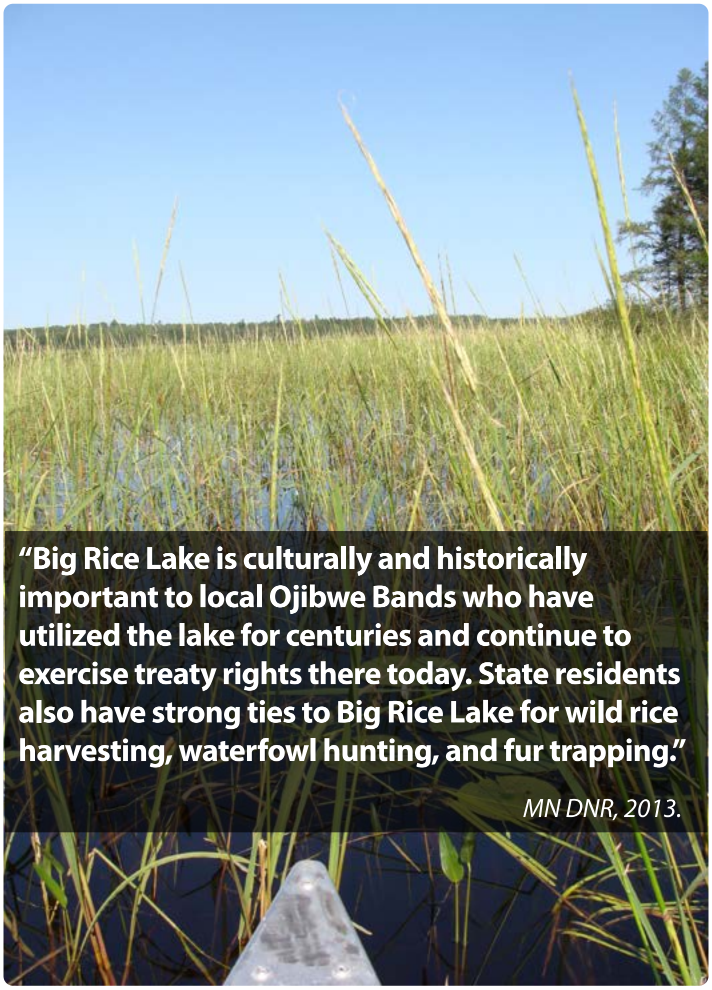
Efforts to manage Big Rice Lake have not improved Manoomin functionality

Manoomin continues to be affected by hydrologic conditions and other threats

Historically, Big Rice Lake was one of the best-producing Manoomin (wild rice) lakes in northeastern Minnesota, and Manoomin on this lake provided cultural, ecological, and educational services to the Anishinaabe people. Over the last two decades, natural resource managers actively managed Big Rice Lake to improve conditions of Manoomin and its associated habitat. However, their actions – including water management, vegetation control, and beaver control – have been largely ineffective in recent years and Manoomin abundance continues to remain low. Manoomin and its habitat at Big Rice Lake have declined across all cultural and ecological metrics, and ginoozhegoons (pickerelweed) continues to outcompete Manoomin in parts of the lake. This case study highlights the difficulties in restoring degraded Manoomin and its associated habitat, and the importance of protecting it.

Threats to Manoomin at Big Rice Lake

Hydrologic changes, impacts from competing vegetation, and perhaps climate change have threatened Manoomin at Big Rice Lake. Manoomin is very sensitive to changes in water levels. Low or stable water conditions over long periods can encourage the proliferation of other vegetation, such as ginoozhegoons (pickerelweed), which can outcompete Manoomin for space and resources. Ginoozhegoons has expanded considerably on Big Rice Lake, especially on the eastern half of the lake. In addition to the artificial controls on water levels, climate change could change precipitation patterns, which may increase both the likelihood of drought and the frequency of heavy rain events that can cause high water levels and flooding in Big Rice Lake.



"Big Rice Lake is culturally and historically important to local Ojibwe Bands who have utilized the lake for centuries and continue to exercise treaty rights there today. State residents also have strong ties to Big Rice Lake for wild rice harvesting, waterfowl hunting, and fur trapping."

MN DNR, 2013.

Credit: 1854 Treaty Authority.

About Big Rice Lake

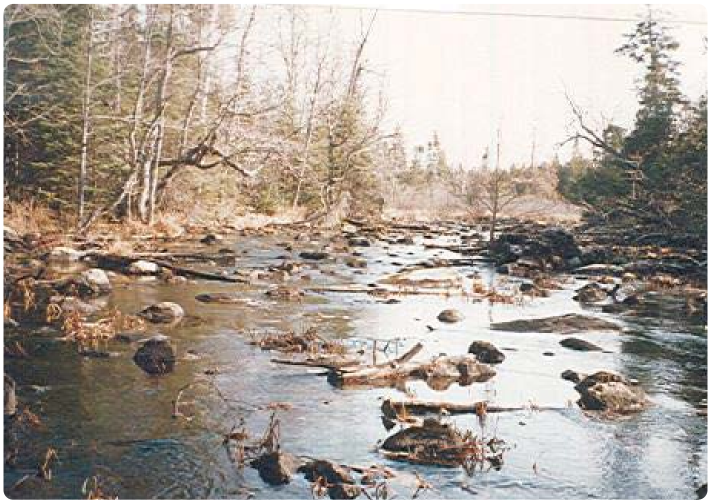
Big Rice Lake, located in St. Louis County in northeastern Minnesota, is approximately 1,870 acres. The area was traditionally used for ricing, sugar bush, and hunting activities; and archaeological evidence indicates human use on sites surrounding the lake for hundreds – perhaps thousands – of years.

The lake is an important feeding and resting area for migrating waterfowl. In years of good Manoomin production, mallards, goldeneyes, wood ducks, blue winged teal, and ring-necked ducks use the lake. In 1992, Big Rice Lake became a Designated Wildlife Lake because of its "outstanding value to wildlife." Currently, the lake supports a bald eagle nesting territory, as well as muskrats, minks, beaver, otter, great blue herons, and trumpeter swans.

Actions taken to improve the abundance of Manoomin at Big Rice Lake

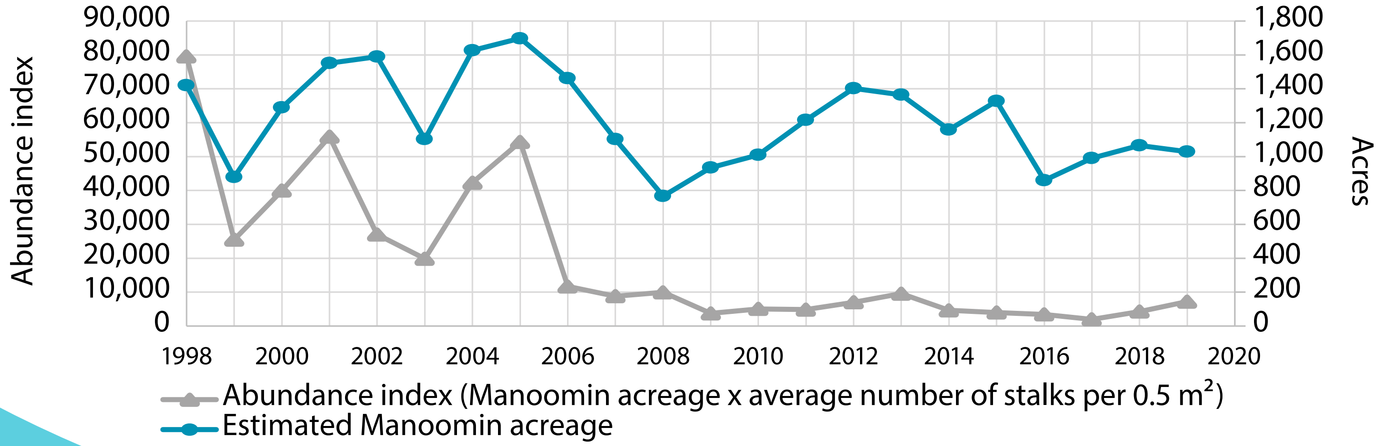
Natural resource managers have taken several actions to increase Manoomin at Big Rice Lake. In 1995, federal and state agencies built a rock weir at the outlet of the lake to increase the water flow out of the lake and reduce rapid water-level changes that can negatively impact Manoomin growth (MN DNR, 2013). Initially, the installation of the rock weir seemed to improve Manoomin coverage at Big Rice Lake; however, despite adjustments to the weir and varied beaver management, the more stable water level appears to have favored ginoozhegoons over Manoomin.

Since 2006, a cooperative effort of several federal, state, and tribal partners has taken additional management activities to further support Manoomin (Vogt, 2020). In addition to allowing water levels to vary naturally, natural resource managers are cutting ginoozhegoons. Natural resource managers use an airboat with chains to disturb the substrate of Big Rice Lake to encourage the germination of Manoomin seed in several test plots (Vogt, 2020). These efforts control about 100 acres of ginoozhegoons each year, but Manoomin regrowth in cut areas has been minimal (Vogt, 2020). Over the years, partners have also trapped beavers and removed beaver dams to control water levels.



Natural rock rapids at the outlet of Big Rice Lake in 1992.
Credit: MN DNR, 2019.

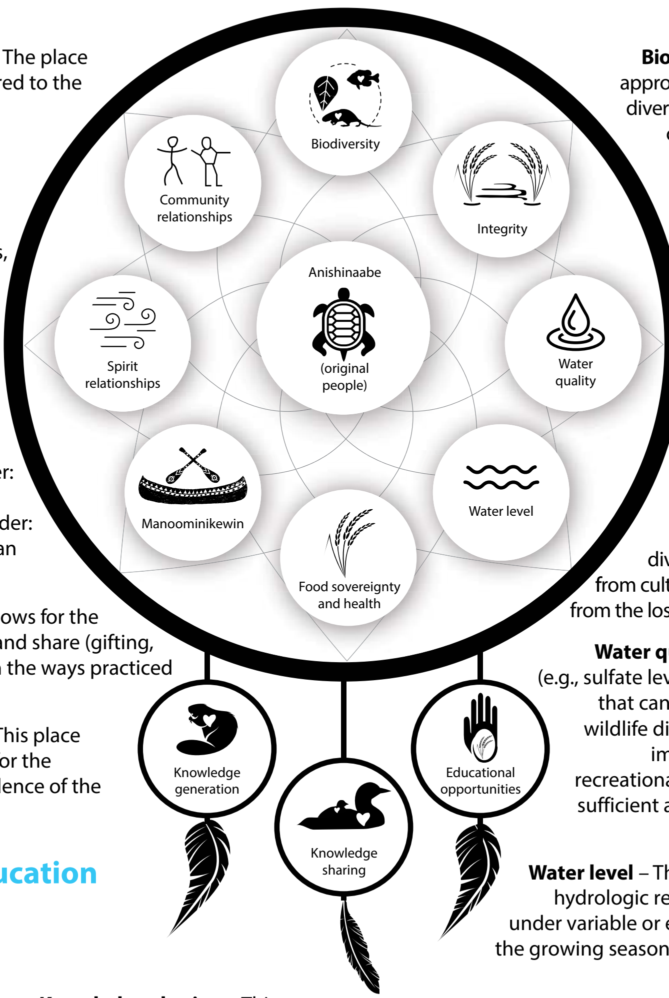
Rock weir at the outlet of Big Rice Lake in 2016.
Credit: MN DNR, 2019.



Manoomin abundance index and acres on Big Rice Lake.

Approach to characterizing Manoomin at Big Rice Lake

Twelve metrics characterize the cultural and ecological functions of Big Rice Lake's Manoomin and its associated habitat. These metrics describe how Manoomin at Big Rice Lake contributes to maintaining connections with the Anishinaabe culture, how ecological functionality is supported and resilient to changing conditions, and how continued learning and sharing of Anishinaabe values are promoted.



Cultural Metrics

Anishinaabe (original people) – The place provides Manoomin, which is sacred to the Anishinaabe and central to the foundations of their culture, sovereignty, and treaty rights.

Community relationships – Manoomin at this place contributes to bonding, traditions, and strengthening family and community connections.

Spirit relationships – Manoomin at this place enables the Anishinaabe to maintain connections and balance with spirit beings (or relatives) from all other orders of creation (first order: rock, water, fire and wind; second order: other plant beings; third order: animal beings; fourth order: human beings).

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Food sovereignty and health – This place provides the capacity to provide for the sustenance, health, and independence of the Anishinaabe.

Ecological Metrics

Biodiversity – Healthy Manoomin and appropriate habitat at this place supports diverse biological communities (e.g., free of invasive species) that indicate the capacity of the place to support abundant associated plant and animal species (e.g., other native aquatic vegetation, fish, waterfowl, muskrat), providing for spiritual and subsistence needs.

Integrity – Physical habitat and hydrology, and water and sediment chemistry support stands of Manoomin that exhibit natural annual variability; viable seed bank ensures that sustainable Manoomin populations will persist even after occasional poor production years. Natural genetic diversity is maintained without impact from cultivated strains, or reduced gene flow from the loss of nearby Manoomin populations.

Water quality – This place has clean water (e.g., sulfate levels below 10 ppm) and sediments that can support robust stand density and wildlife diversity; is free of contamination or impacts from industrial, agricultural, recreational, or residential influence; and is of sufficient areal extent to sustain a Manoomin population.

Water level – This place has a natural or managed hydrologic regime that can maximize resilience under variable or extreme climatic conditions across the growing season (maintaining optimal depth range and flow).

Cultural and Ecological Education Metrics

Knowledge generation – This place allows for continued learning and generation of the Anishinaabe practices, values, beliefs, and language through experience.

Knowledge sharing – This place allows for the continued sharing and transmittal of the Anishinaabe practices, values, beliefs, and language among family members and community.

Educational opportunities – This place provides opportunities for language, land stewardship, and other educational programs, such as educational rice camps.

Cultural and ecological characterization at Big Rice Lake

Big Rice Lake's Manoomin and its associated habitat were characterized over three time periods. Each metric was ranked using the following five-point descriptive scale: No use, Very bad, Not very good, Pretty good, Doing great

1900 to 1994: Before rock weir construction

Based on the combined ranking of the cultural and ecological metrics, Big Rice Lake was characterized as "pretty good." During this period, Big Rice Lake was dominated by Manoomin with variable production across years, which provided high-quality waterfowl and wildlife habitats, and the opportunity for harvesting. The lake was culturally and historically important to Ojibwe Bands who used the lake during this period and exercised their treaty rights.

1995 to 2005: After rock weir construction

Immediately after the installation of the rock weir in 1995, Manoomin coverage at Big Rice Lake improved in some years. However, over time the more stable water level favored ginoozhegoons over Manoomin, and Manoomin began to decline, although it remained at the "pretty good" ranking score based on the combined ranking of cultural and ecological metrics.

Credit: 1854 Treaty Authority.

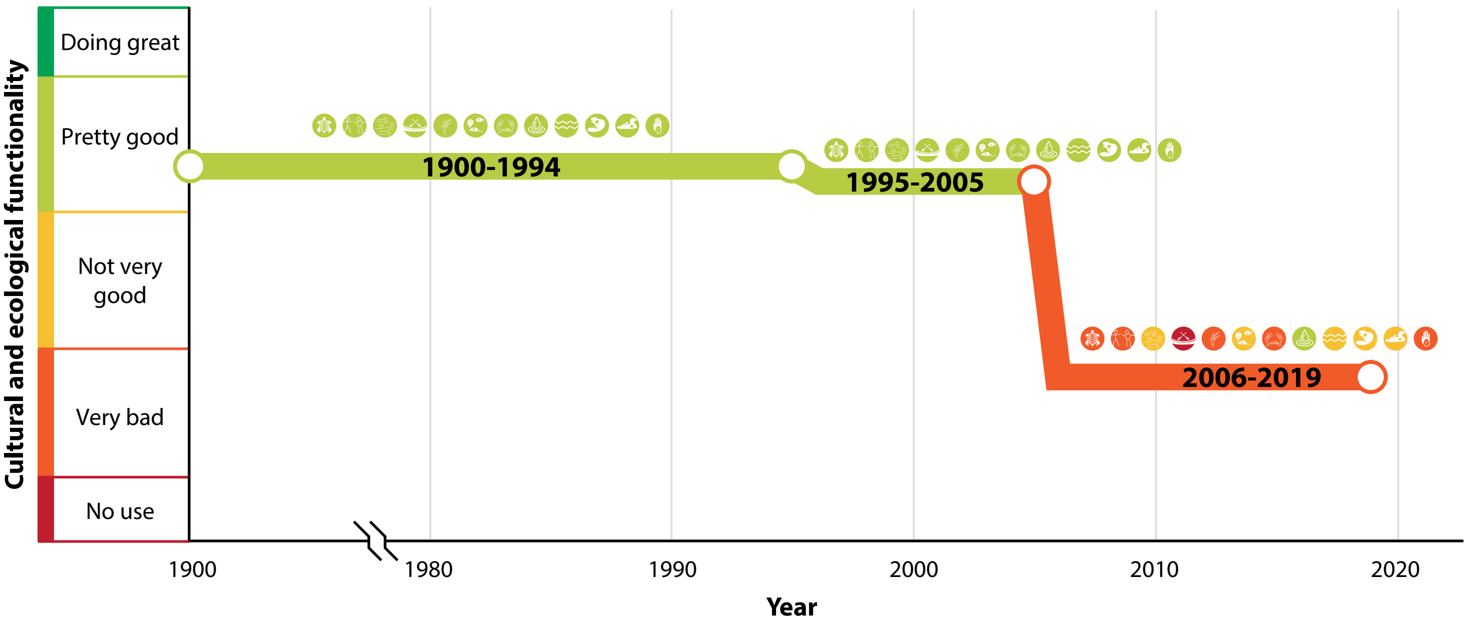
2006 to 2019: With active management of Manoomin

By 2006, Big Rice Lake ranked as "very bad" based on the combined ranking of cultural and ecological metrics. Hydrologic changes, competition from ginoozhegoons, and perhaps other unknown factors led to the dramatic decline of Manoomin. From 2006 to 2019, natural resource managers took active management steps to recover Manoomin at Big Rice Lake; however, it remained sparse in coverage, with only a few small, moderate-to-good density stands found on the lake. As a result, community members were unable to harvest, prepare, and share Manoomin in ways practiced by their ancestors. This also limited sharing, transmittal, and generation of Anishinaabe practices. The decline in Manoomin has also negatively affected migratory waterfowl that use the lake.

Credit: 1854 Treaty Authority.

Cultural and ecological characterization of Big Rice Lake

Cultural and ecological services provided by Manoomin and its associated habitat at Big Rice Lake decreased over time, both in total and for individual metrics.



Additional restoration needed

Since the 1990s, natural resource managers have tried to improve the conditions of Manoomin and its associated habitat at Big Rice Lake; however, recent actions have not been successful and conditions continue to be diminished.

Restoration funds have recently been awarded to undertake further actions at the lake (Helmberger, 2019). If these actions were to improve functionality, we could use a Habitat Equivalency Analysis (HEA) to demonstrate the additional equivalent units of restoration that would be needed to counter-balance the severity and timespan of degradation. For example, if actions were implemented over the next 20 years (2020 to 2040) to improve habitat functionality by 2.5%, we would need over 400,000 acres of similar Manoomin restoration to counter-balance the lost habitat functionality that has occurred over time (from 1995 to 2019). This is equivalent in size to over 200 Big Rice Lakes. The table to the right provides the HEA results, assuming several hypothetical scenarios of improvements in habitat functionality; it is important to note that we do not know what actions are needed to create these percent improvements. The main purpose of these scenarios is to highlight that if only minimal restoration is achieved at Big Rice Lake (which may be anticipated, given the long history of attempting restoration, with minimal response), then significant equivalent amounts of this restoration would be needed to balance the prolonged period of degradation at this lake.

Hypothetical percentage of improvement in habitat functionality from 2020 to 2040	Acres needed to counter-balance historical losses given hypothetical improvement *(Acres rounded to the nearest hundred)*	Number of Big Rice Lakes needed to counter-balance historical losses given hypothetical improvement
2.5%	426,100	228
5.0%	213,100	114
10.0%	106,500	57
20.0%	53,300	29

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Acknowledgments

The Project Team would like to acknowledge Darren Vogt (1854 Treaty Authority) and Nancy Schuldt (Fond du Lac Band of Lake Superior Chippewa) for their valuable input and feedback in the development of this case study. In addition, the Project Team would like to thank Thomas Howes (Fond du Lac Band of Lake Superior Chippewa), Tara Geshick (Bois Forte Band of Lake Superior Chippewa), Daniel Ryan (U.S. Forest Service), and Melissa Thompson and Tom Rusch (Minnesota Department of Natural Resources) for participating in the cultural and ecological characterization of Big Rice Lake.

Low ecological and cultural functionality characterized at the Twin Lakes

Manoomin is unable to rebound due to ongoing sulfate loading from mine discharges

Historically, Sandy Lake and Little Sandy Lake, also known as the Twin Lakes, were important ricing sites for Ojibwe Bands in northeastern Minnesota. Manoomin (wild rice) on these lakes provided cultural and ecological services to the Anishinaabe people. Since U.S. Steel constructed a tailings basin for their Minntac iron ore operation in the mid-1960s, Manoomin has declined drastically in these lakes, with only remnant plants and no stands existing today. While some restoration actions – including beaver dam management and small-scale Manoomin reseeding – have been attempted, they have not addressed the fundamental problem of sulfate discharge from the mine. A seepage collection system, constructed to collect mine waste water discharging from the tailings basin, has not fully stopped the flow of sulfate into the lakes. This case study highlights the difficulties in restoring degraded Manoomin habitat, the relationship between water pollution and Manoomin, and the importance of protecting existing Manoomin and its associated habitat.

Threats to Manoomin at the Twin Lakes

U.S. Steel's Minntac iron ore operation facility includes two mining areas, several processing plants, a heating and utility plant, a water reservoir, and a tailings basin (MWH, 2004). Construction of the tailings basin began in 1966 (MWH, 2004). Part of the seepage from the tailings basin discharges to the east into the Sand River, flows into the Twin Lakes, and into the Sand River watershed. Discharge from the tailings basin has changed the chemical composition and hydrologic condition of the Twin Lakes by increasing sulfate levels and, to a lesser extent, increasing the volume of water in the lakes.

Water seeping out of the Minntac tailings basin and moving toward the Twin Lakes in Minnesota. Credit: GLIFWC, 2016.

About the Twin Lakes

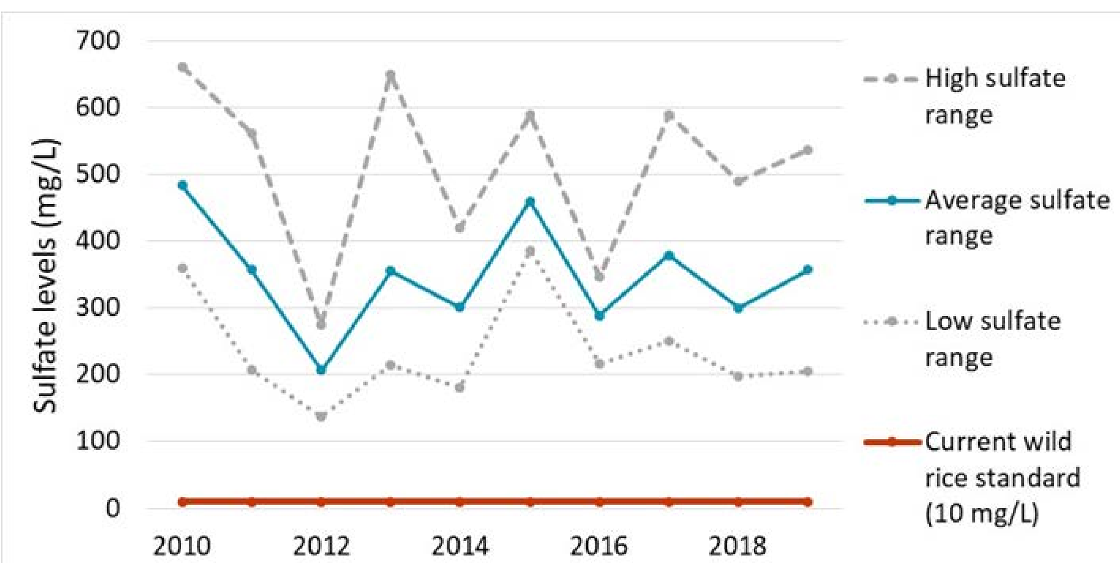
The Twin Lakes are located in St. Louis County in northeastern Minnesota. Sandy Lake is approximately 120 acres and Little Sandy Lake is approximately 90 acres. The Twin Lakes are located immediately downstream of the tailings basin for U.S. Steel's Minntac iron ore operation. Prior to mining operations, the Twin Lakes produced good stands of Manoomin and were important ricing sites for Ojibwe Bands and vital habitat for a range of wildlife species.

Ongoing sulfate loading renders restoration ineffective at the Twin Lakes

The Twin Lakes are severely degraded by sulfate-laden mine waste from U.S. Steel's tailings basin. Because sulfate concentrations are high, any attempts to restore Manoomin stands that do not address this fundamental issue have proven largely ineffective. For example, multiple attempts by natural resource managers to adjust water levels through beaver management (in the 1970s to 1990s and 2015 to 2018) have not improved Manoomin stands in a measurable way. Modest reseeding efforts (in 1991 and 1992) have also not been effective. Restoration efforts are not successful because sulfate levels at the Twin Lakes are at least 10 times higher than the Manoomin sulfate standard; the current sulfate standard is 10 mg/L (see graph below; Tribal Wild Rice Task Force, 2018).

In 2010, U.S. Steel was required to construct a seepage collection system to collect some of the mine wastewater discharging at the base of the tailings basin. While this reduced the total volume of water discharging from the mine site, it did not fully stop it. As a result, mine waste high in sulfate continued to contaminate the Twin Lakes after the collection system was installed. The 1854 Treaty Authority monitored lake conditions before the installation of the seepage collection system (2010) and after (2011 to 2019). Data collected included information on water quality (sulfate and other water quality indicators) and water-depth recordings; as well as data from inlet and outlet field surveys, vegetation surveys, and aerial surveys (Vogt, 2020). Results showed that sulfate levels remained elevated well above the standard over the nine years of monitoring after the installation of the seepage system, and remained substantially unchanged from conditions prior to the installation (see graph below).

During the monitoring study, very limited Manoomin stalks were also observed across the Twin Lakes. In 2015, U.S. Steel planted test plots to determine if Manoomin had the potential to grow in the Twin Lakes. In this small-scale test plot, U.S. Steel reseeded with 40 pounds of Manoomin. After seeding, Manoomin success has varied but has been limited across years (Vogt, 2020). Full-scale reseeding was not attempted.



Sulfate concentrations at the inlet to the Twin Lakes compared to current standard sulfate levels (10 mg/L) for Manoomin, 2010 to 2019.

Approach to characterizing Manoomin at the Twin Lakes

Twelve metrics characterize cultural and ecological functions of the Twin Lakes' Manoomin and its associated habitat. These metrics describe how Manoomin at the Twin Lakes contributes to maintaining connections with the Anishinaabe culture, how ecological functionality is supported and resilient to changing conditions, and how continued learning and sharing of Anishinaabe values are promoted.

Cultural Metrics

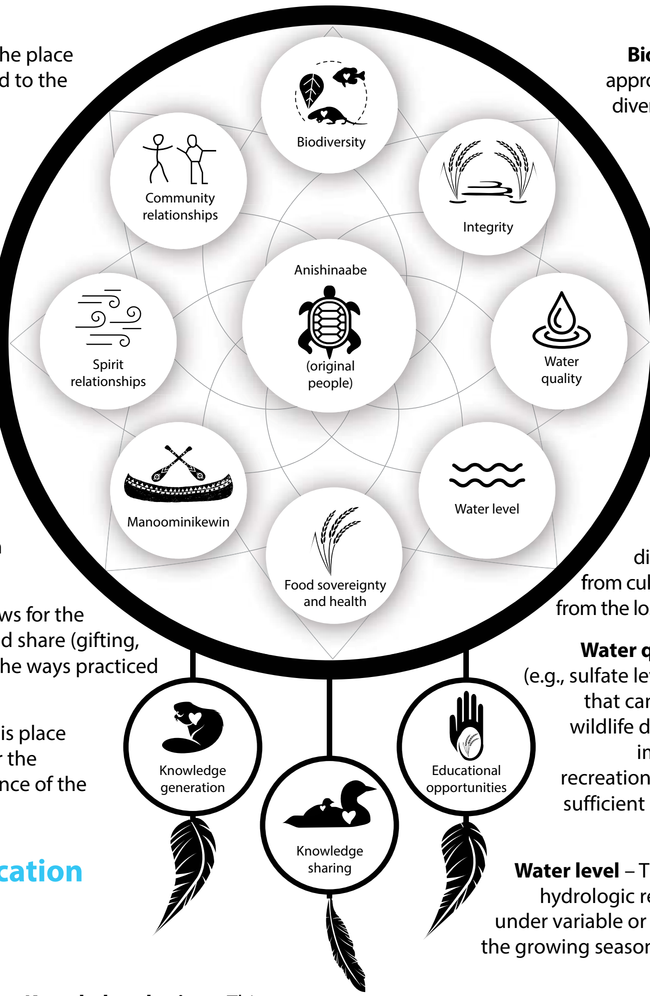
Anishinaabe (original people) – The place provides Manoomin, which is sacred to the Anishinaabe and central to the foundations of their culture, sovereignty, and treaty rights.

Community relationships – Manoomin at this place contributes to bonding, traditions, and strengthening family and community connections.

Spirit relationships – Manoomin at this place enables the Anishinaabe to maintain connections and balance with spirit beings (or relatives) from all other orders of creation (first order: rock, water, fire and wind; second order: other plant beings; third order: animal beings; fourth order: human beings).

Manoominikewin – This place allows for the Anishinaabe to harvest, prepare, and share (gifting, healing, and eating) Manoomin in the ways practiced by their ancestors for centuries.

Food sovereignty and health – This place provides the capacity to provide for the sustenance, health, and independence of the Anishinaabe.



Ecological Metrics

Biodiversity – Healthy Manoomin and appropriate habitat at this place supports diverse biological communities (e.g., free of invasive species) that indicate the capacity of the place to support abundant associated plant and animal species (e.g., other native aquatic vegetation, fish, waterfowl, muskrat), providing for spiritual and subsistence needs.

Integrity – Physical habitat and hydrology, and water and sediment chemistry support stands of Manoomin that exhibit natural annual variability; viable seed bank ensures that sustainable Manoomin populations will persist even after occasional poor production years. Natural genetic diversity is maintained without impact from cultivated strains, or reduced gene flow from the loss of nearby Manoomin populations.

Water quality – This place has clean water (e.g., sulfate levels below 10 ppm) and sediments that can support robust stand density and wildlife diversity; is free of contamination or impacts from industrial, agricultural, recreational, or residential influence; and is of sufficient areal extent to sustain a Manoomin population.

Water level – This place has a natural or managed hydrologic regime that can maximize resilience under variable or extreme climatic conditions across the growing season (maintaining optimal depth range and flow).

Cultural and Ecological Education Metrics

Knowledge generation – This place allows for continued learning and generation of the Anishinaabe practices, values, beliefs, and language through experience.

Knowledge sharing – This place allows for the continued sharing and transmittal of the Anishinaabe practices, values, beliefs, and language among family members and community.

Educational opportunities – This place provides opportunities for language, land stewardship, and other educational programs, such as educational rice camps.

Cultural and ecological characterization at the Twin Lakes

The Twin Lakes' Manoomin and its associated habitat were characterized over four time periods. Each metric was ranked using the following five-point descriptive scale: No use, Very bad, Not very good, Pretty good, Doing great

1950 to 1965: Before construction of the tailings basin

Based on the combined ranking of cultural and ecological metrics, conditions at the Twin Lakes were characterized as "doing great" during this period. Prior to the discharge of mine waste into the Twin Lakes, both lakes had moderately dense to dense stands of Manoomin. The Bois Forte Band of Chippewa, Grand Portage, and other community members historically harvested Manoomin in these lakes. In addition, Manoomin supported waterfowl (e.g., mallard, black ducks, green winged teal, wood ducks), fish such as northern pike, and other wildlife during this period (Minnesota Division of Game and Fish, 1966a, 1966b).

1966 to 1989: After construction of the tailings basin

After the discharge of mine waste started, Manoomin coverage in the Twin Lakes steadily declined. Compared to a 1966 vegetation survey of the Twin Lakes (Minnesota Division of Game and Fish, 1966a, 1966b), a 1987 survey found that Manoomin was essentially absent from both lakes, while water levels were considerably higher and water clarity increased dramatically (State of Minnesota, 1987). By 1989, the Twin Lakes ranked as "no use" based on the combined ranking of cultural and ecological metrics.

1990 to 2009: With limited restoration actions

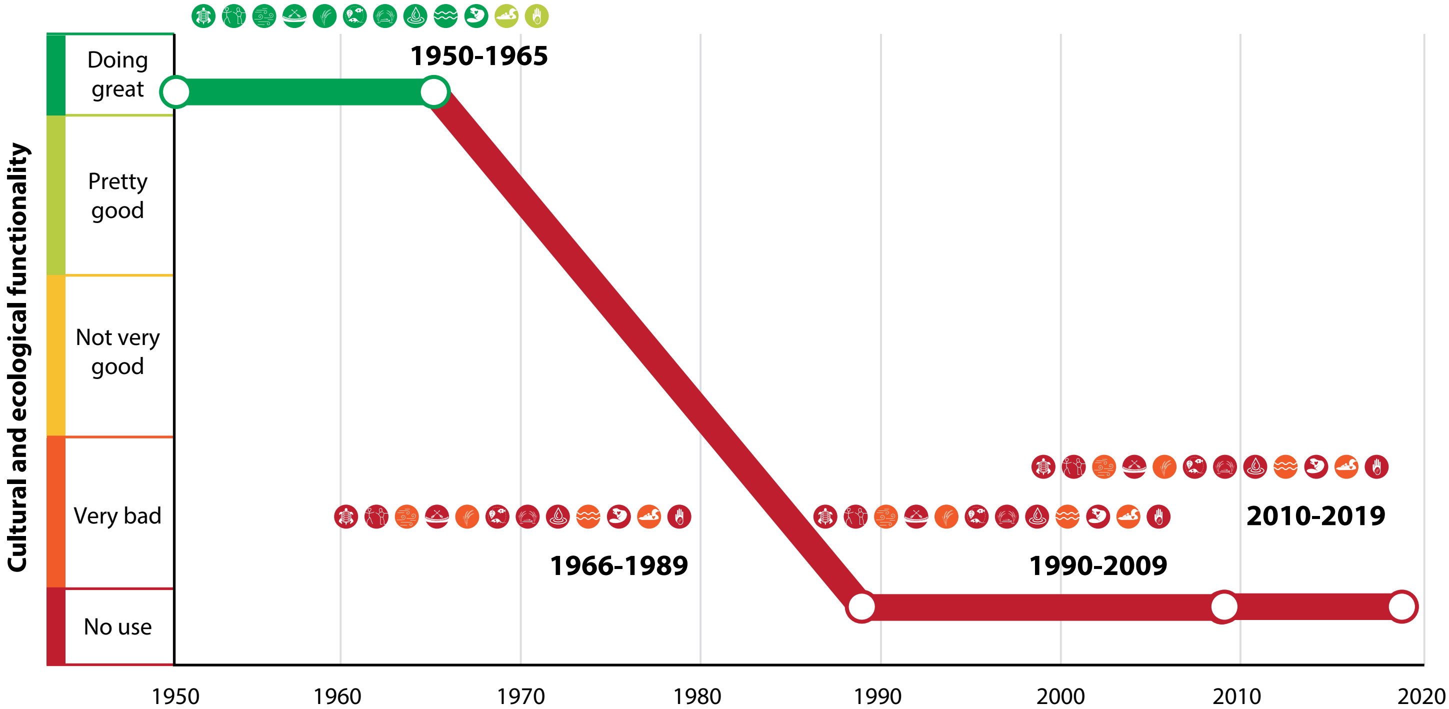
During this period, some actions were undertaken to recover Manoomin, including beaver management and small-scale reseeding efforts. However, these actions did not address the fundamental issue of high levels of sulfate and were largely ineffective at restoring the abundance of Manoomin and its associated habitat at the Twin Lakes. Given the absence of Manoomin on the lakes, community members were unable to harvest, prepare, and share Manoomin in ways practiced by their ancestors. The lost use of the Twin Lakes also limits sharing, transmittal, and generation of Anishinaabe practices at these lakes. During this period, the ranking of the Twin Lakes remained near "no use" based on the combined ranking of cultural and ecological metrics.

2010 to 2019: After construction of the seepage collection system

After U.S. Steel constructed the seepage system, Manoomin remained essentially absent from the Twin Lakes. With the lakes unable to support Manoomin, community members remained unable to harvest, prepare, and share Manoomin in ways practiced by their ancestors. During this period, the ranking of the Twin Lakes remained near "no use" based on the combined ranking of cultural and ecological metrics.

Cultural and ecological characterization of the Twin Lakes

Cultural and ecological functionality provided by Manoomin and its associated habitat at the Twin Lakes declined over time, both in aggregate and for the individual metrics.



Additional actions needed

Since the installation of a tailings basin for the U.S. Steel's Minntac facility in the mid-1960s, the abundance of Manoomin at the Twin Lakes has steadily declined. Actions taken at the Twin Lakes to improve Manoomin and its associated habitat have been limited and have not addressed the fundamental problem of sulfate loading from the mine. If actions were taken to improve conditions in the future, we could use a Habitat Equivalency Analysis (HEA) to demonstrate the additional equivalent units of restoration needed to counter-balance the severity and timespan of degradation. For example, if actions were implemented over the next 20 years (2020 to 2040) to improve habitat functionality by 2.5%, over 100,000 acres of similar Manoomin restoration would be needed to counter-balance the lost habitat functionality that has occurred over time (from 1966 to 2019). This is equivalent in size to over 550 Twin Lakes. The table to the right provides the HEA results, assuming several hypothetical scenarios of improvements in habitat functionality; it is important to note that we do not know what actions are needed to create these percent improvements, but they would likely require addressing the fundamental problem of sulfate loading from the mine. The main purpose of these scenarios is to highlight that if only minimal restoration is achieved at Twin Lakes (which may be anticipated, given the long history of attempting restoration, with minimal response), then significant equivalent amounts of this restoration would be needed to balance the prolonged period of degradation at these lakes.

Hypothetical percentage of improvement in habitat functionality from 2020 to 2040	**Acres needed to counter-balance historical losses given hypothetical improvement** *(Acres rounded to the nearest hundred)*	**Number of Twin Lakes needed to counter-balance historical losses given hypothetical improvement**
2.5%	116,700	556
5.0%	58,400	278
10.0%	29,200	139
20.0%	14,600	69

This case study demonstrates the difficulty in restoring Manoomin and its associated habitat when the root cause of the degradation – in this case, sulfate discharge – is not addressed. Given the difficulty of restoring degraded habitat, it is important to protect and preserve existing Manoomin habitat to ensure a future with Manoomin.

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About this effort

This case study is part of the Lake Superior Manoomin Cultural and Ecosystem Characterization Study. The project was initiated by a team of Lake Superior Basin Anishinaabe communities, and federal and state agencies, with technical support from Abt Associates. This project aims to describe the importance of Manoomin to help foster community stewardship and education; and to inform Manoomin stewardship, protection, and policy in the Lake Superior region and throughout the Great Lakes. Funding for this project was received via Great Lakes Restoration Initiative. For more information on the Initiative and Action Plan go to https://www.glri.us/.

Acknowledgments

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Minnesota Pollution Control Agency

Sampling and Analytical Methods for Wild Rice Waters

March 2018

Environmental Analysis and Outcomes Division

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

Table of Contents

Background

The Minnesota Pollution Control Agency developed this procedure to ensure that samples taken for the purposes of calculating the numeric expression of the sulfate standard to protect wild rice (Minn. R. 7050.0224) are scientifically defensible and protective of the Class 4D wild rice use. The numeric expression of the sulfate standard is derived from the output of an equation that calculates a sulfate concentration necessary to maintain sulfide concentrations in sediment porewater less than or equal to 0.120 mg/L. The standard is derived using measured concentrations of total organic carbon (TOC) and total extractable iron (TEFe) in a sediment sample to calculate a protective sulfate concentration for each sediment sample. Due to natural processes, TOC and TEFe concentrations vary in the sediment of aquatic ecosystems, which means that the analysis of multiple sediment samples will produce a range of calculated sulfate concentrations that could serve as the numeric expression of the standard.

In order to protect the majority of wild rice habitat in a wild rice water, the numeric sulfate standard for a wild rice water is defined as the 20th percentile of at least 15 protective sulfate concentrations calculated from sediment samples randomly selected from the wild rice habitat. Sediment is only sampled from areas of wild rice habitat, since wild rice does not grow at all locations within a wild rice water.

This document establishes the methodology that must be used to collect sediment samples from wild rice habitat in wild rice waters, analyze the samples, apply the equation, and determine the numeric sulfate standard.

The terms used in this document have the following meanings.

- Wild rice water is the entire WID identifying a Class 4D wild rice water as shown in Minn. R. 7050.0471.
- Wild Rice Habitat (WRH) are the area(s) of the wild rice water that (1) support or have supported wild rice, or (2) are identified as likely to support wild rice. Once the referencing period has ended, WRH has been delineated, and sediment samples have been taken, the WRH areas defined for a wild rice water do not change. The MPCA will post on its website maps for each wild rice water that has had WRH delineated.
- Each Candidate Sample Site (CSS) is a point randomly selected from within the WRH, identified by its spatial coordinate. At least 100 CSS points must be identified for each wild rice water prior to obtaining sediment samples that will be analyzed for the determination of a numeric sulfate standard. Sediment samples must be taken from at least 15 of the candidate sample sites.
- Referencing period identifies the time within which desktop review and on-site reconnaissance occurs in preparation for the final delineation of WRH and sampling of sediment. The referencing period ends when the first complete set of sediment samples is collected.
- The numeric sulfate standard of a wild rice water is defined as the 20th percentile of the 15 or more protective calculated sulfate concentrations.

Section 1. Sediment sampling procedure for wild rice waters

A. Identifying wild rice habitat areas

Before sediments are sampled, WRH must be delineated within the wild rice water. The entire wild rice water (WID) must be evaluated to determine WRH. The process of identifying WRH in a wild rice water must be completed in two steps: (1) a desktop review of available information prior to any field reconnaissance, and (2) a pre-sampling field reconnaissance of the wild rice water. The intent of these two steps is to produce a map of WRH within the wild rice water. The map produced from this survey must be in a format that is compatible with performing a random selection of candidate sample sites as described in part B.

Delineation of Areas of Potential WRH

Step 1. Desktop review: On a map or aerial photograph of the wild rice water, outline the areas of potential WRH based on the following information:

- Areas where existing information identifies the past location of wild rice plants. Examples of acceptable information are annotated maps, documented plant surveys, sampling events, or historical records from which the areas containing wild rice plants can be determined.
- Areas where satellite or aerial photographs indicate the past presence of floating-leaved or emergent plants.

Step 2. Pre-sampling field reconnaissance:

After conducting the desktop review, the map of potential WRH must be compared to direct observation by conducting a field survey during the growing season of wild rice. This field survey must be done at a time when wild rice plants can be effectively identified; the best time period is when the growth of wild rice is at least at the tiller stage (July through September).

Areas identified as potential WRH in the desktop review must be examined in the field for evidence of wild rice plants. The survey must include visual observation of all areas of potential WRH. The wild rice water must also be surveyed for evidence of wild rice plants outside of the areas identified in the desktop review. Available information must also be gathered about possible phenomena that may have reduced that year's wild rice population, such as unusually high water levels. If the available information show a likelihood that the year's wild rice population has been significantly impacted by such phenomena, the referencing period must be extended by performing additional field reconnaissance in a following year.

Information on each area of potential WRH must be recorded, including which hierarchy level each site falls into, as described here:

Level 1 – Areas that Support or Have Supported Wild Rice

#1a. Areas where wild rice is observed growing or where there is evidence of recent growth, such as rooted wild rice plants that have been grazed, or wild rice plant residue from previous year's growth.

#1b. Areas that have supported wild rice in the past, as identified from evidence included in the desktop review.

Level 2 – Areas Likely to Support Wild Rice

#2a. Areas with either floating-leaved plants or emergent plants where water depth is less than 120 cm. Examples of floating-leaved or emergent plants whose presence approximates the conditions for wild rice growth are yellow or white waterlilies (*Nuphar variegata* and *Nymphaea odorata*), pondweeds (*Potamogeton* species), watershield (*Brasenia schreberi*), pickerelweed (*Pontederia cordata*), and arrowhead (*Sagittaria latifolia*). WRH does not include areas dominated by species that form dense monocultures that exclude wild rice, such as cattails

(*Typha* species), phragmites *(Phragmites australis*), purple loosestrife (*Lythrum salicaria*), and reed canary grass (*Phalaris arundinacea*).

#2b. Areas where water depth is between 30 and 120 cm.

Delineating Final WRH

If any Level 1 area is identified, then the entirety of the Level 1 areas (both 1a and 1b) represent the final WRH for that wild rice water. If no Level 1 area is identified, then any Level 2a areas are the WRH. If no Level 2a areas are identified, then the Level 2b areas are the WRH. The map of the final delineated WRH must be used to define at least 100 random candidate sample sites, as described below in Part B.

B. Selecting sediment core sample sites

All sediment sampling must occur within the delineated WRH. Using the map of the delineated WRH within the wild rice water, identify the randomly located 100 candidate sample sites as potential locations for sediment sampling. Each candidate sample site must be geo-referenced, specifying latitude and longitude to 5 decimal places.

The CSS sites may be identified by laying a grid over the WRH and randomly locating potential sites where the gridlines overlap, or through the use of geographic information system (GIS) software that randomly selects points within the WRH layer.

Once at least 100 points of the CSS are randomly established within the WRH, the CSS points must be tabulated and randomly numbered. Sort the sites by the random numbers and number them in order from 1 to 100.

The candidate sample sites must be selected in order as sites for the collection of sediment samples for analysis. At least the first 15 samples must be collected. Additional samples may be collected, moving sequentially through the random number list, to ensure that sufficient samples are available in case the analysis of some samples fail the QA/QC procedures specified in Sections 2 and 3 of this document. At least 15 pairs of acceptable total organic carbon (TOC) and total extractable iron (TEFe) concentrations must be available from laboratory analysis in order to calculate the numeric expression of the standard, as specified in part 4 of this document.

A map showing WRH and the sites selected for sampling must be submitted to the MPCA and placed on the website that houses information on the Class 4D wild rice waters.

C. Conducting Sediment Sampling

The selected sample locations may be visited in any order and at any time during the open water season. Sampling can take place the same year as the WRH was delineated, or at a later date. For instance, sediment can be collected early the following summer, before emergent wild rice becomes dense. Sampling before the wild rice population is dense has the potential advantage of allowing navigation across the wild rice water without damaging emergent plants.

A global positioning system (GPS) receiver must be used to locate the position of the site in the field, and accuracy of the receiver must be at least 3 meters. Sediment must be collected in a place with overlying water that is within 3 meters of the predetermined location.

At each of the selected sampling points, use the following methods to collect a sediment core sample:

1. Each sediment sample is the top 10 centimeters of a sediment core after the overlying water has been removed.
2. Place the sediment sample into a clean container that is clearly labeled with an identification number associated with the table of random numbers, water body, collection date, latitude, and longitude.
3. Store the samples on ice in the field and keep the samples at ≤ 6° C until delivered to an analytical lab for analysis.

D. Data Reporting

Document and report to the MPCA the following information about the sediment sampling:

1. Name and WID of the wild rice water
2. Name of person responsible for desktop review, and summary of findings.
3. Reconnaissance date and names of field crew.
4. Sediment sampling date(s) and names of field crew.
5. Description of coring device and diameter of coring tube.

6. The map or aerial photograph of the wild rice water, marked with the areas of wild rice habitat delineated in part A, steps 1 and 2, and the location of the final sample points determined in part B.
7. A table of the CSS that gives the latitude and longitude of at least the first 100 randomly selected sites and identifies the final sample sites;

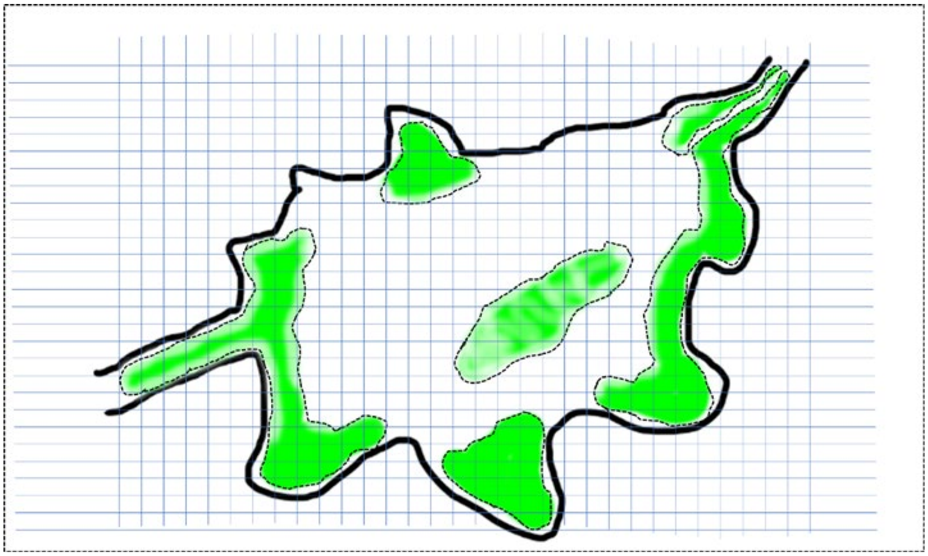

Figure 1. Example of grid overlay on a base map of a wild rice water with areas of wild rice habitat delineated. Potential sampling points are the grid intersections within areas of wild rice habitat. Alternatively, random sites within wild rice habitat can be randomly selected by GIS software.

Section 2. Analytical method for the determination of total extractable iron in sediment

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

1. Prior to analysis, store the samples at ≤ 6° C to minimize biological activity. Samples must be analyzed within 180 days of collection date.
2. Dry and prepare the sample using either procedure 2a or 2b:

   2a.

   - Manually remove large materials such as rocks, shells, and sticks, and add a description of removed materials to the lab report.
   - Dry the sample in an oven at 50° C until constant weight is achieved.
   - Manually break the dried sample into pieces.
   - Pulverize the dry sample using a mill.

   2b.

   - Freeze-dry the sample.
   - Homogenize the sample using a stainless steel spatula.
   - Manually remove r~~emaining~~ large materials such as rocks, shells, and sticks, and add a description of removed materials to the lab report.

3. After the sample has been prepared, digest a small aliquot of the sample (0.25 +/- 0.02 grams) and all necessary QA/QC samples by adding 25 mL of 0.5 N hydrochloric acid to all digestion tubes. Digest samples (and all necessary QA/QC samples) on a hot block at 80-85° C or in a water bath at 80-85° C. Once samples reach 80° C, digest samples for 30 additional minutes. After 30 minutes, remove samples immediately and cool to room temperature, and bring to a constant volume. Immediately either centrifuge the tubes at 1000 rpm for 10 minutes or filter using a 0.45 µm PES-type filter. Remove an aliquot and dilute with reagent water to known volume for iron analysis. Determine iron in the diluted aliquot using Inductively Coupled Plasma-Atomic Emission Spectrometry. Report the results in mg/kg (dry weight).
4. Acceptable performance must be demonstrated on an ongoing basis. With every digestion batch, the laboratory must perform the following:

   - Low Background: At the beginning of each batch, analyze a blank (BLK) to determine reagent or laboratory contamination. The background level of the BLK must be below the report level before samples are analyzed.
   - Accuracy: With every batch of 20 samples processed as a group, analyze a Laboratory Control Sample (LCS). The LCS should be prepared at concentrations similar to those expected in the field samples and ideally at the same concentration used to prepare the matrix spike (MS). The acceptance criteria for recovery of the analyte in the LCS is 80 – 120%.

- Matrix spike. A MS must be prepared and analyzed with each batch of 20 samples processed as a group, or a minimum of 10% of the field samples analyzed, whichever is greater. The same solution used to fortify the LCS is used to fortify the MS. The acceptance criteria for recovery of the analyte in the MS is 80 – 120%.
- Precision: Analyze a Laboratory Duplicate (DUP) with each batch of field samples processed as a group, or 10% of the field samples analyzed, whichever is greater. The acceptance criteria for the relative percent difference (RPD) is ≤ 20%.

  RPD is a measure of precision, calculated as: RPD = (X1 – X2)/Xave x 100, where X1 and X2 are the concentrations of duplicates. Xave is the average of the two concentrations, calculated as: Xave = (X1 + X2)/2.

Section 3.Analytical method for the determination of total organic carbon in sediment

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

1. Prior to analysis, store the samples at ≤ 6° C to minimize biological activity. Samples must be analyzed within 28 days of collection date.
2. Dry and prepare the sample using either procedure 2a or 2b:

   2a.

   - Manually remove large materials such as rocks, shells, and sticks, and add a description of removed materials to the lab report.
   - Dry the sediment sample in an oven at 50° C until constant weight is achieved.
   - Manually break the dried sample into pieces.
   - Pulverize the remaining dry sediment using a mill.

   2b.

   - Freeze-dry the sample.
   - Homogenize the material using a stainless steel spatula,
   - Remove remaining large materials such as rocks, shells and sticks, and add a description of removed materials to the lab report .
3. After the sample has been prepared:

- Treat an aliquot of the homogenized sample with a 5% solution of H_3PO_4 to remove any inorganic carbon.
- Either air-dry or oven-dry (at 105°C) the sample until constant weight is achieved.
- Analyze the sample (and all necessary QA/QC samples) for Total Organic Carbon content using a Standard Operating Procedure based on EPA Method 9060A.
- Analyze all environmental samples in duplicate.
- Report the results in mg C/kg dry sediment, and as percent C in dry sediment.

4. Acceptable performance must be determined for every digestion batch by performing the following activities:
   - Low Background: At the beginning of each batch, analyze a blank (BLK) to determine reagent or laboratory contamination. The background level of the BLK must be below the report level before analyzing samples.
   - Accuracy: With every batch of 20 samples processed, analyze a Laboratory Control Sample (LCS). The LCS must prepared at the same concentrations as the field samples and at the same concentration used to prepare the matrix spike (MS). The acceptance criteria for recovery of the analyte in the LCS is 70 – 130%.

- Matrix spike: Prepare and analyze a MS with every 20 samples processed as a group, or a minimum of 10% of the field samples analyzed, whichever is greater. The same solution used to fortify the LCS is used to fortify the MS. The acceptance criteria for recovery of the analyte in the MS is 70 – 130%.
- Precision: Analyze a Laboratory Duplicate or a MS duplicate with every 20 samples processed as a group, or 10% of the field samples analyzed, whichever is greater. The acceptance criteria for the relative percent difference (RPD) is ≤ 30%.

  Analyze every environmental sample in duplicate. The RPD between duplicates must be ≤ 30%.

  RPD is a measure of precision, calculated as: RPD = (X1 – X2)/Xave x 100, where X1 and X2 are the concentrations of duplicates. Xave is the average of the two concentrations, calculated as: Xave = (X1 + X2)/2.

Section 4. Calculating the numeric sulfate standard using the equation.

A protective sulfate concentration (mg/L) is computed based on each sediment sample using the following equation:

$$MBLR120\ Sulfate = 0.0000854\ \times \frac{TEFe^{1.637}}{TOC^{1.041}}$$

If any sample has an organic carbon concentration that is lower than 0.20 percent carbon, then the concentration of 0.20 percent carbon must be substituted for the lower concentration. If any sample has an iron concentration greater than 83,421 micrograms/gram, then the concentration of 83,421 micrograms/gram must be substituted for the higher concentration.

The numeric expression of the sulfate standard is the 20th percentile of all calculated sulfate concentrations resulting from the application of the equation to each pair of organic carbon and iron concentrations (including any substituted concentrations).

There are several different ways to calculate percentiles; for this purpose, 20th percentile can be calculated through the use of the Microsoft Excel function PERCENTILE.INC, or through the following procedure:

1. Sort all calculated sulfate concentrations, ranked from low to high (e.g., 1st, 2nd, 3rd, 4th, etc.).
2. Calculate values for x and y in the following expression: x.y=0.2(N-1)+1 (N is the total number of calculated sulfate concentrations; if there are 15 samples, x.y = 3.8).
3. Calculate the 20th percentile as xth sulfate concentration plus [0.y times (value of xth+1 sulfate concentration minus the value of xth sulfate concentration)]. For instance, if there were 15 samples, the 20th percentile sulfate concentration would be:

   [value of 3rd + 0.8(value of 4th – value of 3rd)].

At least 15 pairs of TOC and TEFe concentrations must be used to calculate the numeric expression of the sulfate standard. All acceptable (based on Sections 2 and 3) concentrations of TOC and TEFe must be used to calculate the numeric expression of the sulfate standard, even if those concentrations were gathered from different sampling events.

If the numeric sulfate concentration is above 335 mg/L sulfate, then the numeric expression of the sulfate standard for the wild rice water from which the sediment samples were taken is 335 mg/L. If the numeric sulfate concentration is below 0.5 mg/L sulfate, then the numeric expression of the sulfate standard for the wild rice water from which the sediment samples were taken is 0.5 mg/L.