South Whaletail Alum Treatment

Feasibility Study

Submitted

To

MINNESOTA POLLUTION CONTROL AGENCY

Submitted

By

ThreeRivers PARK DISTRICT

Pioneer-Sarah Creek Watershed Management Commission

CITY OF MINNETRISTA

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Section 1.0 – Introduction

Whaletail Lake was identified as a sentinel lake within the 3rd Generation (2015) and the recently approved 4th Generation (2020) Pioneer-Sarah Creek Watershed Management Plans. The Minnesota Pollution Control Agency (MPCA) listed Whaletail Lake on the impaired water's list for excessive nutrients (South basin in 2006 & North basin in 2008). A Total Maximum Daily Load (TMDL) analysis was completed for Whaletail Lake as part of the Pioneer-Sarah Creek Watershed TMDL that was approved by the MPCA in 2017. The approved TMDL recommended an alum treatment to control internal phosphorus loading as a preferred management approach for improving the water quality of Whaletail Lake. Alum is an aluminum sulfate or sodium aluminate compound that has a strong binding capacity to phosphorus. The application of alum within a lake will sequester redox-sensitive phosphorus from being release from the sediments into the overlying water column. Since the completion of the TMDL, there has been additional monitoring data collected and analysis conducted for Whaletail Lake. This document will summarize the findings from the most recent data collected and further evaluate the feasibility of conducting an alum treatment on the South basin of Whaletail Lake. The primary objective of the feasibility study is to pursue MPCA approval/support for the implementation of an alum treatment on the South basin of Whaletail Lake.

Section 2.0 Background

Section 2.1 Bathymetry and Watershed Characteristics

Whaletail Lake is a 526-acre lake located in the western portion of Hennepin County within the City of Minnetrista. The lake has a relatively small watershed that is approximately 2,246 acres located entirely within the Pioneer-Sarah Creek Watershed (Figure 1). The watershed drainage includes Little Long Lake flowing south through a series of wetlands into the South basin of Whaletail Lake. The water flows from the South basin into the North basin of Whaletail Lake where the outlet becomes the headwaters of Deer Creek. The South and North basin of Whaletail Lake has different bathymetric characteristics (Table 1). Due to the morphological differences between basins, the Minnesota Pollution Control Agency (MPCA) considers the lake as having two distinct basins relative to the Minnesota water quality nutrient standards with the South basin classified as a deep lake and the North basin classified as a shallow lake. The MPCA water quality standards for the North Central Hardwoods Forest Ecoregion applied to each basin classification is defined in Table 2.

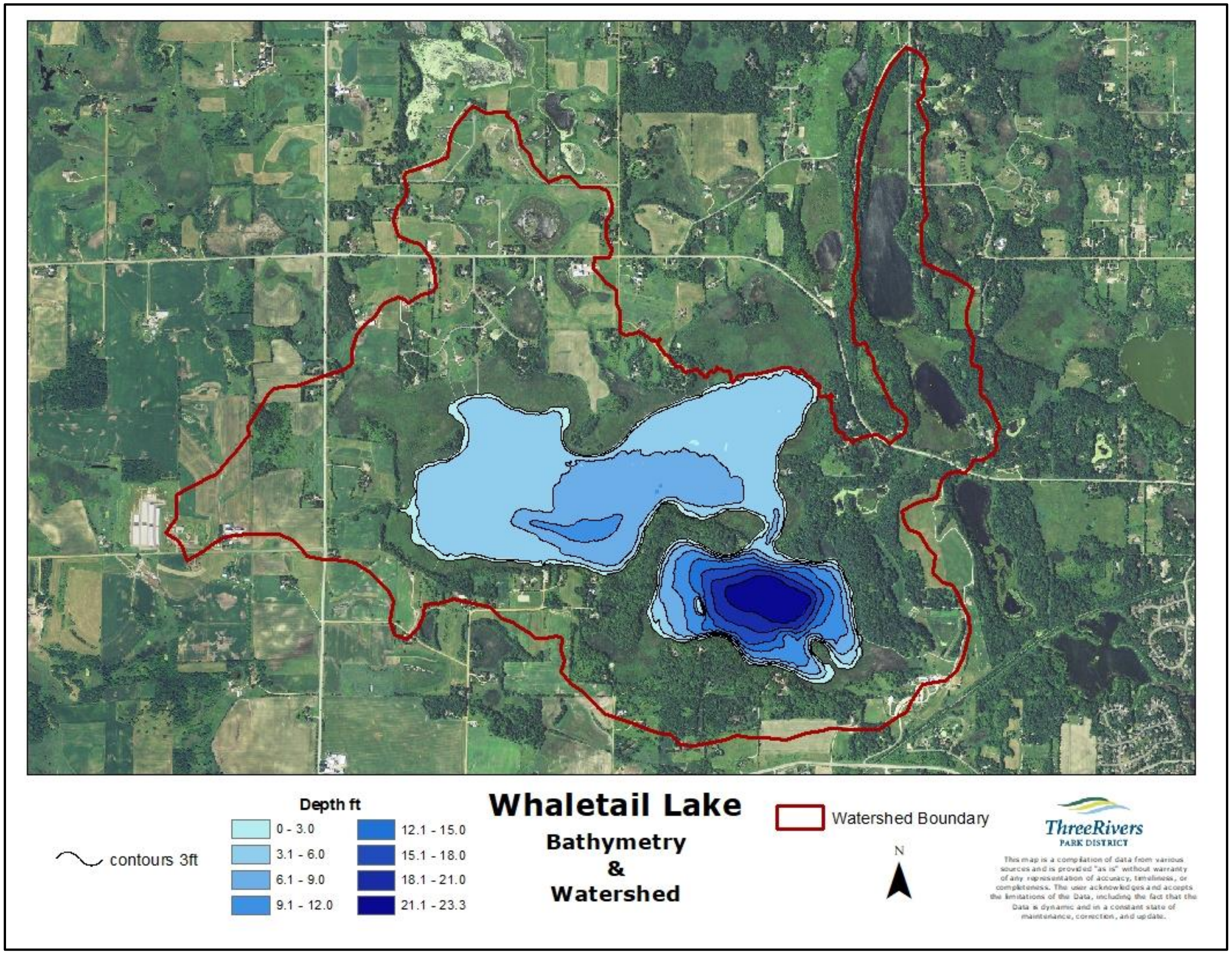


Figure 1: Whaletail Lake Bathymetry and Watershed Boundary.

Table 1: Whaletail South & North basin Lake and Watershed Characteristics.

Whaletail South Lake and Watershed Characteristics	
MnDNR #	27-0184-02
Lake Surface Area	156 Acres
Maximum Depth	23.3 feet
Average Depth	12.1 feet
Volume	1,895 Acre-feet
Percent Littoral Area	66%
Watershed Area	661 Acres
Watershed:Lake Area Ratio	4.2 to 1
Impairment	Excess Nutrients in 2006
Classification	Deep Lake

Whaletail North Lake and Watershed Characteristics	
MnDNR #	27-0184-01
Lake Surface Area	370 Acres
Maximum Depth	10.3 feet
Average Depth	5.2 feet
Volume	1,904 Acre-feet
Percent Littoral Area	100%
Watershed Area	1,585 Acres
Watershed:Lake Area Ratio	4.3 to 1
Impairment	Excess Nutrients in 2008
Classification	Shallow Lake

Table 2: Minnesota Pollution Control Agency water quality standards for each basin of Whaletail Lake.

Basin	Classification	MPCA Water Quality Parameter Standards		
		TP (µg/L)	Chl-a (µg/L)	Secchi (m)
Whaletail-South	Deep Lake	40	14	1.4
Whaletail-North	Shallow Lake	60	20	1

Section 2.2 Whaletail Lake Water Quality

Three Rivers Park District has been periodically monitoring the water quality of Whaletail Lake for the Pioneer-Sarah Creek Watershed Management Commission since 1998. Both the South and North basins of Whaletail Lake were listed on the MPCA impaired water's list for excessive nutrients in 2006 and 2008. TRPD has been consistently monitoring the water quality of both basins of Whaletail Lake since being placed on the impaired water's list in 2008. The South and North basins have exceeded the state's nutrient standards from 2008 – 2017 with exception of the North basin meeting phosphorus standards in 2011 and 2014. A Total Maximum Daily Load (TMDL) analysis was approved by the MPCA for Whaletail Lake as part of the Pioneer-Sarah Creek Watershed TMDL in 2017. Since the completion of the TMDL, the Whaletail South basin has exceeded the state's phosphorus and secchi transparency standard in all but one year over the past 5- years monitored; and has exceeded the chlorophyll-a standard every year the past 5-years (Figure 2). The water quality of the Whaletail North basin has noticeably improved, in which phosphorus has met the standard every year the past five years as well as meeting the secchi transparency standard 3 of the last five years (Figure 3). Despite meeting standards for phosphorus and clarity, Whaletail North basin chlorophyll-a concentrations has exceeded the state standard every year the past 5 years (Figure 3). The most recent water quality conditions for each basin are further summarized as a report card in Appendix A.

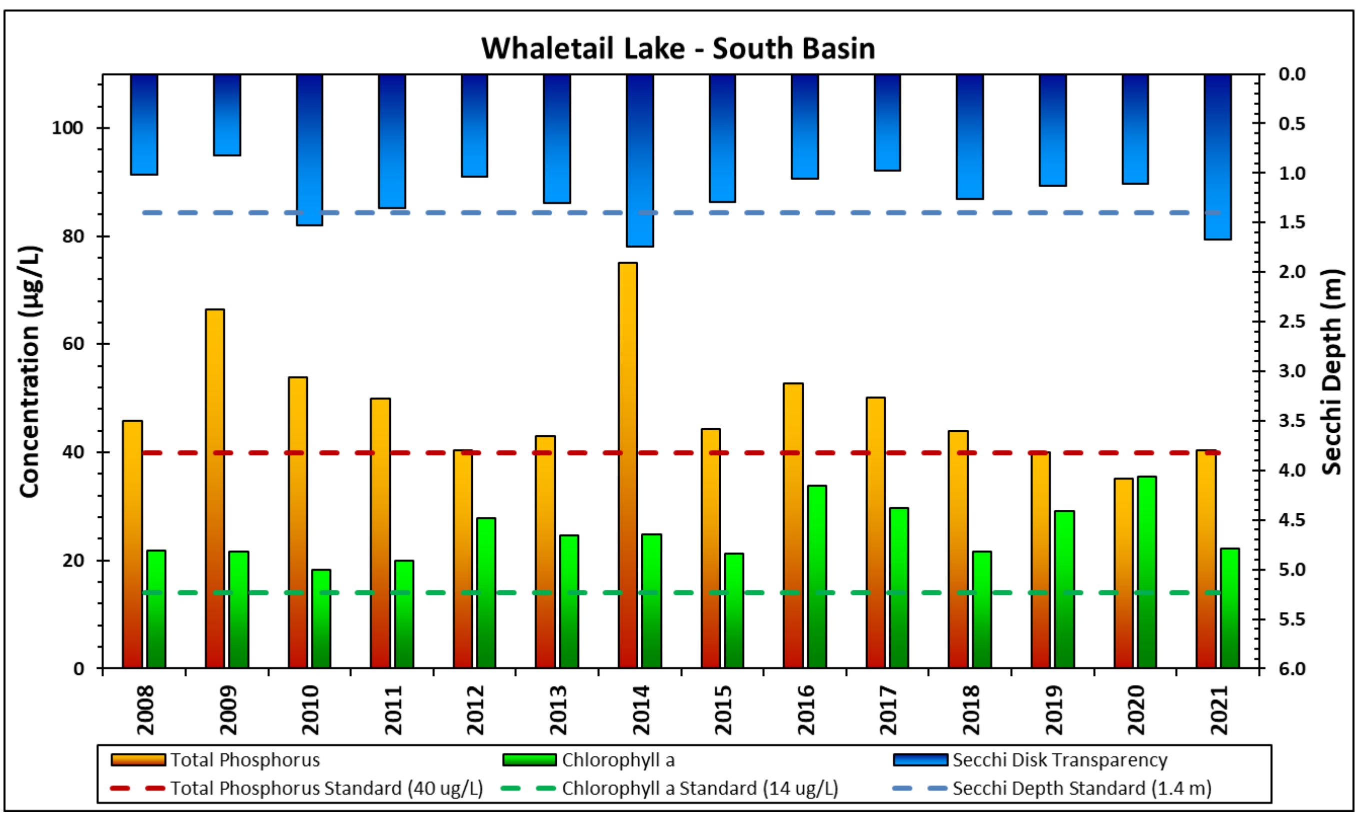


Figure 2: Whaletail Lake-South basin average (June-September) water quality from 2008-2021.

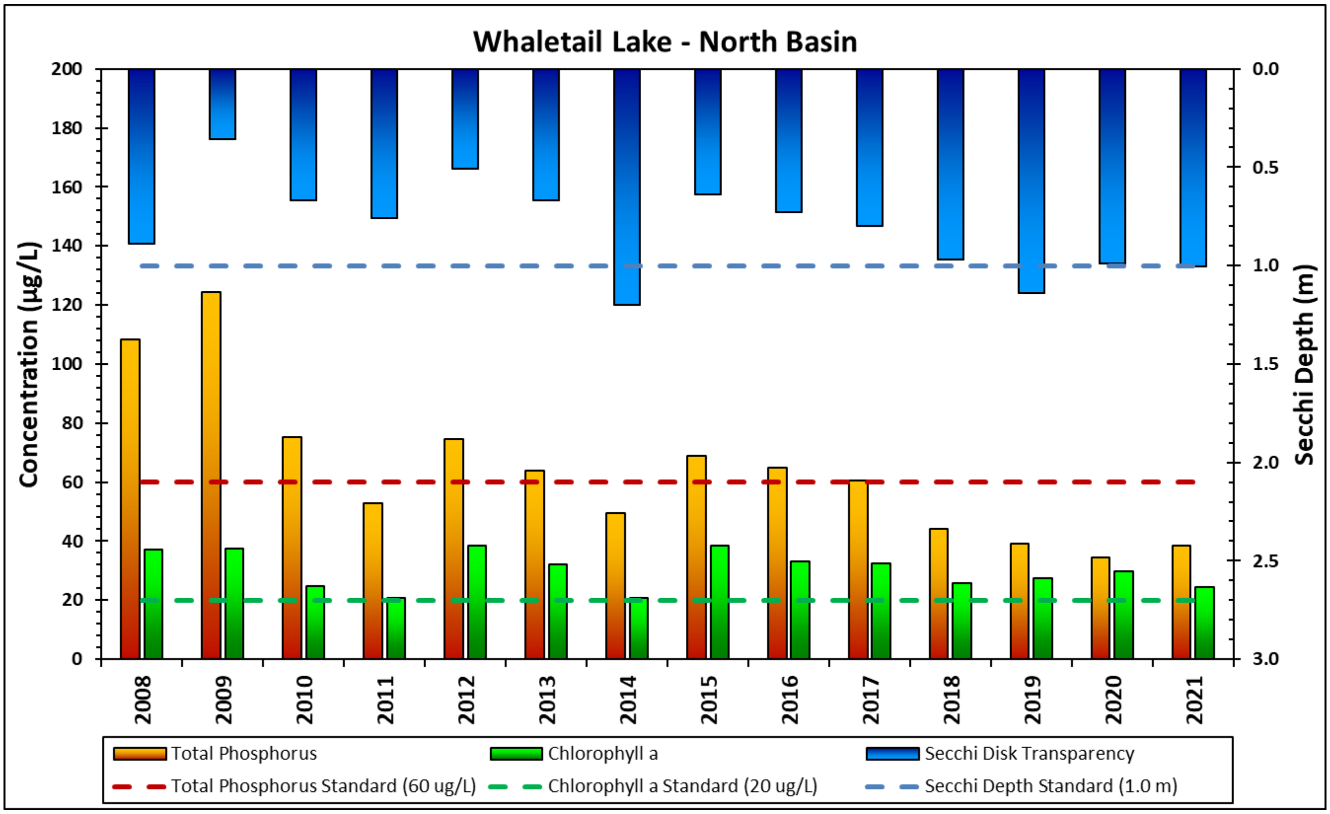


Figure 3: Whaletail Lake-North basin average (June-September) water quality from 2008-2021.

Section 2.3 Whaletail Lake TMDL

Three Rivers Park District completed the Pioneer-Sarah Creek Watershed TMDL study in July of 2017. The TMDL study addressed the excessive nutrient impairment for the South and North basins of Whaletail Lake. The TMDL goals pertaining to this feasibility assessment are the following:

1. Identify sources of pollutant loading contributing to the excessive nutrient impairments for the South and North basins of Whaletail Lake.

2. Quantify the pollutant load reductions needed to meet state water quality standards.

3. Develop management recommendations to improve water quality conditions.

Section 2.3.1 Nutrient Loading Sources

Phosphorus is the primary limiting nutrient that contributes to excess productivity in lakes. Excess productivity manifests itself as an increase in algal blooms and a consequent decrease in water clarity, both of which may significantly impair or prohibit the use of lakes for aquatic recreation. There are three primary sources of phosphorus loading that ultimately determines lake water quality:

1. Watershed loading
2. Internal Loading
3. Atmospheric Loading

The watershed loading for Whaletail Lake was estimated using the Generalized Watershed Loading Function (GWLF) model (Evans 2011). The GWLF model was used to estimate phosphorus loads and water budget for each basin of Whaletail Lake. Watershed modeling details are further described in the Pioneer-Sarah Creek Watershed TMDL (2017).

The internal loading for each basin was estimated using the Nürnberg approach based on phosphorous sediment release rates calculated from the incubation of intact sediment cores collected from each basin. The University of Wisconsin-Stout Laboratory analyzed the sediment cores, and details for sediment core analysis are provided in a report (James 2014) attached as Appendix B.

Atmospheric phosphorus loads were set to the default value of 0.27 lbs/yr/acre of lake surface area, which are similar to values reported in a technical memorandum to the MPCA (Barr Engineering 2007).

The TMDL nutrient loading budgets were developed for Whaletail South (Table 3 & Figure 4) and North basins (Table 4 & Figure 5). Details for nutrient loading sources are provided in the Pioneer-Sarah Creek Watershed TMDL report in 2017.

Whaletail South basin:

The total phosphorus load for the South basin of Whaletail Lake was approximately 529 pounds. Internal loading accounted for 80% of the phosphorus load affecting the surface water quality in the lake, while only 12% comes from watershed loading sources and 8% comes from atmospheric deposition. Since the water flows from the south to the north, the South basin water quality conditions potentially can impact and influence the water quality of the North basin.

Table 3: *Whaletail Lake-South basin phosphorus loading sources.*

Whaletail South		
	Phosphorus Load	
Source	lbs/yr	%
Watershed	63.7	12.0
Internal	423.5	80.1
Atmospheric	41.7	7.9
Total	528.9	100.0

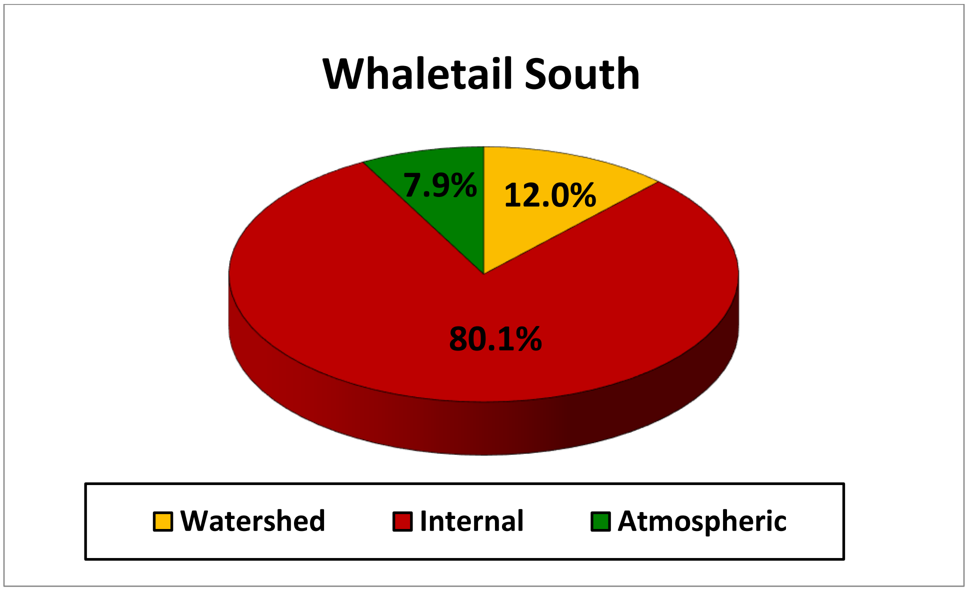


Figure 4: Whaletail Lake-South basin phosphorus load percentage.

Whaletail North basin:

The loading sources for the North basin of Whaletail Lake are considerably different in comparison to the South basin. The total phosphorus load for the North basin of Whaletail Lake was approximately 801 pounds. The watershed accounted for 51% of the total phosphorus load, in which the Whaletail South basin water quality contributed 26% of the watershed loading to the North basin. Other sources of loading included internal and atmospheric deposition accounting for 36% and 12% of the total load.

Table 4: Whaletail Lake-North basin phosphorus loading sources.

Whaletail North		
	Phosphorus Load	
Source	lbs/yr	%
Watershed	411.2	51.3%
Internal	291.0	36.3%
Atmospheric	99.2	12.4%
Total	801.4	100.0

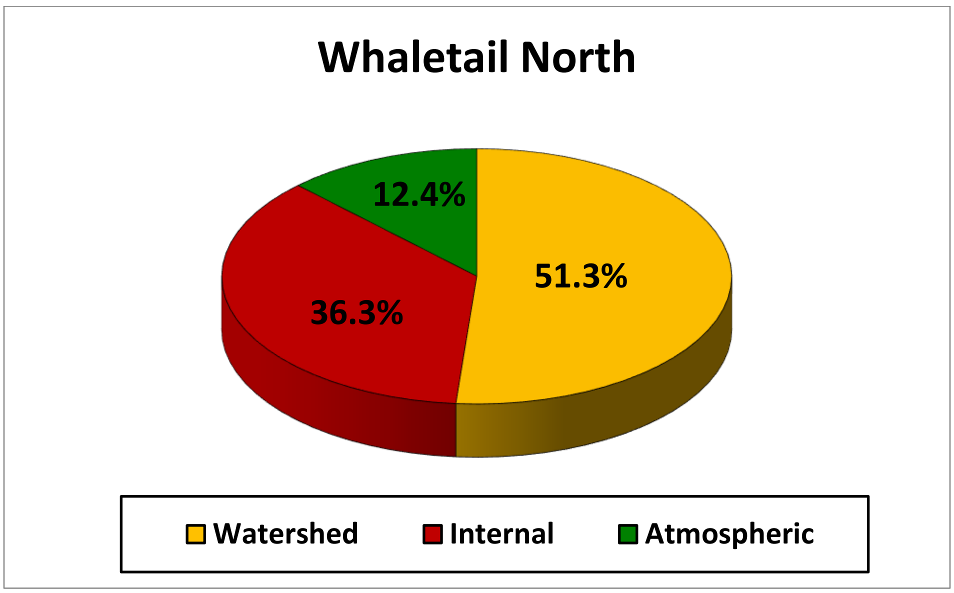


Figure 5: Whaletail Lake-North basin phosphorus load percentage.

Section 2.3.2 Loading Capacity

The nutrient loading capacity for a lake is defined as the maximum nutrient load it can receive and still meet water quality standards. To determine the loading capacity for Whaletail Lake, the phosphorus load and water budget was input into an in-lake response model (BATHTUB) that was calibrated to monitored water quality conditions. The in-lake response model was used to develop a load response curve that reflected the relationship between total phosphorus loading and in-lake water quality (Appendix B). The curve was used to determine the total load required to meet the in-lake phosphorus standard. The total load at which the in-lake water quality goal is achieved becomes the loading capacity for the lake. Below are the loading capacities for the South and North basins of Whaletail Lake.

Whaletail South basin:

Whaletail South basin will require a 31% reduction of the existing total phosphorus load for the lake to meet the state water quality goal of 40 µg/L. The phosphorus annual loading capacity of Whaletail South basin is 367 pounds. Consequently, the Whaletail South basin total phosphorus load needs to be reduced by 162 pounds per year from the existing total load of 529 pounds. The load response curve that was developed for the Whaletail South basin TMDL is provided in Figure 6.

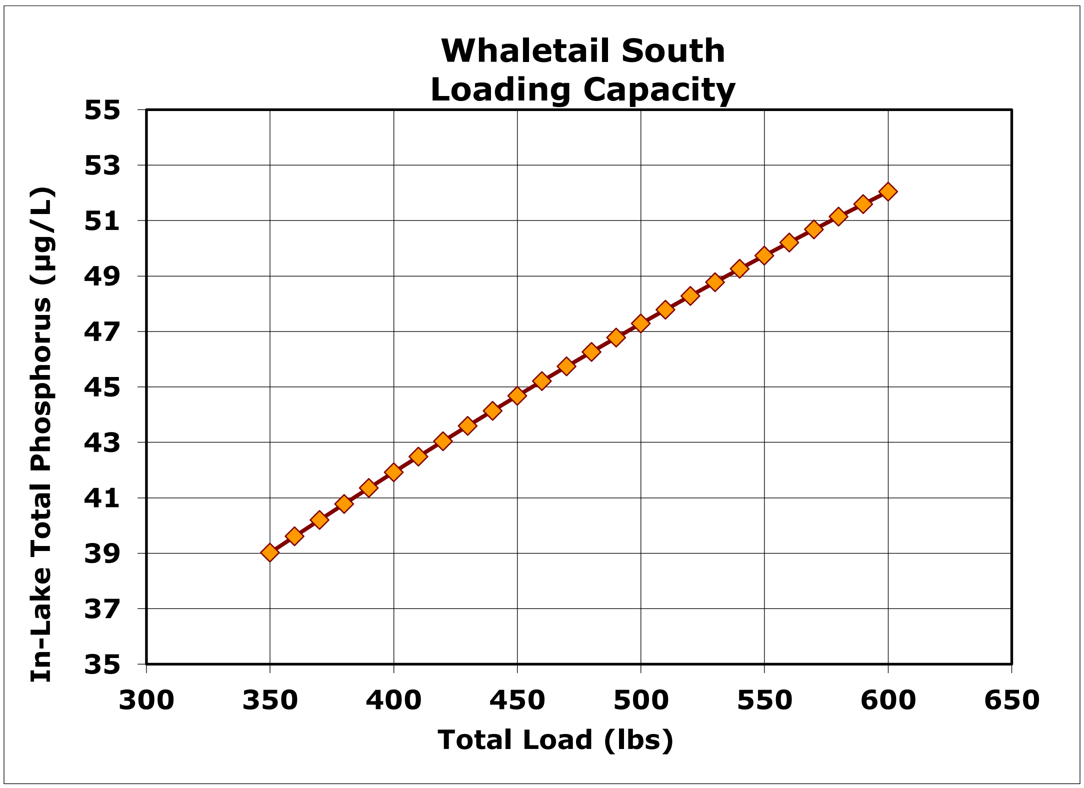


Figure 6: Whaletail Lake-South basin load response curve.

Whaletail North basin:

Whaletail North basin will require a 23% reduction of the existing total phosphorus load for the lake to meet the state water quality goals of 60 µg/L. The phosphorus annual loading capacity of Whaletail North basin is 620 pounds. Consequently, the Whaletail North basin total phosphorus load needs to be reduced by 181 pounds per year from the existing total load of 801 pounds. The load response curve that was developed for the Whaletail North basin TMDL is provided in Figure 7.

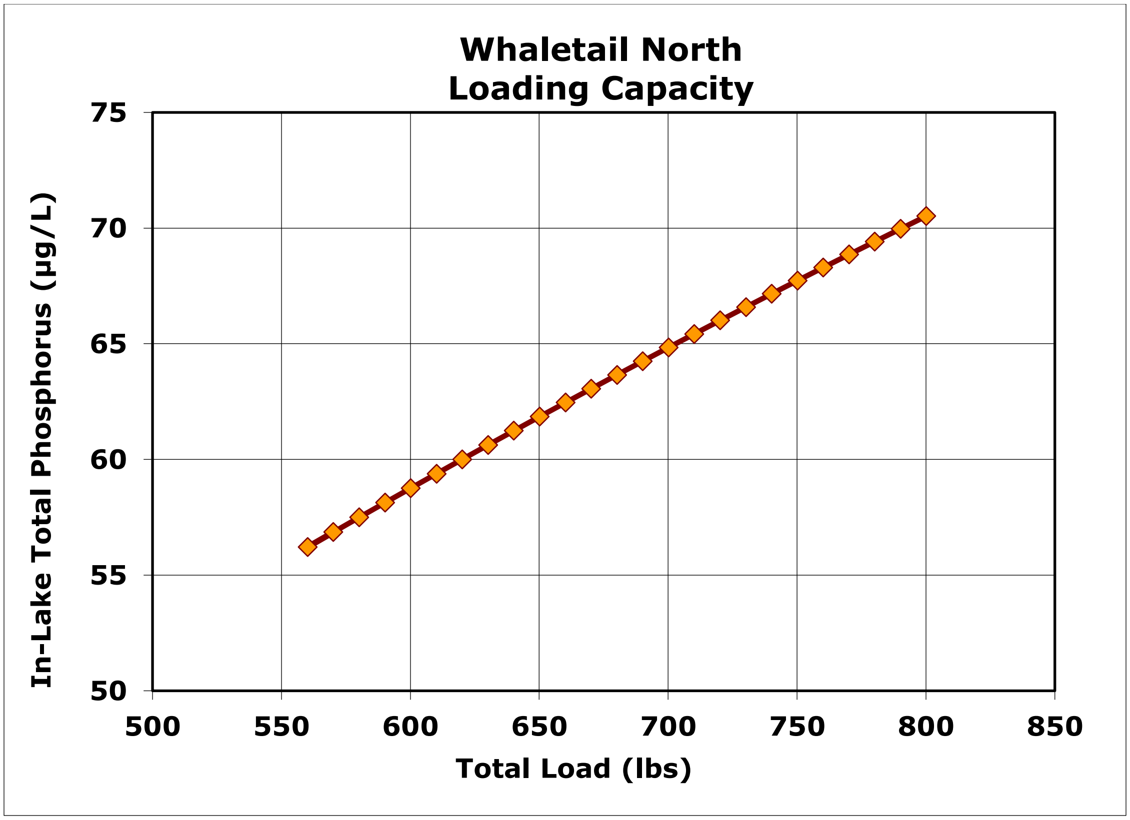


Figure 7: Whaletail Lake-North basin load response curve.

Section 2.3.3 Management Recommendations

The primary focus in managing nutrient enrichment in Minnesota lakes has been to emphasize the control of phosphorus because of its role as a limiting nutrient in lake productivity. The onset of severe algal blooms with a corresponding decrease in water clarity is an in-lake response for lakes with excessive amounts of phosphorus. Consequently, the reduction of phosphorus loading sources for both Whaletail South & North basins are the recommended management strategies to improve water quality.

The Pioneer-Sarah Creek Watershed TMDL indicated that the Whaletail South basin water quality is significantly influenced by internal loading sources. Internal loading accounted for 80% of the total phosphorus load to the South basin while watershed loading only accounted for 12% of the total phosphorus load. Based on the nutrient budget data, Whaletail South is an excellent candidate to improve water quality through the implementation of an alum treatment for the long-term control of internal loading. The TMDL recommended an alum treatment for control of in-lake phosphorus sediment release as the primary management strategy to improve water quality for the South basin (Table 5); and that the control of sediment phosphorus release would achieve the necessary phosphorus load reductions required for the lake to meet the State's water quality standards and ultimately be removed from the MPCA's impaired water's list.

Table 5: Whaletail Lake-South basin lake phosphorus TMDL and allocations.

Whaletail South Lake						
Load Category	Load Component	Existing Load (lbs/yr)	Allowable Load (lbs/yr)	Estimated Load Reduction		TMDL (lbs/day)
				(lbs/yr)	%	
Wasteload Allocation	Construction/Industrial Stormwater	3.7	3.7	0.0	0%	0.010
	Total WLA	**3.7**	**3.7**	**0.0**	**0%**	**0.010**
Load Allocation	Non-MS4 Runoff	60.0	60.0	0.0	0%	0.164
	Atmospheric deposition	41.7	41.7	0.0	0%	0.114
	Internal Load	423.5	243.3	180.2	43%	0.667
	SSTS	0.029	0.000	0.029	100%	0.000
	Total LA	**525.2**	**345.0**	**180.2**	**43%**	**0.667**
Margin of Safety		**0.0**	**18.4**			**0.050**
TOTAL LOAD		**528.9**	**367.0**	**180.2**	**34%**	**1.005**

Note: TMDL allocations include the margin of safety to ensure meeting water quality goals.

Table 6: Whaletail Lake-North basin lake phosphorus TMDL and Allocations.

Whaletail North Lake						
Load Category	Load Component	Existing Load (lbs/yr)	Allowable Load (lbs/yr)	Estimated Load Reduction		TMDL (lbs/day)
				(lbs/yr)	%	
Wasteload Allocation	Construction/Industrial Stormwater	6.2	6.2	0.0	0%	0.017
	Total WLA	**6.2**	**6.2**	**0.0**	**0%**	**0.017**
Load Allocation	Upstream Lake Whaletail S	107.5	86.2	21.3	20%	0.236
	Non-MS4 Runoff	297.4	201.0	96.5	32%	0.551
	Atmospheric deposition	99.2	99.2	0.0	0%	0.272
	Internal Load	291.0	196.6	94.4	32%	0.539
	SSTS	0.060	0.000	0.060	100%	0.000
	Total LA	**795.2**	**583.0**	**212.2**	**27%**	**1.597**
Margin of Safety		**0.0**	**31.0**			**0.085**
TOTAL LOAD		**801.4**	**620.2**	**212.2**	**26%**	**1.699**

Note: TMDL allocations include the margin of safety to ensure meeting water quality goals.

The improvement in water quality for the South basin may provide a secondary water quality benefit for the North basin. It was determined from the TMDL that the South basin accounted for 26% of the total watershed loading to the North basin. At the time the TMDL was completed, the North basin was close to meeting water quality standards every year from 2011 to 2016. The TMDL recommended reducing watershed loading from non-MS4 by 32% and from upstream Whaletail South basin by 20% (Table 6). It was also recommended that a 32% reduction in internal load would be needed for the lake to achieve water quality standards (Table 6). However, the most recent data after the TMDL was completed indicated that the North basin water quality has improved and has been meeting the phosphorus standard the past several years since 2017. The primary factors contributing to the overall water quality improvement for the North basin are uncertain, but most likely triggered by a change in the submersed aquatic plant community after the TMDL was completed. Water quality improvements of the South basin could ultimately be the tipping point that ensures the lake will continue to meet water quality standards and be removed off the impaired water's list.

In summary, an alum treatment implemented on the South basin could significantly reduce the phosphorus loading to both basins (South & North) that would be needed to ensure removal from the impaired water's list. Despite the potential water quality benefits for both basins, this feasibility study is focused on primarily improving the water quality of the South basin through the implementation of an alum treatment.

Section 3.0 Alum Feasibility

Sediment cores were collected (2014) on the South and North basin of Whaletail Lake to estimate internal loading attributed to sediment phosphorus release for the Pioneer-Sarah Creek Watershed TMDL. The University of Wisconsin Stout Laboratory analyzed sediment cores for determination of phosphorus release under aerobic and anaerobic conditions (Appendix B; James 2014). The upper 10-cm layer was sectioned from duplicate cores to further evaluate sediment physical-textural and chemical characteristics. The sediment chemistry data was used to determine alum dosage needed to sequester redox-sensitive phosphorus from being released during anoxic conditions. The sediment analysis study (Appendix B) was used for the alum feasibility portion of this document.

Section 3.1 Sediment Phosphorus Release Rates

Sediment cores were collected in Whaletail Lake for determination of rates of phosphorus release under aerobic and anaerobic conditions. A gravity sediment coring device equipped with an acrylic core liner was used to collect sediment from three locations in October of 2014 (Figure 8). The sediment cores were incubated at a constant temperature (20° C). The oxidation-reduction environment in the overlying water was controlled by gently bubbling air (aerobic) or nitrogen (anaerobic) through an air stone placed just above the sediment surface in each core. Water samples were collected daily for soluble reactive phosphorus (SRP) analysis.

Regression analysis was used to estimate phosphorus sediment release rates over the linear portion of the data.

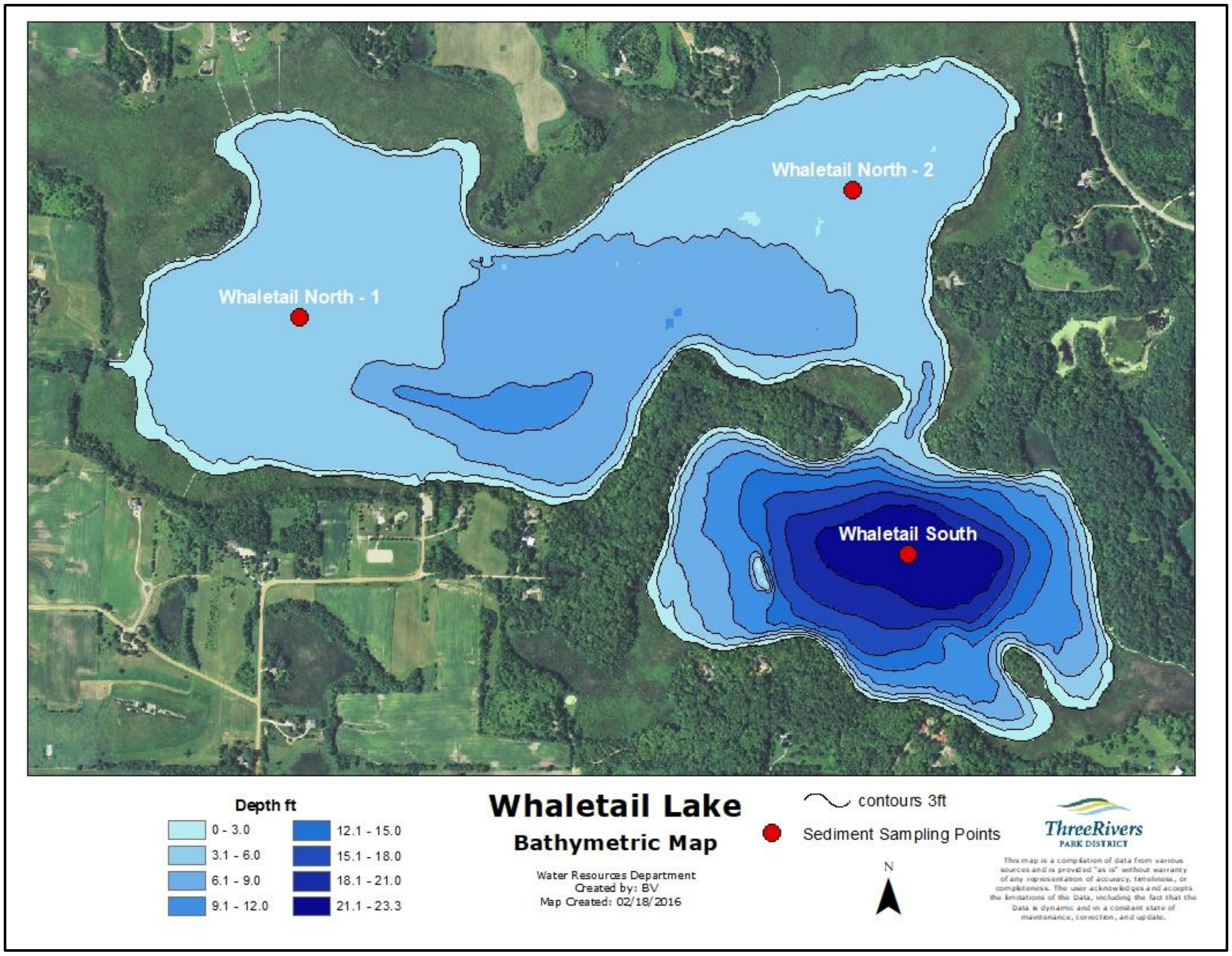


Figure 8: Whaletail Lake sediment sampling stations for North and South basins.

Sediment phosphorus release rates under anaerobic conditions increased linearly throughout the incubation period. Phosphorus concentrations (SRP) were highest for Whaletail South basin in comparison to the North basin. The average SRP concentrations for the South basin were 684 µg/L at the end of the incubation period (Table 7). In contrast, the average SRP concentration for Whaletail North basin was more than a magnitude lower for station 1 at 37 µg/L and station 2 at 26 µg/L (Table 7). The higher SRP concentrations in the South basin corresponds to a higher phosphorus release rate of 5 mg/m^2 per day in comparison to the North basin release rates for station 1 at 0.29 mg/m^2 per day and station 2 at 0.23 mg/m^2 per day (Table 7).

Soluble phosphorus accumulation in the overlying water column was lower under aerobic conditions in comparison to anaerobic conditions. The average SRP concentration for the South basin was relatively low at 52 µg/L with a phosphorus release rate of 1.0 mg/m^2 per day (Table 7). In contrast, the SRP concentrations and phosphorus release rates for the North basin was considerably lower for station 1 (24 µg/L; 0.37 mg/m^2 per day) and station 2 (< 5 µg/L; 0.03 mg/m^2 per day) (Table 7).

Table 7: Whaletail Lake average sediment phosphorus release rates and concentrations under aerobic and anaerobic conditions near the end of the incubation period.

Station	Sediment Phosphorus Release			
	Aerobic		Anaerobic	
	mg/m^2 day	µg/L	mg/m^2 day	µg/L
Whaletail North - 1	0.37	24	0.29	37
Whaletail North - 2	0.03	< 5	0.23	26
Whaletail South	1.00	52	5.00	684

Note: Appendix B for additional detail.

The sediment phosphorus release rates were used to determine the internal loading potential for each basin as part of the TMDL. Internal loading for each basin was estimated using the Nürnberg (1984 & 1988) method where sediment release rates were multiplied by the surface areas for anaerobic (anoxic) or aerobic (oxic) conditions and then multiplied by the number of anoxic days per year. The Nürnberg internal loading estimates were used as a reference for adjusting the internal load needed to calibrate the in-lake response model to the observed water quality conditions.

The sediment phosphorus release data supports the TMDL recommendation for a prescribed alum treatment in the South basin of Whaletail Lake. The internal phosphorus loading potential under both aerobic and anaerobic conditions was greatest for the South basin and negligible for the North basin. In addition, the phosphorus concentrations and sediment phosphorus release rates were highest during anaerobic conditions. The alum treatment should focus on the deepest areas of the South basin that have anoxic conditions with the highest sediment phosphorus release. The internal load estimates are beneficial with regards to providing a target to achieve phosphorus reductions needed to meet water quality standards for Whaletail South basin.

Section 3.2 Sediment Chemistry

The sediment chemistry data is important for the determination of alum dosage to target redox-sensitive phosphorus release. Previous studies analyzing different fractions of sediment phosphorus at 1-cm intervals have indicated that the upper 10-cm layer is the most active with respect to diffusive sediment-phosphorus flux (James 2013 & 2018). Consequently, the upper 10-cm layer was the primary focus for sediment chemistry analysis. The upper 10-cm layer was sectioned from duplicate cores to evaluate sediment physical-textural and chemical characteristics. The specific methods used for sediment chemistry analysis are provided in the Whaletail Lake sediment analysis report (Appendix B). Whaletail Lake physical-textural and chemical sediment analysis results are provided in the following Tables 8 – 10.

Table 8: The physical textural characteristics of the upper 10-cm layer for sediment cores collected from the South and North basins of Whaletail Lake.

Station	Moisture Content (%)	Wet Bulk Density (g/cm^3)	Dry Bulk Density (g/cm^3)	Organic Matter (%)
Whaletail North - 1	94.8	1.007	0.053	77.1
Whaletail North - 2	96.4	1.007	0.037	69.1
Whaletail South	94.9	1.019	0.053	39.6

The sediment physical textural characteristics for both basins had high moisture content with very low bulk densities in the upper sediment layers indicating very flocculent and high porosity sediments. These characteristics are very conducive for an alum floc to mix into the surface sediments to sequester redox-sensitive phosphorus flux. A high percentage of the sediment composition for the North basin of Whaletail Lake is made up of organic matter (Table 8). The sediment composition for the South basin also has a moderate amount of organic matter that is considerably lower in comparison to the North basin. Sediment with high organic matter content typically have lower potential for redox-sensitive phosphorus flux. Based on organic matter content, the North basin doesn’t appear to be a good candidate for an alum treatment. The data further suggests that the South basin has a higher potential for redox-sensitive phosphorus flux that is more conducive to target with an alum treatment application.

Table 9: Concentrations of biologically labile and refractory phosphorus in the upper 10-cm layer for sediment cores collected from the North and South basins of Whaletail Lake.

Station	Loosely-bound P (mg/g DW)	Iron-bound P (mg/g DW)	Iron-bound P (µg/g FW)	Labile organic P (mg/g DW)	Aluminum-bound P (mg/g DW)
Whaletail North - 1	0.026	0.079	4	0.405	0.092
Whaletail North - 2	0.046	0.122	4	0.576	0.132
Whaletail South	0.105	0.603	31	0.564	0.170

Note: DW = Dry Mass & FW = Fresh Mass

Table 10: Concentrations of sediment total phosphorus (P), redox-sensitive P (Redox P is the sum of the loosely-bound and iron-bound P fraction) and biologically-labile P (Bio-labile is the sum of redox-P and labile organic P), in the upper 10-cm sediment North and South basins of Whaletail Lake.

Station	Total P	Redox P		Bio-labile P	
	(mg/g DW)	(mg/g DW)	(% total P)	(mg/g DW)	(% total P)
Whaletail North - 1	0.977	0.105	10.8%	0.510	52.2%
Whaletail North - 2	1.232	0.168	13.6%	0.744	60.4%
Whaletail South	1.929	0.708	36.7%	1.272	66.0%

Note: DW = Dry Mass

Sediment chemistry data confirms that the Whaletail South basin has a higher redox-sensitive phosphorus flux potential than the North basin. The South basin sediments exhibited much higher concentrations of total phosphorus, loosely-bound phosphorus, and iron-bound phosphorus (Tables 9 & 10). In contrast, the loosely-bound and iron-bound phosphorus concentrations were very low in the North basin sediments and biologically-labile phosphorus was dominated by organic phosphorus fractions. This coincided with the very high organic matter content in the North basin sediments as it accounted for 70% to 77% of the sediment composition (Table 8).

The redox phosphorus is the sum of the loosely-bound and iron-bound phosphorus fractions, which represents the portion of phosphorus released during periods of anaerobic conditions. The South basin had higher redox phosphorus concentrations than the North basin. James and Bischoff (2015) have indicated that redox-phosphorus concentrations greater than 0.1 mg/g are associated with lake sediments that have high phosphorus release rates. Sediments from the South basin had a very high redox-phosphorus concentrations of 0.708 mg/g (Table 10). In contrast, the North basin had substantially lower redox-phosphorus concentrations ranging from 0.105 mg/g to 0.168 mg/g (Table 10). The redox-phosphorus concentrations correspond with the higher sediment phosphorus release rates observed for the South basin in comparison to the North basin. An alum application is the recommended management approach for the South basin because sediments are more conducive to target and sequester redox-sensitive phosphorus to improve water quality.

Section 3.3 Alum Dosage and Application Strategy

Redox-phosphorus concentrations were used to determine an alum dosage for the South basin of Whaletail Lake. The redox-sensitive phosphorus (sum of loosely-bound P & iron-bound P) concentration (mg/g) analyzed as a composite for the upper 10-cm sediment layer was used to estimate a range of alum dosages at 1-cm intervals from the upper 5-cm to 7-cm sediment layer. The dry mass concentration of redox-phosphorus (mg/g) from the sediment chemistry data (Table 10) was converted to an aerial concentration (g/m^2) using the following equation:

Redox-P (g/m^2) = Redox-P (mg/g) * ρ (g/cm^3) * θ * h (m) * 1,000,000 (cm^3/m^3) * 0.001 (g/mg)

ρ = Sediment Wet bulk density (g/cm^3)

θ = Percentage of sediment solids (100-percent moisture content/100)

h = sediment thickness (m)

The alum dosage concentration (g/m^2) was estimated by multiplying the Redox-P (g/m^2) for each sediment layer by the Aluminum to Phosphorus binding ratio (Al:P). The Al:P ratio was the amount of alum required to bind one part of redox-sensitive phosphorus. The Al:P binding ratio was derived empirically from an equation developed by James and Bischoff (2015) for east-central Minnesota and west-central Wisconsin lakes. The Al:P ratio estimated for the Whaletail South basin was 37.74.

Al (g/m^2) = Redox-P (g/m^2) * Al:P

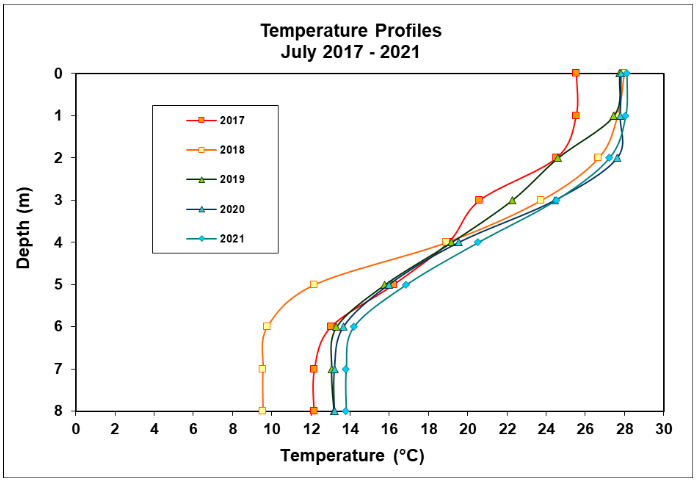
Al:P = 30.20649 * (Redox-P (mg/g) $^{-0.644638}$

The alum dosage estimated as a function of sediment thickness for each 1-cm intervals from the 5-cm to the 7-cm layer are provided in Table 11. The alum dosages ranged from 69.4 g/m^2 to 97.2 g/m^2 for the upper 5-cm to 7-cm sediment layer. Redox-phosphorus concentrations typically are the highest within the upper 5-cm layer while concentrations decrease deeper (> 5-cm) in the sediment column (James 2016). Consequently, alum dosage typically targets the sequestration of peak redox-phosphorus concentration within the upper 5-cm sediment layer. A slightly more conservative approach for this feasibility study recommends a prescribed alum dosage of 84 g/m^2 that would target the sequestration of redox-sensitive phosphorus within the upper 6-cm sediment layer.

Table 11: Estimated alum dosage for the upper 5-cm to 7-cm sediment layer at 1-cm intervals.

Sediment Thickness	Redox-P (mg/g)	Alum Dosage (g/m^2)
0-5-cm	0.708	69.4
0-6 cm	0.708	83.3
0-7 cm	0.708	97.2
Average	0.708	83.3

Another factor that needs to be considered for the alum application is defining the treatment area. The data indicated that highest phosphorus sediment release for Whaletail South basin occurred during anaerobic (anoxic) conditions. Anoxic depth is defined as the sediment area that is exposed to dissolved oxygen lower than 2 mg/L, which typically corresponds with the seasonal changes in lake stratification. The temperature and dissolved oxygen profiles collected during the bi-weekly water quality monitoring was used to determine the anoxic depth for the Whaletail South basin. The most recent temperature and dissolve oxygen profiles from 2017 to 2021 indicated that Whaletail South basin anoxic depth was 3-meters (9.8 ft) during the peak of anoxia and summer stratification in July (Figure 9). Consequently, the 9-ft depth contour for Whaletail South represented the area that will be treated with alum. It was determined that the alum application treatment area for depths greater than 9-ft was approximately 101.2 acres (Figure 10).



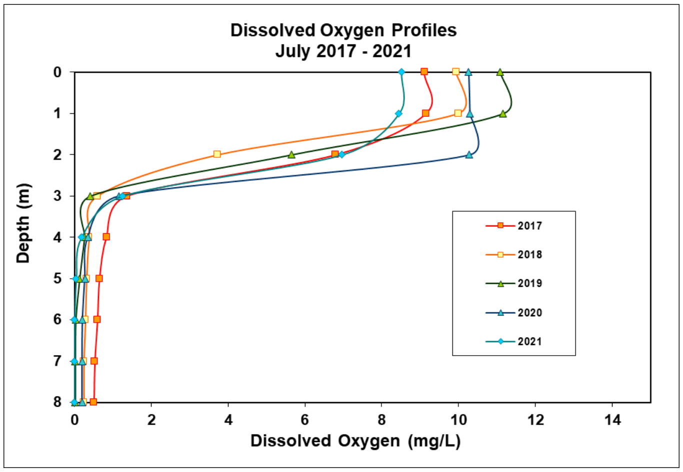


Figure 9: Whaletail Lake-South basin temperature and dissolved oxygen profiles for July 2017-2021.

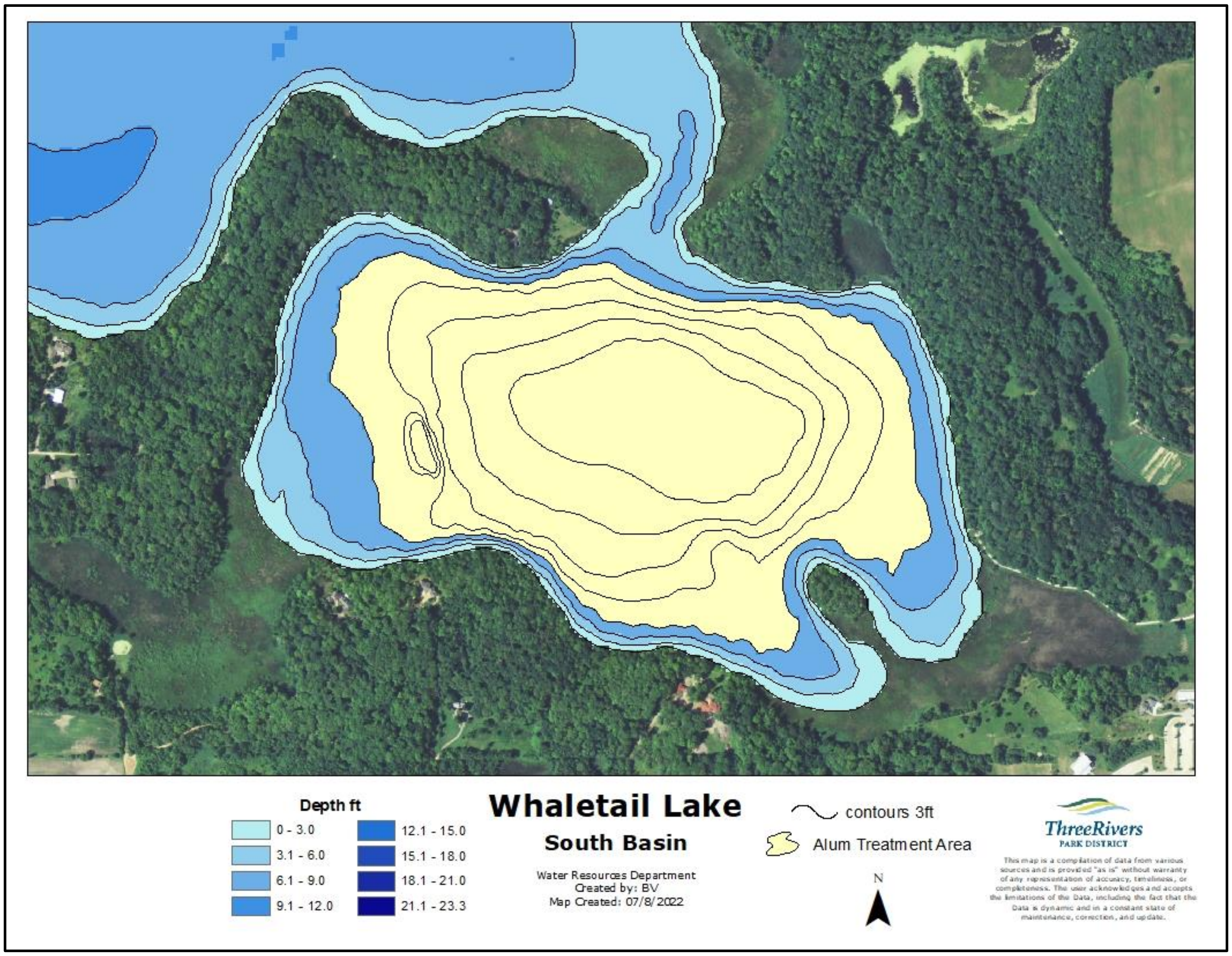


Figure 10: Whaletail Lake-South basin alum treatment area.

The alum dosage for South basin of Whaletail Lake accounts for the binding of the more rapidly mobilized redox-sensitive phosphorus. Resent research has indicated that it is important that alum is readily exposed to sediment redox-sensitive phosphorus within 90-days to improve overall binding efficiency (Berkowitz et al. 2005; De Vicente et al. 2008). Alum binding efficiency decreases in the absence of phosphorus exposure due to changes in crystalline structure of the floc. It is suggested that smaller doses spread out over several years, versus one large dose, might maintain higher binding efficiencies for any potential future phosphorus sources that may decrease alum effectiveness. It is recommended that the Whaletail Lake South basin alum treatment should be applied as two smaller half-doses of 42 g/m^2 to improve overall binding efficiency and long-term control of internal loading.

Section 3.4 Estimated Load Reduction and In-lake Response

Alum dosage was estimated as the concentration (g/m^2) required to bind at least 90% of the redox-phosphorus in the sediments. The Al:P binding ratio is important for the determination of the alum dosage. James and Bischoff (2015) developed relationships between variations in in the Al:P binding ratio over a broad range of redox-phosphorus concentrations for sediment collected from a variety of lakes in Wisconsin and Minnesota. The Al:P ratio equation provided in Section 3.3 for Alum dosage calculation estimates the binding ratio required to adsorb at least 90% of the redox-phosphorus in the sediment (James and Bischoff 2015). It is anticipated that the proposed alum treatment for the South basin of Whaletail Lake will reduce internal loading by at least 90%.

The South basin of Whaletail Lake has an estimated internal load from redox-phosphorus of 423 pounds per year. An estimated internal load reduction of 90% after the alum treatment would result in an annual internal loading estimate of approximately 42 pounds of phosphorus per year. This is an estimated internal load reduction of approximately 381 pounds of phosphorus per year.

The in-lake response model developed for the South basin of Whaletail Lake was used to determine the anticipated in-lake phosphorus concentration change. The internal load portion of the model was reduced approximately 381 pounds of phosphorus to reflect the 90% binding efficiency of the redox-sensitive phosphorus from the alum treatment. The model estimated that the anticipated internal load reduction from the alum treatment would result in an in-lake phosphorus concentration of 25.7 µg/L. This is significantly below the MPCA in-lake phosphorus standard of 40 µg/L.

Table 12: Whaletail Lake-South basin estimated in-lake phosphorus concentration after 90% reduction of internal phosphorus loading after the alum treatment.

Condition	Phosphorus Loading (Pounds)				In-Lake TP (µg/L)
	Watershed	Internal	Atmosphere	Total	
TMDL Existing	63.7	423.5	41.7	528.9	49.9
Alum Treatment	63.7	42.0	41.7	147.4	25.7
Difference	0	381.5	0	381.5	24.2

It is anticipated that in-lake phosphorus concentration improvements for the South basin would effectively reduce the phosphorus load to the North basin of Whaletail Lake. The North basin receives approximately 107.5 pounds of phosphorus per year from the South basin, which accounts for approximately 26% of the watershed load and 13.4% of the total phosphorus loading identified in the TMDL for the North basin. The anticipated improvement in the South basin phosphorus concentration of 25.7 µg/L would reduce the phosphorus loading to the North basin by 51.7 pounds. This reduction would suggest that the South basin would account for approximately 55.8 pounds of phosphorus per year delivered to the North basin following an alum treatment. The phosphorus load reduction due to the alum treatment in the South basin represents approximately 24% of the load reduction that was identified for the North basin to meet MPCA state phosphorus standards. Since the North basin has been meeting the phosphorus standards since the TMDL was completed, any water quality improvements in the South basin would ensure that the North basin will continue to meet standards.

Section 3.5 Alum Longevity

Alum treatments on lakes have been occurring for decades (Huser et al. 2016). There have been several studies that have evaluated the variations in overall effectiveness and longevity relative to water quality improvements (Welch & Cooke 1999, Huser et al. 2016, James & Bischoff 2020). A study conducted by Huser et al. 2016 examined 114 lakes previously treated with alum to determine the main factors influencing treatment longevity and effectiveness. Stepwise Multiple Linear Regression analysis was used to identify the most important variables influencing treatment longevity. A Multiple Linear Regression model was then developed using these most influential variables to predict the overall longevity and effectiveness of future alum treatments (Huser et al. 2016).

$$\textbf{Log(TP Longevity)} = \beta_0 + \beta_1\textbf{*Log(Al dose)} + \beta_2\textbf{*Log(WA:LA)} + \beta_3\textbf{*Log(OI)}$$

Table 13: TP Longevity model variables and regression coefficients developed to predict future alum treatment longevity and effectiveness. Model developed by Huser et al. 2016.

Model		Regression
Parameter	**Term**	**Coefficient**
Y-Intercept	Intercept	$\beta_0 = -0.50$
Al Dose	Alum dose	$\beta_1 = 1.3$
WA:LA	Watershed:Lake Area Ratio	$\beta_2 = -0.79$
OI	Osgood Index	$\beta_3 = 0.37$

Osgood Index = $Zm/(A)^{0.5}$

Zm= Mean water column depth (m)

A is surface area of water body in (km^2)

The Multiple Linear Regression Model has a coefficient of determination (R^2 = 0.82) that suggests the model variables accurately predicts alum longevity (Huser et al. 2016). It is anticipated that the alum treatment will significantly improve water quality of the South basin of Whaletail Lake. To estimate the longevity of the alum treatment, the parameters for the South basin of Whaletail Lake were input into the Multiple Linear Regression Model. The model predicted that the alum treatment would be effective for a period of 57 years. It is important to note that this analysis should not be interpreted as the exact life of the alum treatment. The longevity effectiveness does not account for the gradual released labile organic phosphorus, the slower phosphorus diffusion upward from deeper sediments, or the rate of sediment deposition that buries the Alum floc overtime. It is difficult to predict the overall impact these other sources of phosphorus have on alum treatment longevity.

Section 3.6 Alum Application Costs & Cost-Benefit Analysis

The breakdown of total cost estimates for the alum application on the South basin of Whaletail Lake are provided in Table 14. There are two chemical treatment cost scenarios provided for the alum application using aluminum sulfate versus aluminum sulfate-sodium aluminate buffer. The alum chemical product used for the application will be based on jar testing procedures to determine the anticipated pH change in response to the prescribed alum dose of each chemical treatment scenario. The jar testing procedure will be important to ensure that there are no negative ecological impacts related to low pH levels in response to the alum treatment. Aluminum-sulfate will be the preferred alum treatment option unless jar testing procedures indicates a decrease in pH levels below a critical threshold that potentially can cause ecological damage; whereby, buffered alum with sodium aluminate will be the preferred treatment option to ensure that there are no negative pH ecological impacts related to the application. The alum chemical used for the treatment will be determined prior to requesting bids for the project.

The feasibility study recommends an alum treatment at a dosage of 84 g/m^2 applied at depths greater than 9-feet over 100 acres of the South basin of Whaletail Lake. The alum treatment should be applied as two smaller half-doses of 42 g/m^2 to improve overall binding efficiency and long-term control of internal loading. Sediment cores should be taken to verify the second dose application rates are still valid or need to be adjusted to convert redox-phosphorus in the uppermost 6-cm to aluminum bound phosphorus. Assuming alum dosage does not need to be adjusted for the second application, the total cost estimates of the alum applications (total dosage of 84 g/m^2) would range from $430,714 to $504,228 depending on the alum chemical used for the treatment. Although the regression model predicted that the alum treatment would be effective for a period of 57 years, a more conservative estimate of 20 years was used for the cost-benefit analysis. It was assumed that the alum application was successful at sequestering 90% of the redox-phosphorus in the upper 6-cm and removed approximately 381 pounds of phosphorus per year. Based on the total cost of the alum application and the estimated internal load reduction over a 20-year period, the alum application cost-benefit analysis indicates that it costs approximately $57 to $66 to remove one pound of phosphorus. This estimated alum treatment cost-benefit for phosphorus removed is considerably lower in comparison to best management practices implemented in the watershed with cost-benefit ranging from $500 to $3000 per pound of phosphorus removed.

Table 14: Cost estimates for aluminum sulfate vs aluminum sulfate/sodium aluminate treatment dosage of 84 g/m² applied at depths > 9-feet (3-m) over 100 acres of the South basin of Whaletail Lake.

Item	Unit	Quantity	Unit Cost	Total Cost
Mobilization & Demobilization of Staging Area	**Each**	**2**	**$23,000**	**$46,000**
1st Aluminum Sulfate Treatment-Dosage of 42 g/m² applied at depths > 9 feet over 100 acres	Gallons	77,490	$2.35	$182,102.09
2nd Aluminum Sulfate Treatment-Dosage of 42 g/m² applied at depths > 9 feet over 100 acres	Gallons	77,490	$2.35	$182,102.09
Application Total-Dosage of 84 g/m² applied at depths > 9 feet over 100 acres	**Gallons**	**154,981**	**$2.35**	**$364,204.18**
Total Cost Estimate = Mobilization + Total Alum Treatment Costs for 82 g/m²				**$410,204.18**
Total Cost Estimate with 5% Contingency				**$430,714.39**

Item	Unit	Quantity	Unit Cost	Total Cost
Mobilization & Demobilization of Staging Area	**Treatments**	**2**	**$23,000**	**$46,000**
1st Aluminum Sulfate Treatment-Dosage of 42 g/m² applied at depths > 9 feet over 100 acres	Gallons	33,350	$2.35	$78,372.50
1st Sodium Aluminate Buffer-Dosage of 42 g/m² applied at depths > 9 feet over 100 acres	Gallons	16,675	$8.32	$138,736.00
Sub-total for 1st Treatment				**$217,108.50**
2nd Aluminum Sulfate Treatment-Dosage of 42 g/m² applied at depths > 9 feet over 100 acres	Gallons	33,350	$2.35	$78,372.50
2nd Sodium Aluminate Buffer-Dosage of 42 g/m² applied at depths > 9 feet over 100 acres	Gallons	16,675	$8.32	$138,736.00
Sub-total for 2nd Treatment				**$217,108.50**
Total Cost for Alum Treatment-Dosage of 84 g/m²	**Treatments**	**2**	**$217,108.50**	**$434,217.00**
Total Cost Estimate = Mobilization + Total Alum Treatment Costs for 84 g/m²				**$480,217.00**
Total Cost Estimate with a 5% Contingency				**$504,227.85**

Section 4.0 Additional Management Considerations

This section identifies the additional management activities that needed to be considered prior to the development of the alum treatment feasibility study. We recognize that there are always additional sources of phosphorus loading (watershed and internal) that potentially may compromise the longevity of the alum treatment. These alternative sources of phosphorus loading were monitored and/or evaluated prior to the development of the feasibility study to ensure the optimal longevity and effectiveness of the proposed alum treatment. Currently, these potential sources of phosphorus loading were shown to have minimal impact on the longevity of a prescribed alum treatment application. However, it should be noted that these potential sources of phosphorus loading need to be continually monitored or evaluated to ensure overall alum effectiveness and longevity. Adaptive management approaches will need to be considered if these alternative sources of phosphorus loading become significant and potentially impact alum treatment longevity.

Section 4.1 Watershed Loading

The South basin of Whaletail Lake does not receive a significant amount of watershed loading. The Pioneer-Sarah Creek Watershed TMDL indicated that the South basin of Whaletail Lake receives approximately 64 pounds of phosphorus loading from the 661 acres of watershed area draining to the lake (unit area load of 0.1 pound/acre). The watershed loading accounts for approximately 12% of the total nutrient loading budget to the South basin of the lake. Factors that contribute to the low amount of the watershed loading include the following:

- The South basin of Whaletail Lake has a small watershed to lake area ratio of 4.2 to 1.
- A major portion of the watershed is approximately 36% natural park reserve land use. Other land uses within the watershed include 26% undeveloped, 3.6% agricultural, and only 4% of the watershed is considered developed single family residential.
    - Three Rivers Park District - Kingswood Park consists of 122-acres of natural park land located in Minnetrista on Little Long Lake. The park has unique glacial terrain as well as a tamarack bog. It also has a large stand of the original big woods forest comprised mostly of old growth sugar maple and basswood.
    - Three Rivers Park District -Gale Woods Regional Park is a 410-acre park located in Minnetrista. Gale Woods has approximately 119-acres of natural park land comprised of old growth forest and wetlands that is within the Whaletail South basin watershed.
- Little Long Lake located at the headwaters of the watershed drains to the South basin of Whaletail Lake. Kingswood Park includes over 70% of the Little Long Lake natural shoreline. The lake and surrounding uplands are considered some of the most pristine high quality natural resources in the area. Little Long Lake also has exceptional water quality that can support a two-story fishery that includes trout as well as panfish and northern pike. The lake is known to have the best water quality in Hennepin County.

There have not been any significant changes in the Whaletail Lake South basin watershed since the completion of the TMDL in 2017 (Appendix D). The Kingswood Park property has a Department of Natural Resources conservation easement that ensures the protection of a rare glacial esker as well as a rich fen wetland and natural shoreline along Little Long Lake. The conservation easement also protects the area from being developed. In addition, Three Rivers Park District purchased an additional 16-acres that was residential property adjacent to Kingswood Park on Little Long Lake in 2019. The residential home was demolished and removed from the site; and the property was restored to more natural conditions to become part of Kingswood Park. The Kingswood Park land corridor extends south to connect with the Gale Woods Regional Park that has 1.9 miles of shoreline on Whaletail Lake (represents 29% of the entire lake shoreline). These two areas make up a significant portion of the watershed acreage draining to the South basin of Whaletail Lake. These parks will continue to remain within their natural condition, which will ultimately benefit the long-term water quality of the South basin of Whaletail Lake.

The watershed for the North basin of Whaletail Lake includes the South basin subwatershed as well as a drainage area that is located west and north of the lake. The Whaletail Lake North basin receives approximately 108 pounds of phosphorus from the South basin, which represents 26% of the total watershed phosphorus load (411 pounds). The remaining 74% of the watershed phosphorus load (303 pounds of phosphorus) is primarily from 924-acres from the area located west and north of Whaletail Lake North basin. There have not been any significant changes in this portion of the watershed since the TMDL has been completed (Appendix D). A significant portion of the west and north drainage area (approximately 49%) classified as undeveloped land use is predominately wetland. Agricultural land use also represents a significant portion of the watershed accounting for 31% of the 924-acres. Other land uses include 11% Single Family Residential, 4% Industrial/Commercial, and 3% Parkland. Based on the percentages of different land use types, there is more of an opportunity to implement best management practices in the watershed draining to Whaletail Lake North basin.

Currently, the North basin of Whaletail Lake is meeting the MPCA state phosphorus standards since the completion of the TMDL in 2017. An alum treatment in the South basin of Whaletail Lake was already a management strategy proposed to improve the water quality of both the South and North basins. The alum treatment would most certainly improve the water quality for the South basin with the anticipated future removal from the MPCA's impaired water's list. The alum treatment would further help ensure that the North basin will continue to meet state phosphorus standards. It is also recommended that monitoring changes in land use for both the South and North basin watershed will be critical relative to maintaining or improving water quality for the lake. Best management practices implemented in the South and North basin watershed when opportunities become available would help ensure the longevity of the alum treatment and ensure the North basin continues to meet water quality standards.

Section 4.2 Curly-leaf Pondweed Senescence

Another source of internal loading that has potential water quality impacts is the senescence of curly-leaf pondweed. The senescence of curly-leaf pondweed can be a significant source of internal phosphorus loading due to its unique life cycle. The plant germinates from turions (seed structures) in early fall and continues to grow slowly during the winter months. Growth increases substantially after ice-out due to increased light availability. The plant begins to die-off (senescence) after the completion of turion production by the end of June or early July. Nutrients released from senescence are in a soluble form readily available for algae uptake. Consequently, algal blooms frequently develop after senescence causing a decrease in water quality earlier in the season.

The nutrients released from curly-leaf pondweed senescence were taken into consideration for the estimate of internal loading for both the South and North basin of Whaletail Lake. Aquatic vegetation point-intercept surveys were conducted on both basins of Whaletail Lake in 2013 as part of the development of the TMDL. At the time, the Whaletail South basin had small enough amounts of curly-leaf pondweed where it was not considered part of the internal load calculation. However, there was a marginal amount of curly-leaf pondweed found in the North basin where internal load from senescence was estimated at 213 pounds per year.

Since the Whaletail Lake TMDL has been completed, there has been point-intercept aquatic vegetation surveys conducted on both basins from 2016 to 2022 (Appendix E). Based on these surveys, the percent frequency of curly-leaf pondweed found in both basins has not been very significant. The percent frequencies for the South basin have ranged from 3% in 2019 to 15% in 2021; and the percent frequencies for the North basin have ranged from 2% in 2019 to 7% in 2021. Previous studies conducted by Three Rivers Park District indicated that curly-leaf pondweed can have a significant impact on internal loading and water quality for lakes with nuisance growth conditions at percent frequencies above 60% of occurrence. Whaletail Lake currently has percent frequencies for both basins well below nuisance growth levels that would degrade water quality conditions.

It is anticipated that there will be changes in the plant community in response to an improvement in water clarity after the alum treatment. The two exotic plant species in Whaletail Lake that could be of special concern are curly-leaf pondweed and Eurasian watermilfoil. An increase in curly-leaf pondweed could certainly compromise the longevity and effectiveness of the alum treatment, and an increase in Eurasian watermilfoil could compete and displace native plant species. Three Rivers Park District will continue to evaluate changes in the plant community as part of the post-alum monitoring efforts by conducting spring and fall point-intercept surveys on both basins of Whaletail Lake. An adaptive management approach will need to be considered to control curly-leaf pondweed and Eurasian watermilfoil if nuisance growth conditions develop.

Section 4.3 Carp Population/Biomass

Carp population-sediment dynamics is an important consideration when recommending a prescribed alum treatment. The common carp is an invasive fish that has the potential to cause ecological damage to aquatic ecosystems. Adult common carp are highly proficient at feeding in bottom sediments where they damage rooted vegetation, release nutrients/sediments in the water column, and degrade water quality. Recent studies have indicated that moderate densities of large carp can increase the mixed sediment layer depth that further exacerbates the release of mobile sediment phosphorus to the water column (Huser et al. 2015). It was further suggested that high populations of carp can potentially affect alum treatment longevity through sediment disturbance.

Most of the studies that have investigated the ecological impacts of common carp have focused on shallow lakes. Previous studies for shallow lakes in Midwestern North America indicated that carp densities that reach about 100 kg/ha have about a 50% reduction in native plant cover, which usually is followed by a shift from plant dominated to algal dominated conditions with degraded water quality (Sorenson and Bajer 2020). It was further reported that aquatic plant communities are typically almost absent in shallow lakes when carp biomass exceed 200 kg/ha (Sorensen and Bajer 2020). Carp removal has become the preferred management approach to reduce overall biomass below the 100 kg/ha threshold that causes ecological damage. The colonization of plants in shallow lakes after carp removal is important for an anticipated water quality benefit. A compilation of carp management studies conducted by a graduate student at the University of Minnesota Invasive Species Research Center indicated that there were noticeable improvements in phosphorus concentrations for shallow lakes that achieved the biomass threshold below 100 kg/ha after carp removal (Kacy Rundquist; data presented by Jill Sweet at Water Resources Conference 2020). It appears that carp management is critical and necessary to improve water quality for shallow lakes that have excessive population and biomass of carp.

Although the ecological impacts of carp on shallow lakes are more predictable, the effects of this species on aquatic vegetation, nutrient recycling, and water quality are more complex for thermally stratified deep lakes. It was suggested that carp removal may have restored the macrophyte community within the littoral area of a deeper stratified lake (Susan) in central Minnesota (Bajer and Sorenson 2015). However, another study indicated that there were no improvements in the native plant community after carp removal for a deep lake (Wassermann) within the Six Mile Creek sub-watershed (data presented by Jill Sweet at Water Resources Conference 2020). The consistent conclusion between both studies was that carp removal did not have any apparent effect on phosphorus concentration and appeared to play a relatively minor role in nutrient transport from benthic sediments in stratified eutrophic lakes. This conclusion was further supported from data compiled on carp removal studies for deep stratified lakes conducted by the University of Minnesota Invasive Species Research Center (Kacy Rundquist; data presented by Jill Sweet at Water Resources Conference 2020). The water quality of deeper stratified lakes appeared to be driven more by internal loading from mobile sediment phosphorus release instead of carp sediment bioturbation.

Whaletail Lake South and North basins has two distinct classifications relative to MPCA water quality standards. There was concern that carp may impact the overall longevity of the prescribed alum treatment in the South basin (classified as a deep lake) as well as impacting the aquatic vegetation and water quality in the North basin (classified as a shallow lake). Three Rivers Park District contracted Carp Solutions to estimate population and biomass for Whaletail Lake as part of this feasibility study. Carp Solutions conducted three mark-re-capture surveys (Bajer and Sorensen 2012) from July through August of 2020. The details for the carp population and biomass assessment can be found in Appendix F. The study indicated that the overall biomass density estimate was 133 kg of carp per hectare. While carp biomass density estimate in Whaletail Lake is slightly over the ecological threshold of 100 kg/ha, the abundance of aquatic vegetation in both the South and North basins suggests that the carp are not an immediate concern (Bajer et al. 2020). This conclusion is further supported by the fact that the North basin is currently meeting MPCA shallow lake water quality standards the past several years. The alum treatment for the South basin of Whaletail Lake was prescribed for depths > 9-ft within the stratified anoxic zone where carp most likely won't actively seek out anaerobic habitat when oxygenated areas are readily available as preferred habitat. Based on the relatively low population and biomass estimates, carp impact on alum treatment longevity most likely is negligible for the South basin especially since it has characteristics of a deep stratified lake. The carp population/biomass assessment recommended that carp removal is not a high priority for Whaletail Lake (Baer et al. 2020). Three Rivers Park District will periodically monitor the changes in carp biomass throughout the life-expectancy of the alum treatment; and an adaptive management approach will be taken into consideration with carp removal if there is a significant change in population/biomass.

Section 5.0 Post-Alum Monitoring Plan

It will be critical to implement a post-alum monitoring plan to ensure the longevity and effectiveness of the treatment. This will be accomplished through the combined efforts of cooperating agencies most notably the Pioneer-Sarah Creek Watershed Management Commission, Hennepin County Environment and Energy, City of Minnetrista, and Three Rivers Park District. As part of the 4th Generation Watershed Management Plan, the Pioneer-Sarah Creek Watershed Management Commission is required to conduct monitoring programs (Minnesota Administrative Rule 8410.0100 Subp. 5) capable of producing accurate data to the extent necessary to determine whether the water quality goals of the organization are being achieved. A post-alum monitoring plan to assess overall alum longevity and effectiveness could be considered part of the sampling program identified within the Watershed Management Plan.

The primary objective of the post-alum monitoring program will assess for changes in water quality as well as potential sources of phosphorus loading that may compromise the longevity and effectiveness of the alum treatment. Adaptive management approaches will need to be considered if these alternative sources of phosphorus loading significantly impacts water quality as well as alum treatment longevity. A summary of each monitoring component as well as a sampling schedule (Table 15) for implementation of the plan over the next 20-years is described below in the following sections.

Section 5.1 Lake Water Quality Monitoring

The water quality for the South and North basins of Whaletail Lake will be monitored by the Pioneer-Sarah Creek Watershed Management Commission in partnership with Three Rivers Park District every year. The basins will be monitored bi-weekly from spring after ice-out (April) through the fall after lake turnover (October) to determine seasonal changes in water quality. Samples will be collected at the deepest location within each basin. At each sampling location, a water quality sonde will be used to measure temperature, dissolved oxygen, pH, and conductivity at 1-m intervals from the surface to the bottom. Water clarity will also be measured at each sampling site. Surface water samples will be collected at each basin for analysis of total phosphorus, soluble reactive phosphorus, total nitrogen, and chlorophyll-*a* concentrations. Since the South basin of Whaletail Lake stratifies during the summer, water samples will also be collected at the top of the hypolimnion and 1-m from the bottom to determine seasonal changes in hypolimnetic phosphorus concentration during anoxic conditions. All water samples collected are analyzed for nutrient analysis at the Three Rivers Park District certified laboratory.

Section 5.2 Aquatic Vegetation Surveys

Three Rivers Park District will conduct point-intercept vegetation surveys on the South and North basins of Whaletail Lake every year post-alum treatment to monitor changes in the submersed aquatic plant community. Surveys will be conducted in the spring (June) and fall (August). Spring surveys will monitor potential changes in the density of curly-leaf pondweed as a potential source of internal loading that may impact water quality. The fall surveys are intended to monitor changes in the Eurasian watermilfoil and native plant communities. Survey points were established as a grid for the littoral areas (depth ≤ 15 feet to support aquatic plant growth) of each basin using Geographic Information System (GIS). The South basin of Whaletail Lake has a total of 78 survey points distributed throughout the littoral zone. The entire North basin of Whaletail Lake is considered littoral area that has 114 survey points distributed throughout the entire surface area of the lake. Rake density ratings ranging from 0 (nothing on the rake) to 5 (vegetation covering the entire rake) for each species are assigned at each sampling point. Trend analysis for changes in the plant community will be based on percent frequencies of occurrence for each plant species.

Section 5.3 Sediment Analysis

Three Rivers Park District will periodically collect sediment cores to monitor overall longevity and effectiveness of the alum treatment. The objective of the sediment core analysis will evaluate the sediment and lake water chemistry long-term response to the alum application. Sediment cores will be collected within the alum application area to measure phosphorus release under anaerobic conditions as well as spatial-vertical evaluation of the sediment characteristics. Duplicate intact sediment cores will be collected at 2 or 3 stations for determination of phosphorus release rates under anaerobic conditions. Additional sediment cores (up to 3 cores per station) will be collected and sectioned vertically over the upper 15-cm layer to evaluate variations in sediment physical-textural and chemical characteristics. Sediment phosphorus fractions and aluminum analysis for different sediment thickness intervals will be conducted to determine aluminum-bound phosphorus concentrations relative to sediment layer depth. The monitoring of both the sediment phosphorus release under anaerobic conditions and the aluminum-bound phosphorus analysis will be used to determine the extent the alum layer has been buried and is no longer effective at sequestering mobile redox-sensitive phosphorus release. It is recommended that the post-alum sediment analysis should occur every 5-years to determine whether a maintenance treatment will be needed for the long-term control of internal loading.

Section 5.4 Carp Population/Biomass Assessment

A carp survey will be periodically completed for Whaletail Lake to determine potential changes in population and biomass estimates. The survey would be contracted with a consultant to conduct boat electrofishing surveys from July through September. Each survey will include carp electrofishing efforts at several transects locations on the lake (South and North basins) for a pre-determined time interval (approximately 20-minutes per transect). All fish captured in the surveys will be measured for total length and weighed; and each fish will have a fin clipped prior to being released back to the lake. The carp population and biomass estimates will be based on mark-and-recapture analysis and catch-per-unit-effort data from the electrofishing surveys. Carp removal efforts will be considered when carp population and biomass estimates are significantly above the ecological threshold of 100 kg/hectare. It is recommended that post-alum carp surveys be conducted every 5-years to implement an adaptive management approach for any anticipated carp removal efforts.

Section 5.5 Watershed Best Management Practices Inventory

A priority identified in the 4th Generation Pioneer-Sarah Creek Watershed Management Plan (2020) was the need to evaluate progress towards meeting Total Maximum Daily Load goals. This process will involve developing an inventory of best management practices implemented within the watershed. The municipalities that are considered MS4s already must annually track and report to the MPCA the load reduction benefits of constructed best management practices undertaken to achieve TMDL wasteload allocations as part of their NPDES General Stormwater Permit. A significant portion of the Whaletail Lake watershed is considered agricultural land use and is not considered part of NPDES General Stormwater Permit. It is anticipated that the Whaletail Lake subwatershed will undergo land use changes in the future. The development of agricultural areas will provide an opportunity to implement best management practices in the watershed that would qualify toward achieving TMDL wasteload allocations for the City of Minnetrista as part of their NPDES General Stormwater Permit. Hennepin County Environment and Energy has also been actively working with rural landowners to implement best management practices for agricultural areas that have significant amount of erosion or nutrient loading, which qualify as load reductions towards achieving non-MS4 TMDL load allocations. It will be important to continue to implement best management practices in the watershed to ensure the longevity and effectiveness of the alum treatment for Whaletail Lake South basin.

The Pioneer-Sarah Creek Watershed Management Commission will review and inventory best management practices that have been implemented as load reduction progress toward achieving TMDL goals. The 4th Generation Watershed Management Plan recommends that a review of best management practices implemented towards meeting TMDL goals should be considered approximately every 5-years to adjust and re-evaluate management strategies within the watershed to improve water quality.

Table 15: Post-alum treatment monitoring plan for the next 20-years.

	Year									
Monitoring	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**	**2031**	**2032**
Water Quality										
Vegetation Survey										
Sediment Analysis										
Carp Survey										
Watershed BMP Inventory										

	Year									
Monitoring	**2033**	**2034**	**2035**	**2036**	**2037**	**2038**	**2039**	**2040**	**2041**	**2042**
Water Quality										
Vegetation Survey										
Sediment Analysis										
Carp Survey										
Watershed BMP Inventory										

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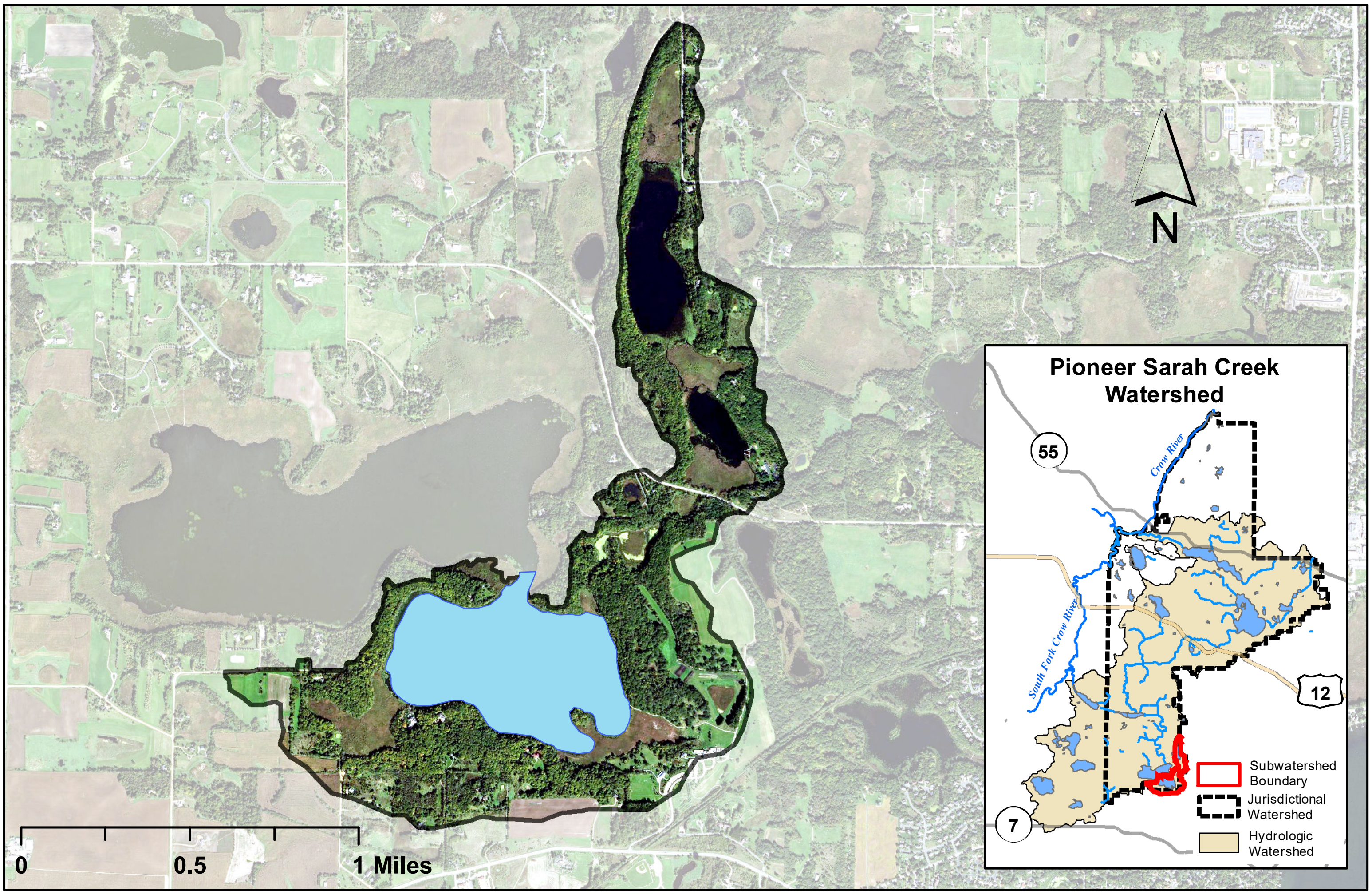
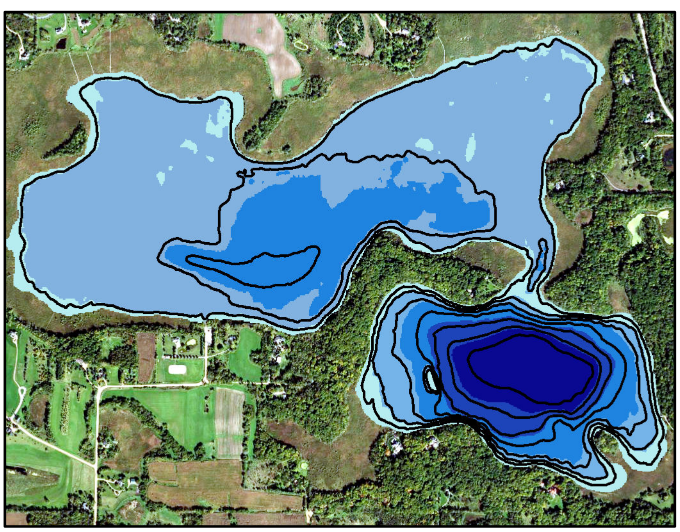
Appendix A

Water Quality Report Cards

Whaletail South Watershed Map



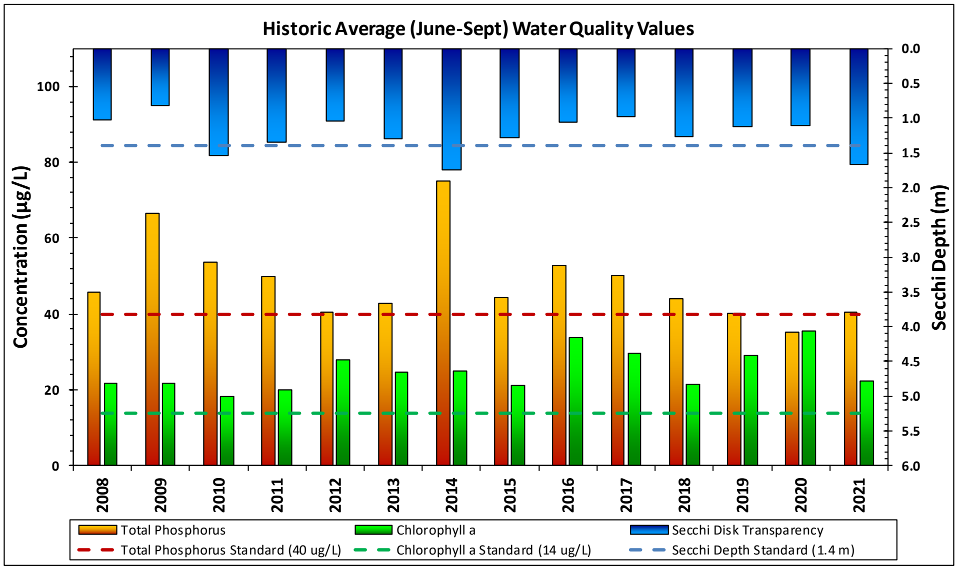
Whaletail South Bathymetry

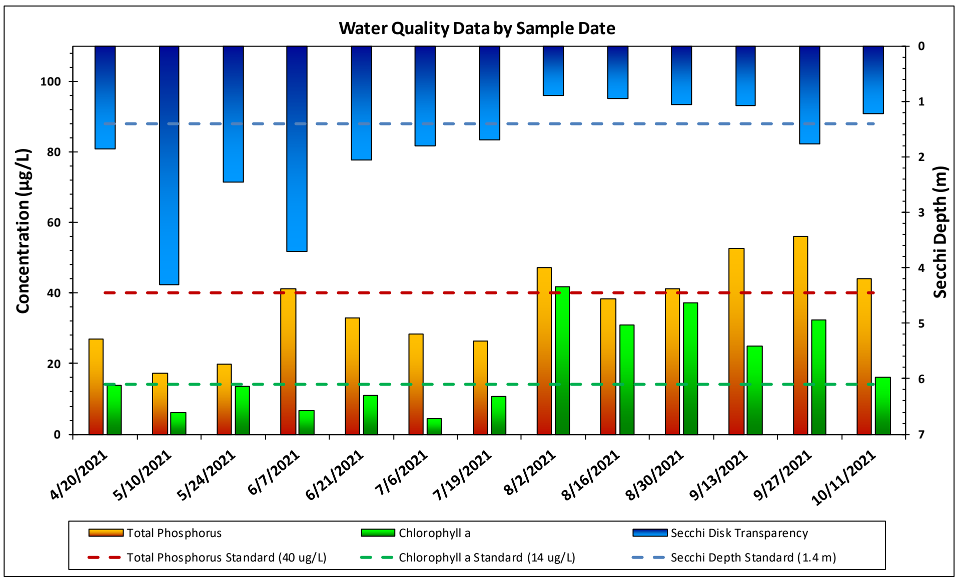


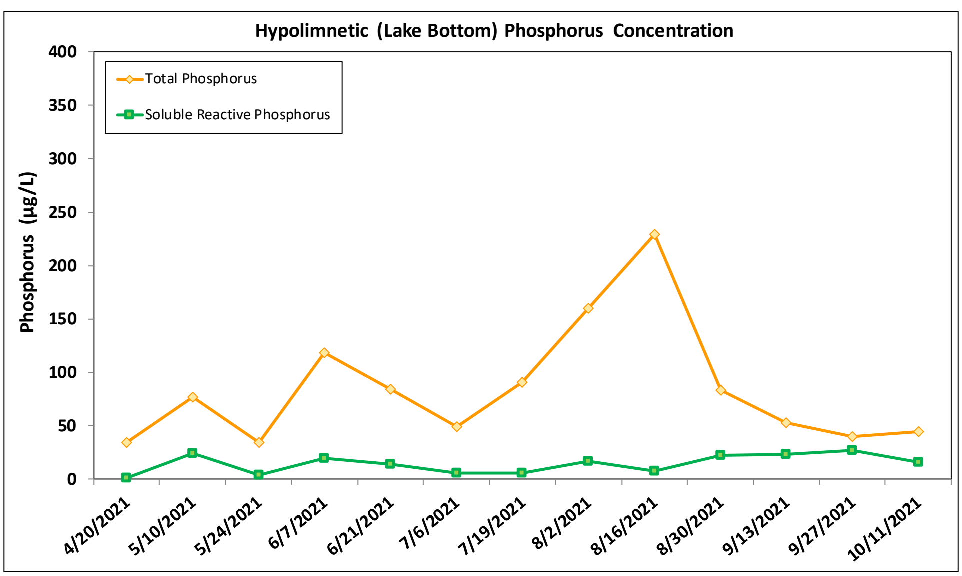
Lake and Watershed Characteristics	
DNR #	27018402
Watershed Area	661 Acres
Lake Area	156 Acres
Percent Littoral Area	66%
Average Depth	12.1 ft.
Maximum Depth	23.3 ft.
Watershed:Lake Ratio	4.2:1
Impairment	Excess Nutrients in 2006
Classification	Deep Lake

Water Resource Department
Map Created: 11/24/2017
Revised Date: 6/4/2021

ThreeRivers
PARK DISTRICT







Whaletail South
Water Quality Report Card

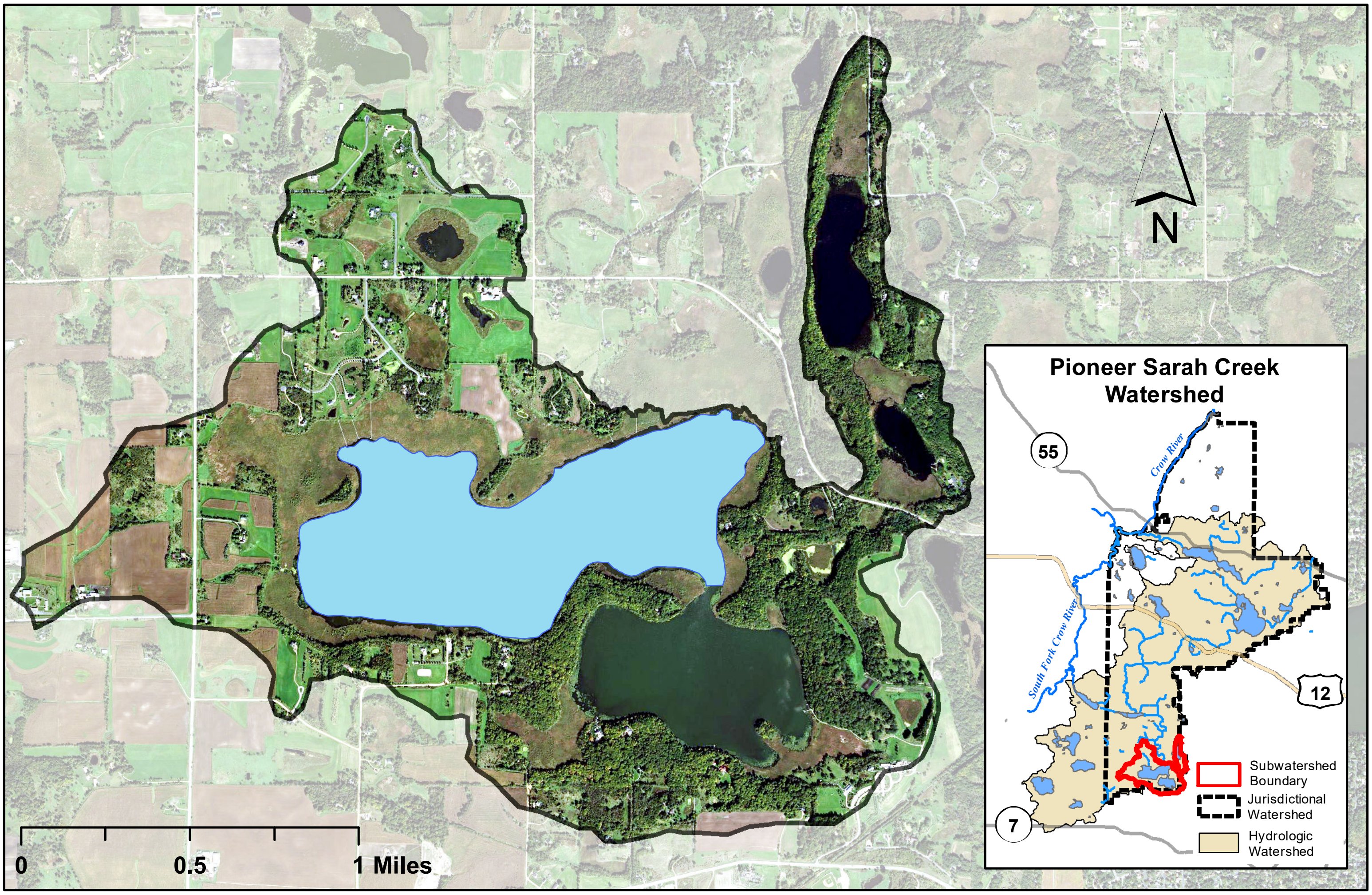
Year	TP	Chl-a	Secchi	Avg Grade
2000	D	B	D	C-
2001	C	C	D	C-
2003	C	C	C	C
2005	C	C	D	C-
2007	C	C	C	C
2008	C	C	D	C-
2009	C	C	D	C-
2010	C	B	C	C+
2011	C	C	C	C
2012	C	C	D	C-
2013	C	C	C	C
2014	D	C	C	C-
2015	C	C	C	C
2016	C	C	D	C-
2017	C	C	D	C-
2018	C	C	C	C
2019	C	C	D	C-
2020	C	C	D	C-
2021	C	C	C	C
MPCA Standard	C	B	C	C+

Met Council Grading System for Lake Water Quality

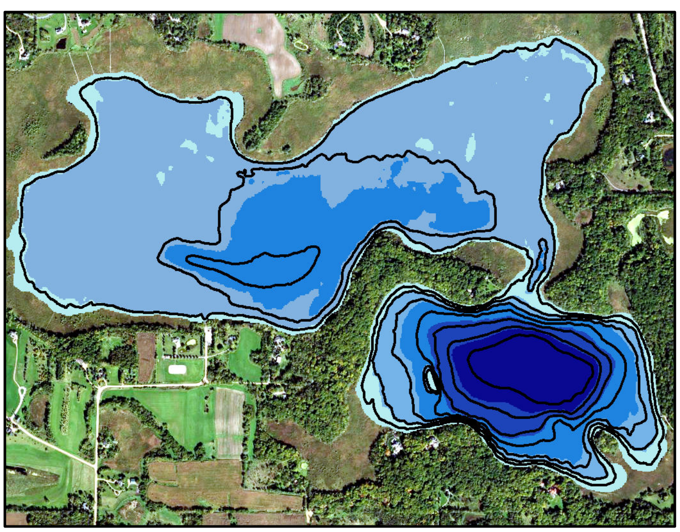
ThreeRivers PARK DISTRICT

Division of Water Resources
December 2021

Whaletail North Watershed Map



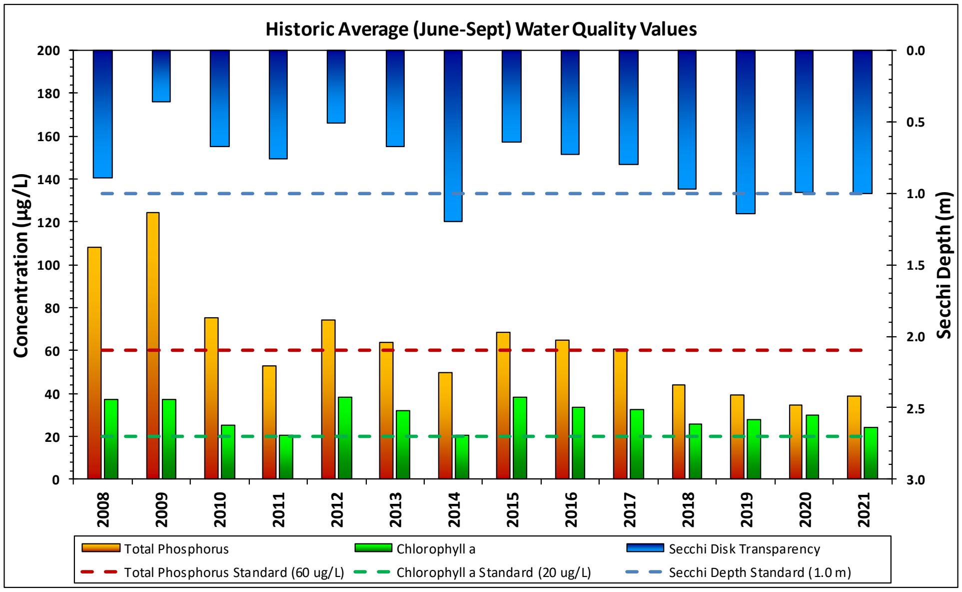
Whaletail North Bathymetry



Lake and Watershed Characteristics	
DNR #	27018401
Watershed Area	1,585 Acres
Lake Area	370 Acres
Percent Littoral Area	100%
Average Depth	5.2 ft.
Maximum Depth	10.3 ft.
Watershed:Lake Ratio	4.3:1
Impairment	Excess Nutrients in 2008
Classification	Shallow Lake

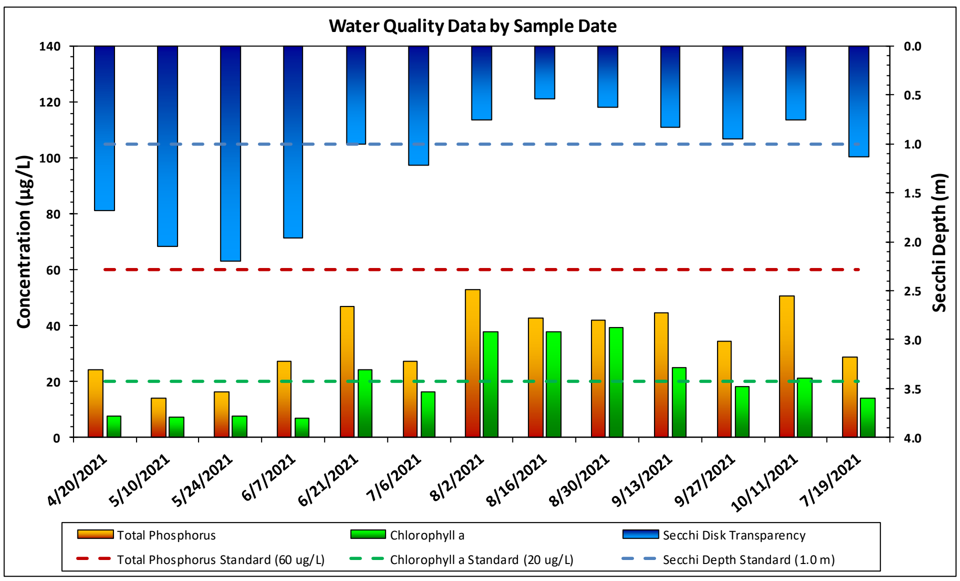
Water Resource Department
Map Created: 11/24/2017
Revised Date: 6/4/2021

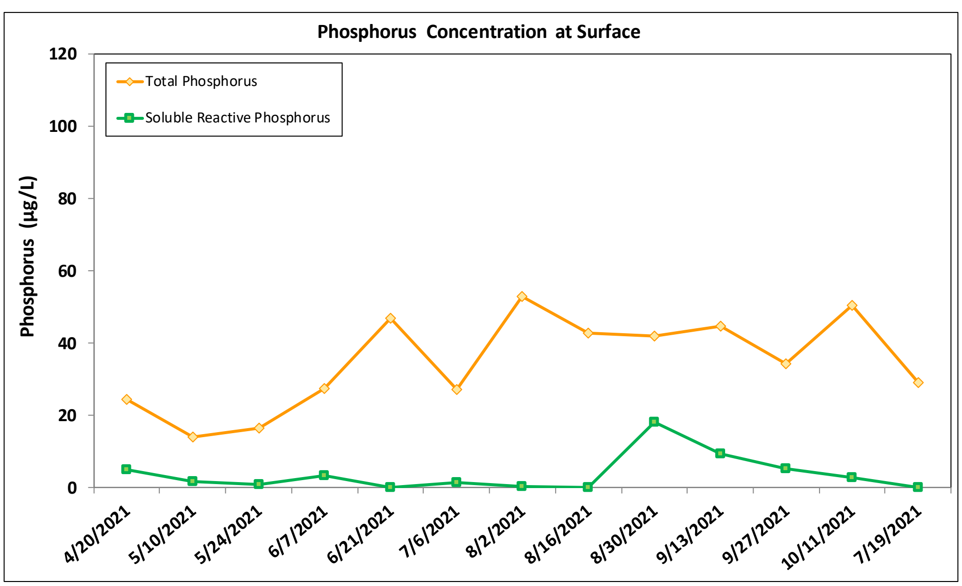
ThreeRivers
PARK DISTRICT



Whaletail North Water Quality Report Card				
Year	**TP**	**Chl-a**	**Secchi**	**Avg Grade**
2008	D	C	D	D+
2009	D	C	F	D
2010	D	C	F	D
2011	C	C	D	C-
2012	D	C	F	D
2013	C	C	F	D+
2014	C	C	C	C
2015	D	C	F	D
2016	C	C	D	C-
2017	C	C	D	C-
2018	C	C	D	C-
2019	C	C	D	C-
2020	C	C	D	C-
2021	C	C	D	C-
MPCA Standard	C	C	D	C-

Met Council Grading System for Lake Water Quality





ThreeRivers PARK DISTRICT

Division of Water Resources December 2021

Appendix B

Whaletail Lake

Sediment Analysis Report

Internal Phosphorus Loading and Sediment Characteristics for Whaletail Lake, Minnesota

Aerial view of Whaletail Lake, MN (Google maps)

26 December, 2014

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OBJECTIVES

The objectives of this investigation were to determine rates of phosphorus (P) release from sediments under laboratory-controlled aerobic and anaerobic conditions and to quantify biologically-labile (i.e., subject to recycling P fractions for sediments collected from Whaletail Lake, Minnesota.

APPROACH

Sediment coring stations and gravity coring methodology. Sediment coring stations and numbers of cores collected for analytical purposes are identified in Table 1. Duplicate intact sediment cores were collected from three stations in Whaletail Lake for determination of rates of P release under aerobic and anaerobic conditions (Figure 1). The upper 10-cm layer was sectioned from an additional core to evaluate sediment physical-textural and chemical characteristics. A gravity sediment coring device (Aquatic Research Instruments, Hope ID) equipped with an acrylic core liner (6.5-cm ID and 50-cm length) was used to collect sediment in October, 2014. The core liners, containing both sediment and overlying water, were immediately sealed using rubber stoppers and stored in a covered container in a cool location until analysis. Additional lake water was collected for incubation with the collected sediment. Sediment cores were sectioned within 24 hours of collection. Fresh sediment sections were stored in heavy-duty quart freezer bags and refrigerated until analysis.

Rates of phosphorus release from sediment. In the laboratory, sediment cores were carefully drained of overlying water and the upper 10 cm of sediment transferred intact to a smaller acrylic core liner (6.5-cm dia and 20-cm ht) using a core remover tool. Surface water collected from the lake was filtered through a glass fiber filter (Gelman A-E), with 300 mL then siphoned onto the sediment contained in the small acrylic core liner without causing sediment resuspension. Sediment incubation systems consisted of the upper 10-cm of sediment and filtered overlying water contained in acrylic core liners that were sealed with rubber stoppers. They were placed in a darkened environmental chamber and incubated at a constant temperature (20 ^{o}C). The oxidation-reduction environment in the overlying water was controlled by gently bubbling air (aerobic) or nitrogen (anaerobic) through an air stone placed just above the sediment surface in each system. Bubbling action insured complete mixing of the water column but did not disrupt the sediment. Duplicate sediment incubation systems were prepared for each condition.

Water samples for soluble reactive P were collected from the center of each system using an acid-washed syringe and filtered through a 0.45 μm membrane syringe filter (Nalge). The water volume removed from each system during sampling was replaced by addition of filtered lake water preadjusted to the proper oxidation-reduction condition. These volumes were accurately measured for determination of dilution effects. Soluble reactive P was measured colorimetrically using the ascorbic acid method (APHA 2005). Rates of P release from the sediment (mg/m^2 d) were calculated as the linear change in mass in the overlying water divided by time (days) and the area (m^2) of the incubation core liner. Regression analysis was used to estimate rates over the linear portion of the data.

Sediment chemistry. A known volume of sediment was dried at 105 ^{o}C for determination of moisture content, wet and dry bulk density, and burned at 500 ^{o}C for determination of loss-on-ignition organic matter content (Avnimelech et al. 2001, Håkanson and Jansson 2002; Table 2). Phosphorus fractionation was conducted according to Hieltjes and Lijklema (1980), Psenner and Puckso (1988), and Nürnberg (1988) for the determination of ammonium-chloride-extractable P (loosely-bound P), bicarbonate-dithionite-extractable P (i.e., iron-bound P), and sodium hydroxide-extractable P (i.e., aluminum-bound P). A subsample of the sodium hydroxide extract was digested with potassium persulfate to determine nonreactive sodium hydroxide-extractable P (Psenner and Puckso 1988). Labile organic P was calculated as the difference between reactive and nonreactive sodium hydroxide-extractable P. Additional sediment was dried to a constant weight, ground, and digested for analysis of total P using standard methods (Anderson 1976).

The loosely-bound and iron-bound P fractions are readily mobilized at the sediment-water interface as a result of anaerobic conditions that lead to desorption of P from sediment and diffusion into the overlying water column (Mortimer 1971, Boström et al. 1982, Boström 1984, Nürnberg 1988; Table 3). The sum of the loosely-bound and iron-bound P fraction represents redox-sensitive P (i.e., the P fraction that is active in P release under anaerobic and reducing conditions; redox-P). In addition, labile organic P can be converted to soluble P via bacterial mineralization (Jensen and Andersen 1992) or hydrolysis of bacterial polyphosphates to soluble phosphate under anaerobic conditions (Gächter et al. 1988, Gächter and Meyer 1993, Hupfer et al. 1995). The sum of redox-P and labile organic P collectively represent biologically-labile P. This fraction is active in recycling pathways that result in exchanges of phosphate from the sediment to the overlying water column and potential assimilation by algae. In contrast, aluminum-bound P is more chemically inert and subject to burial rather than recycling (Table 3).

RESULTS AND INTERPRETATION

Sediment phosphorus release rates. Sediment contained in some of the incubation systems (primarily WTL-N2 and WTL-S) became unconsolidated and portions floated into the overlying water column, necessitating restarting the incubation process after placement of fiberglass screen material (i.e., window screen) inside the acrylic tubes to hold the sediment in place. This phenomenon is not uncommon and may be due to gas production in sediment during anaerobic metabolism.

Under anaerobic conditions, phosphorus mass and concentration increased linearly in the overlying water column of duplicate sediment incubation systems (Figure 2). P concentration increases were greatest in WTL-S sediment incubation systems and much more moderate in the WTL-N1 and WTL-N2 systems. Mean SRP concentrations in the overlying water column at the end of the incubation period were high in WTL-S at 0.684 mg/L (±0.007 standard error; SE; Table 4). In contrast, mean final SRP concentrations were low in WTL-N1 and WTL-N2 systems at only 0.037 mg/L (±0.037 SE) and 0.026 mg/L (±0.026 SE), respectively (Table 4). High variability in the means of these latter systems resulted from overlying water column P accumulation in one of the duplicates and negligible to undetectable P accumulation in the other duplicate (Figure 2). Overall, mean anaerobic P release rates were greatest for WTL-S sediments and minor for sediments located in the north basin of the lake (Table 4).

Soluble phosphorus accumulation in the overlying water column was lower under aerobic versus anaerobic conditions (Figure 2). Significant P increases occurred in the overlying water column of WTL-S, compared to only minor to negligible increases in north basin sediment incubation systems. Mean P concentrations at the end of the incubation period were relatively high for WTL-S at 0.052 mg/L (± 0.023 SE; Table 4), and could represent an important available P source for assimilation by algae. The mean aerobic P release rate was also substantial for WTL-S at 1.0 mg/m^2 d (Table 4). Sediments collected from WTL-N1 exhibited a very moderate to low mean P concentration at the end of the incubation period (0.024 mg/L ± 0.007 SE) and a moderate aerobic P release rate of 0.37 mg/m^2 d (±0.05 SE). Although generally low, this mean aerobic P release rate was equivalent to the mean anaerobic P release rate for WTL-N1 sediment. By comparison, the mean aerobic P release rate was essentially undetectable for WTL-N2 sediments.

Sediment characteristics. Moisture contents were high, while wet and dry bulk densities were very low, in 10-cm sections, indicating very flocculent, high porosity (i.e., volume of interstitial spaces in the sediment column) sediment characteristics (Table 5). In particular, wet bulk densities for sediments located in the north basin approached 1.0 g/cm^3 in conjunction with very high organic matter contents ranging between 69% and 77%. Organic matter content was also relatively high in WTL-S sediments at ~40% (Table 5).

Total P concentrations in the upper 10-cm sediment layer were moderate to moderately high (Table 6). WTL-S sediments exhibited the greatest total P concentration at 1.9 mg/g. For north basin sediments, total P ranged between 0.98 mg/g and 1.23 mg/g. Redox-P (i.e., the sum of the loosely-bound and iron-bound P fractions) accounted for a relatively small fraction of the sediment total P in north basin sediments at 11% to 14%, reflecting low anaerobic P release rates measured at these stations. Redox-P accounted for much more of the total P in WTL-S sediments at 37%. Biologically-labile P (i.e., the sum of redox-P and labile organic P fractions) represented 52% to 66% of the total P (Table 6). Labile organic P accounted for 44% to nearly 80% of the biologically-labile P. In particular, it was the overwhelmingly dominant P fraction in north basin sediments, again coinciding with very high organic matter content. Iron-bound P concentrations were relatively low in the north basin, representing only ~ 15% of the biologically-labile P pool (Table 7). The iron-bound P concentration was much higher in south basin sediment (Table 7), coinciding with a high anaerobic P release rate (Table 4).

Summary. Internal P loading potential under both aerobic and anaerobic conditions was greatest for the south basin of the lake. Results further suggested that internal P loading contributions by north basin sediments were probably negligible. These patterns were consistent with north-south basin differences in the sediment P pools. South basin sediments exhibited much higher concentrations of total P, loosely-bound P, and iron-bound P, reflecting higher laboratory-measured P release rates. In contrast, iron-bound P and redox-P concentrations were very low in north basin sediments and biologically-labile P was dominated by organic P fractions. This pattern coincided with very high organic matter content in the north basin sediments, as it accounted for 70% to 77% of the sediment composition. Laboratory-derived aerobic and anaerobic P release rates were very low in the north basin of the lake, reflecting low redox-P and sediment composed primarily of organic matter.

ACKNOWLEDGMENTS

Rich Brasch and Brian Vlach, Three Rivers Park District, are gratefully acknowledged for coordinating sediment core sampling. Jordan Bauer (Professional Science Masters – Conservation Biology) participated in sediment core processing and analyses. Funding was provided by the Three Rivers Park District. This research was conducted out of the

University of Wisconsin – Stout, Sustainability Sciences Institute – Discovery Center, Center for Limnological Research and Rehabilitation.

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Table 1. Station sediment sampling locations and numbers of sediment cores collected for determination of rates of phosphorus (P) flux under aerobic or anaerobic conditions and biologically-labile P fractions (see Table 2).

Station location	P Flux		P fractions
	Aerobic	Anaerobic	upper 10 cm
North basin 1 (WTL-N1)	2	2	1
North basin 2 (WTL-N2)	2	2	1
South basin (WTL-S)	2	2	1

Table 2. Sediment physical-textural characteristics, phosphorus species, and metals variable list.

Category	Variable
Physical-textural	Moisture content
	Wet and dry sediment bulk density
	organic matter content
Phosphorus species	Loosely-bound P
	Iron-bound P
	Labile organic P
	Aluminum-bound P
	Total P

Table 3. Sediment sequential phosphorus (P) fractionation scheme, extractants used, and definitions of recycling potential.

Variable	Extractant	Recycling Potential
Loosely-bound P	1 M Ammonium Chloride	Biologically labile; Soluble P in interstitial water and adsorbed to $CaCO_3$; Recycled via direct diffusion, eH and pH reactions, and equilibrium processes
Iron-bound P	0.11 M Sodium Bicarbonate-dithionate	Biologically labile; P adsorbed to iron oxyhydroxides (Fe(OOH); Recycled via eH and pH reactions and equilibrium processes
Labile organic P	Persulfate digestion of the NaOH extraction	Biologically labile; Recycled via bacterial mineralization of organic P and mobilization of polyphosphates stored in cells
Aluminum-bound P	0.1 N Sodium Hydroxide	Biologically refractory; Al-P minerals with a low solubility product

Table 4. Mean (1 standard error in parentheses; n = 2) rates of phosphorus (P) release under aerobic and anaerobic conditions and mean P concentration (n = 2) in the overlying water column near the end of the incubation period for intact sediment cores collected from various stations in Whaletail Lake.

Station	Sediment P release rate			
	Aerobic		Anaerobic	
	(mg/m^2 d)	(mg/L)	(mg/m^2 d)	(mg/L)
Whaletail North 1	0.37 (0.05)	0.024 (0.007)	0.29 (0.29)	0.037 (0.037)
Whaletail North 2	0.03 (0.01)	< 0.005	0.23 (0.26)	0.026 (0.026)
Whaletail South	1.00 (0.01)	0.052 (0.023)	5.0 (0.1)	0.684 (0.007)

Table 5. Textural characteristics in the upper sediment layer for sediment cores collected from various stations in Whaletail Lake.

Station	Moisture Content (%)	Wet Bulk Density (g/cm^3)	Dry Bulk Density (g/cm^3)	Organic Matter (%)
Whaletail North 1	94.8	1.007	0.053	77.1
Whaletail North 2	96.4	1.007	0.037	69.1
Whaletail South	94.9	1.019	0.053	39.6

Table 6. Concentrations of sediment total phosphorus (P), redox-sensitive P (Redox P; the sum of the loosely-bound and iron-bound P fraction) and biologically-labile P (Bio-labile P; the sum of redox-P and labile organic P), in the upper 10-cm sediment layer from various stations in Whaletail Lake. DW = dry mass.

Lake	Total P	Redox P		Bio-labile P	
	(mg/g DW)	(mg/g DW)	(% total P)	(mg/g DW)	(% total P)
Whaletail North 1	0.977	0.105	10.8%	0.510	52.2%
Whaletail North 2	1.232	0.168	13.6%	0.744	60.4%
Whaletail South	1.929	0.708	36.7%	1.272	66.0%

Table 7. Concentrations of biologically labile and refractory P in the upper 10-cm sediment layer for sediment cores collected from various stations in Whaletail Lake. DW = dry mass, FW = fresh mass.

Lake	Loosely-bound P	Iron-bound P	Iron-bound P	Labile organic P	Aluminum-bound P
	(mg/g DW)	(mg/g DW)	(ug/g FW)	(mg/g DW)	(mg/g DW)
Whaletail North 1	0.026	0.079	4	0.405	0.092
Whaletail North 2	0.046	0.122	4	0.576	0.132
Whaletail South	0.105	0.603	31	0.564	0.170

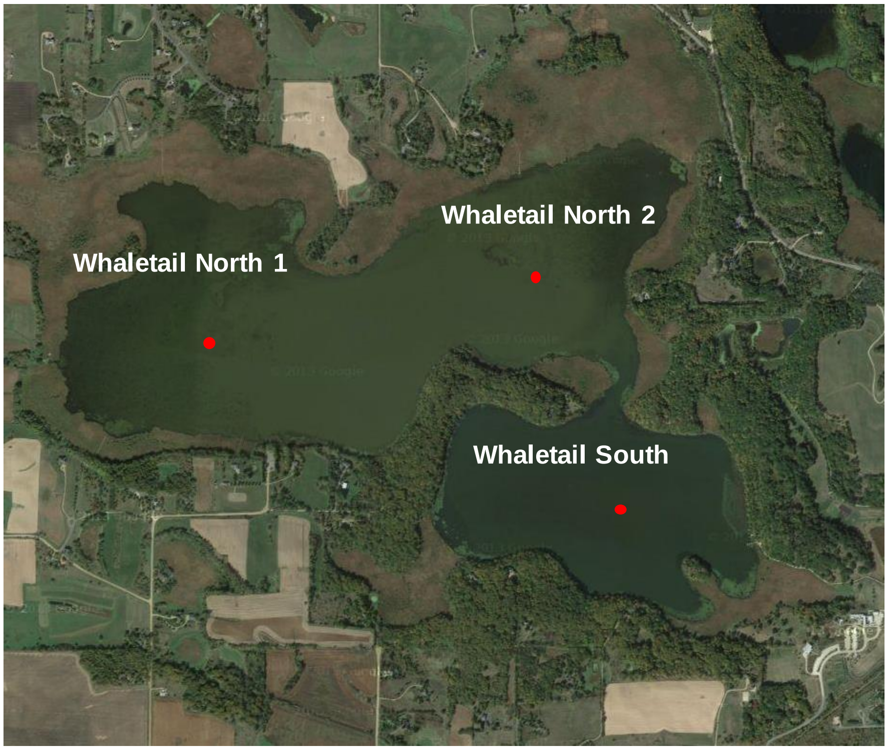

Figure 1. Sediment sampling station locations in Whaletail Lake.

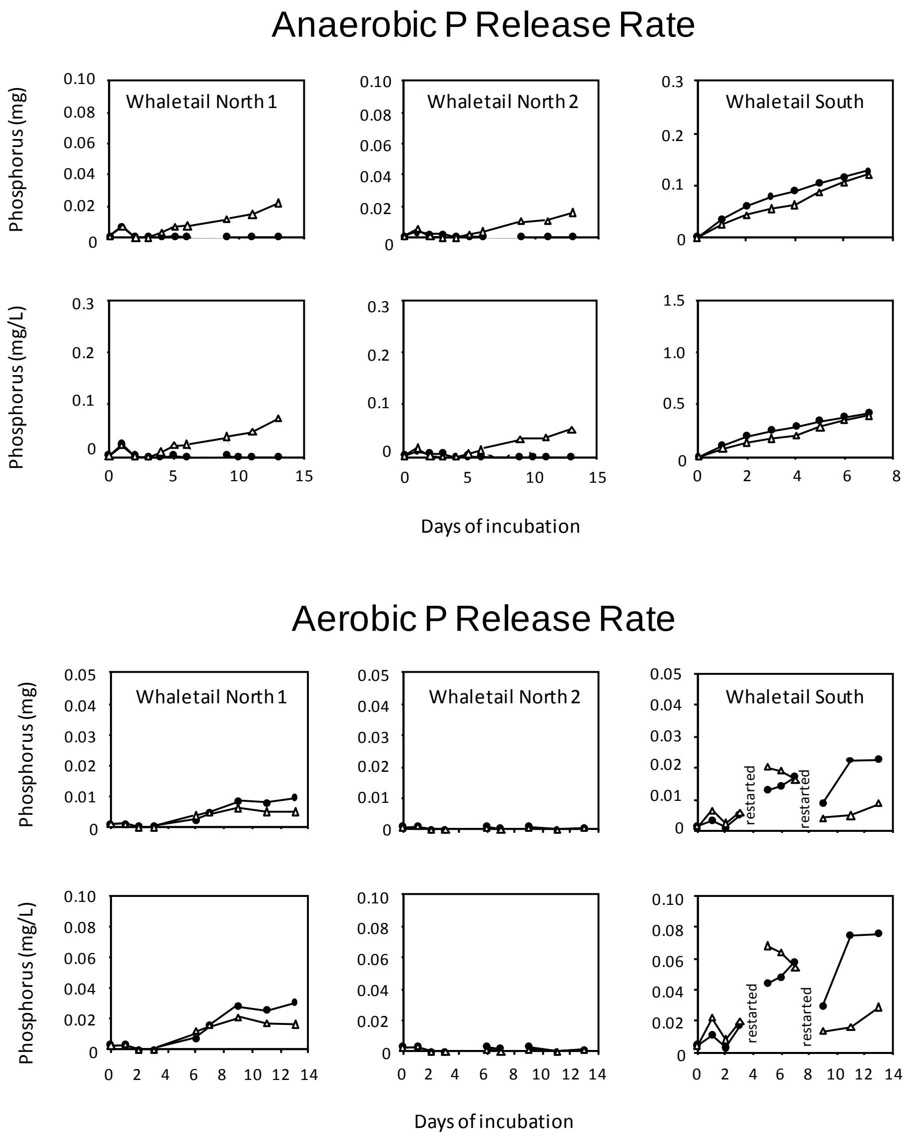

Figure 2. Changes in soluble reactive phosphorus mass and concentration in the overlying water column under anaerobic (upper panels) and aerobic (lower panels) conditions versus time for sediment cores collected from Whaletail Lake.

Appendix C

Whaletail Lake

In-Lake Response

Whaletail South

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Load / Response

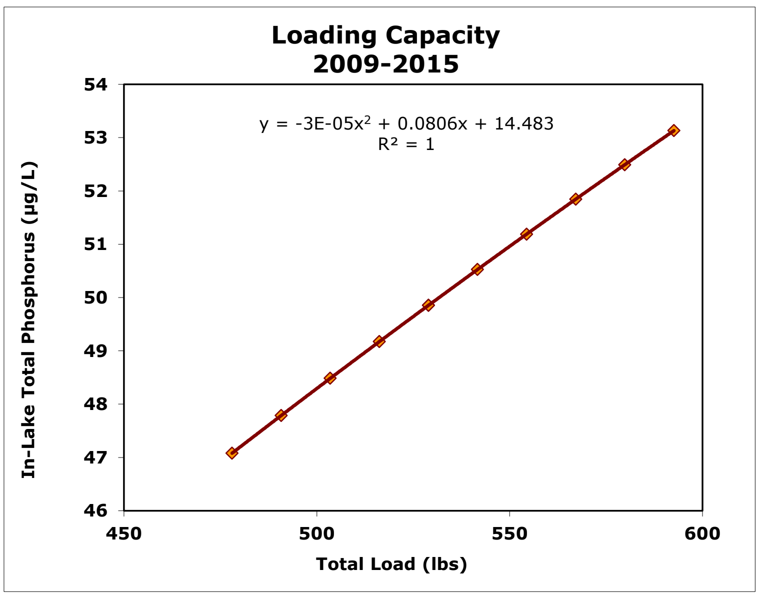
Tributary: All

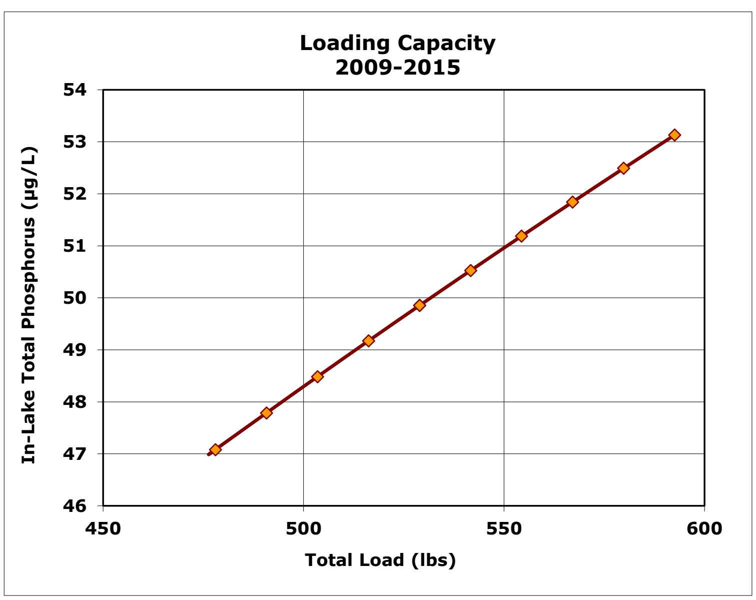
Segment: Area-Wtd Mean

Variable: TOTAL P MG/M3

Scale Factor	Flow hm3/yr	Load kg/yr	Conc mg/m^3	TOTAL P MG/M3 Mean	CV	Low	High	Watershed Load lbs/yr	Total Load lbs/yr
Base:	1.0	28.9	29.5	49.9	0.35	36.9	67.4	63.65	528.95
0.20	1.0	5.8	5.9	47.1	0.35	34.9	63.5	12.73	478.03
0.40	1.0	11.5	11.8	47.8	0.35	35.4	64.5	25.46	490.76
0.60	1.0	17.3	17.7	48.5	0.35	35.9	65.5	38.19	503.49
0.80	1.0	23.1	23.6	49.2	0.35	36.4	66.4	50.92	516.22
1.00	1.0	28.9	29.5	49.9	0.35	36.9	67.4	63.65	528.95
1.20	1.0	34.6	35.5	50.5	0.35	37.4	68.3	76.38	541.68
1.40	1.0	40.4	41.4	51.2	0.35	37.8	69.3	89.11	554.41
1.60	1.0	46.2	47.3	51.8	0.35	38.3	70.2	101.84	567.14
1.80	1.0	52.0	53.2	52.5	0.36	38.7	71.1	114.57	579.87
2.00	1.0	57.7	59.1	53.1	0.36	39.2	72.0	127.30	592.60

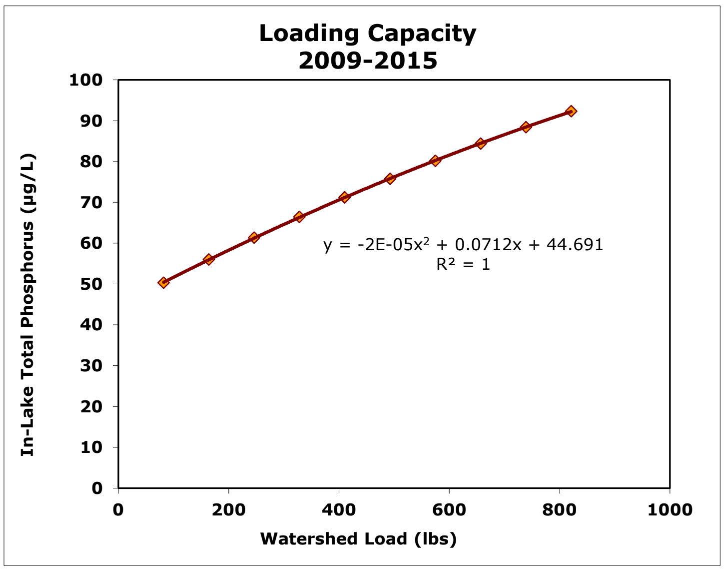
Total Load lbs/yr	TP µg/L
350.0	39.0
360.0	39.6
367.0	40.0
370.0	40.2
380.0	40.8
390.0	41.4
400.0	41.9
410.0	42.5
420.0	43.0
430.0	43.6
440.0	44.1
450.0	44.7
460.0	45.2
470.0	45.7
480.0	46.3
490.0	46.8
500.0	47.3
510.0	47.8
520.0	48.3
530.0	48.8
540.0	49.3
550.0	49.7
560.0	50.2
570.0	50.7
580.0	51.1
590.0	51.6
600.0	52.0
610.0	52.5
620.0	52.9
630.0	53.4
640.0	53.8
650.0	54.2
660.0	54.6
670.0	55.0
680.0	55.4
690.0	55.8
700.0	56.2
710.0	56.6
720.0	57.0
730.0	57.3
740.0	57.7
750.0	58.1
760.0	58.4
770.0	58.8
780.0	59.1
790.0	59.4
800.0	59.8

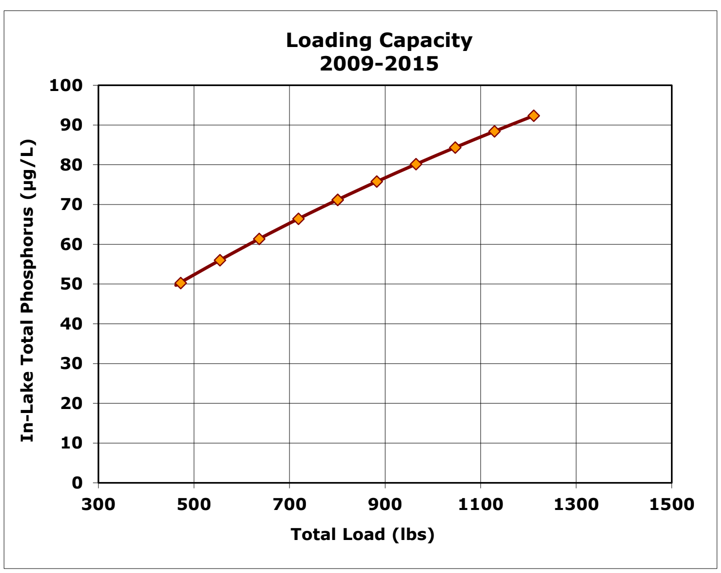




Whaletail North
File: \\admn-file-vm03\users$\101782\Documents\BATHTUB\Pioneer and Sarah Creek\Whaletail North\Whaletail North 5-23-2016.btb
Load / Response
Tributary: All
Segment: Area-Wtd Mean
Variable: TOTAL P MG/M3

Scale Factor	Flow hm3/yr	Load kg/yr	Conc mg/m^3	TOTAL P MG/M3 Mean	CV	Low	High	Watershed Load lbs/yr	Total Load lbs/yr
Base:	2.2	186.6	84.1	71.2	0.19	59.6	85.0	410.45	800.65
0.20	2.2	37.3	16.8	50.3	0.19	42.1	60.0	82.09	472.29
0.40	2.2	74.6	33.6	56.0	0.19	47.0	66.8	164.18	554.38
0.60	2.2	111.9	50.5	61.4	0.19	51.5	73.2	246.27	636.47
0.80	2.2	149.3	67.3	66.4	0.19	55.7	79.2	328.36	718.56
1.00	2.2	186.6	84.1	71.2	0.19	59.6	85.0	410.45	800.65
1.20	2.2	223.9	100.9	75.8	0.19	63.4	90.5	492.54	882.74
1.40	2.2	261.2	117.8	80.2	0.20	67.0	95.8	574.63	964.83
1.60	2.2	298.5	134.6	84.4	0.20	70.5	100.9	656.72	1046.92
1.80	2.2	335.8	151.4	88.4	0.20	73.9	105.9	738.81	1129.01
2.00	2.2	373.1	168.2	92.3	0.20	77.1	110.6	820.90	1211.10



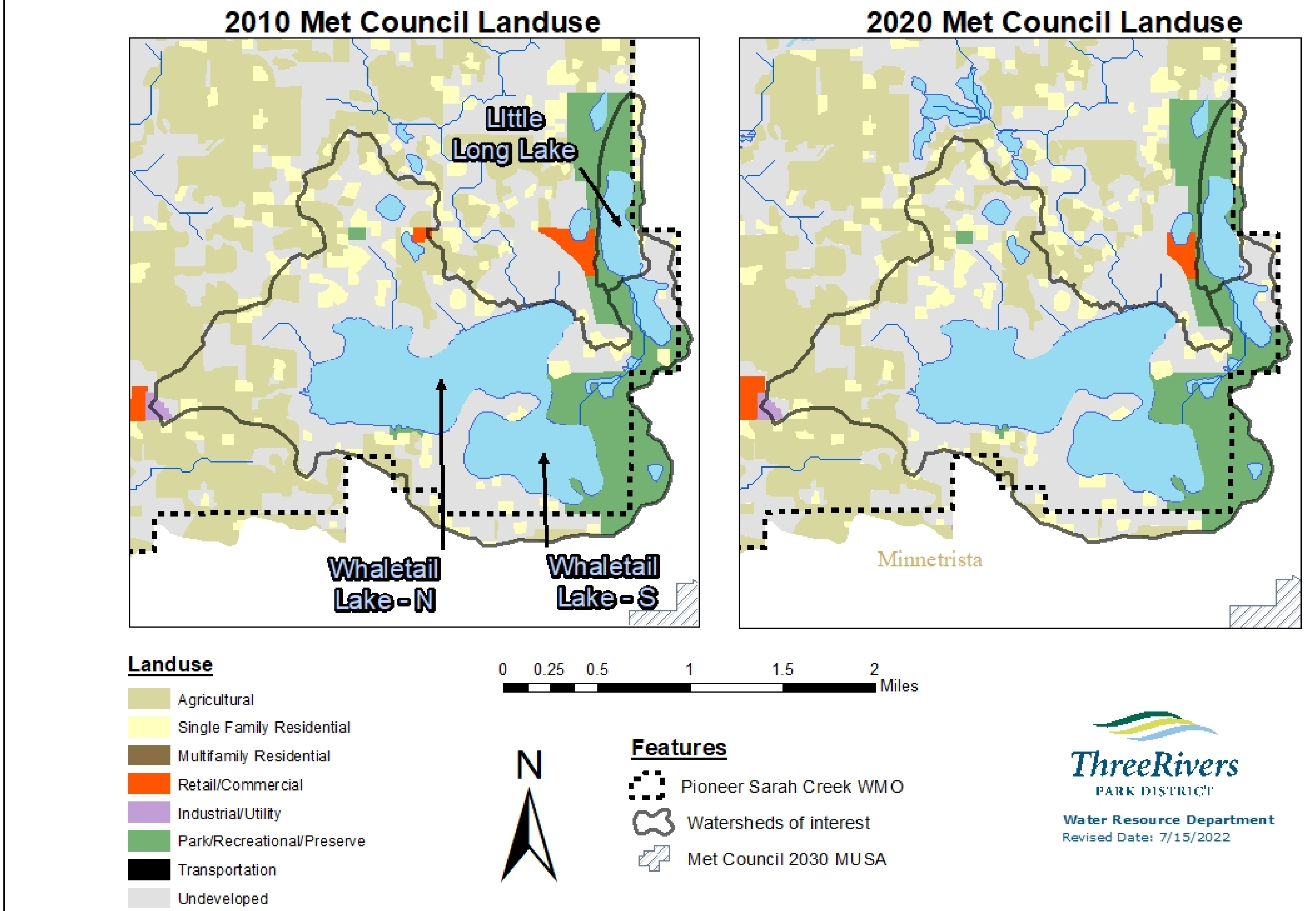


Watershed Load lbs/yr	TP µg/L	Total Load lbs/yr
160.0	**55.6**	**550.2**
165.0	**55.9**	**555.2**
170.0	**56.2**	**560.2**
175.0	**56.5**	**565.2**
180.0	**56.9**	**570.2**
185.0	**57.2**	**575.2**
190.0	**57.5**	**580.2**
195.0	**57.8**	**585.2**
200.0	**58.1**	**590.2**
205.0	**58.4**	**595.2**
210.0	**58.8**	**600.2**
215.0	**59.1**	**605.2**
220.0	**59.4**	**610.2**
225.0	**59.7**	**615.2**
230.0	**60.0**	**620.2**
235.0	**60.3**	**625.2**
240.0	**60.6**	**630.2**
245.0	**60.9**	**635.2**
250.0	**61.2**	**640.2**
255.0	**61.5**	**645.2**
260.0	**61.9**	**650.2**
265.0	**62.2**	**655.2**
270.0	**62.5**	**660.2**
275.0	**62.8**	**665.2**
280.0	**63.1**	**670.2**
285.0	**63.4**	**675.2**
290.0	**63.7**	**680.2**
295.0	**64.0**	**685.2**
300.0	**64.3**	**690.2**
305.0	**64.5**	**695.2**
310.0	**64.8**	**700.2**
315.0	**65.1**	**705.2**
320.0	**65.4**	**710.2**
325.0	**65.7**	**715.2**
330.0	**66.0**	**720.2**
335.0	**66.3**	**725.2**
340.0	**66.6**	**730.2**
345.0	**66.9**	**735.2**
350.0	**67.2**	**740.2**
355.0	**67.4**	**745.2**
360.0	**67.7**	**750.2**
365.0	**68.0**	**755.2**
370.0	**68.3**	**760.2**
375.0	**68.6**	**765.2**
380.0	**68.9**	**770.2**
385.0	**69.1**	**775.2**
390.0	**69.4**	**780.2**
395.0	**69.7**	**785.2**
400.0	**70.0**	**790.2**
405.0	**70.2**	**795.2**
410.0	**70.5**	**800.2**

Appendix D

Whaletail Lake

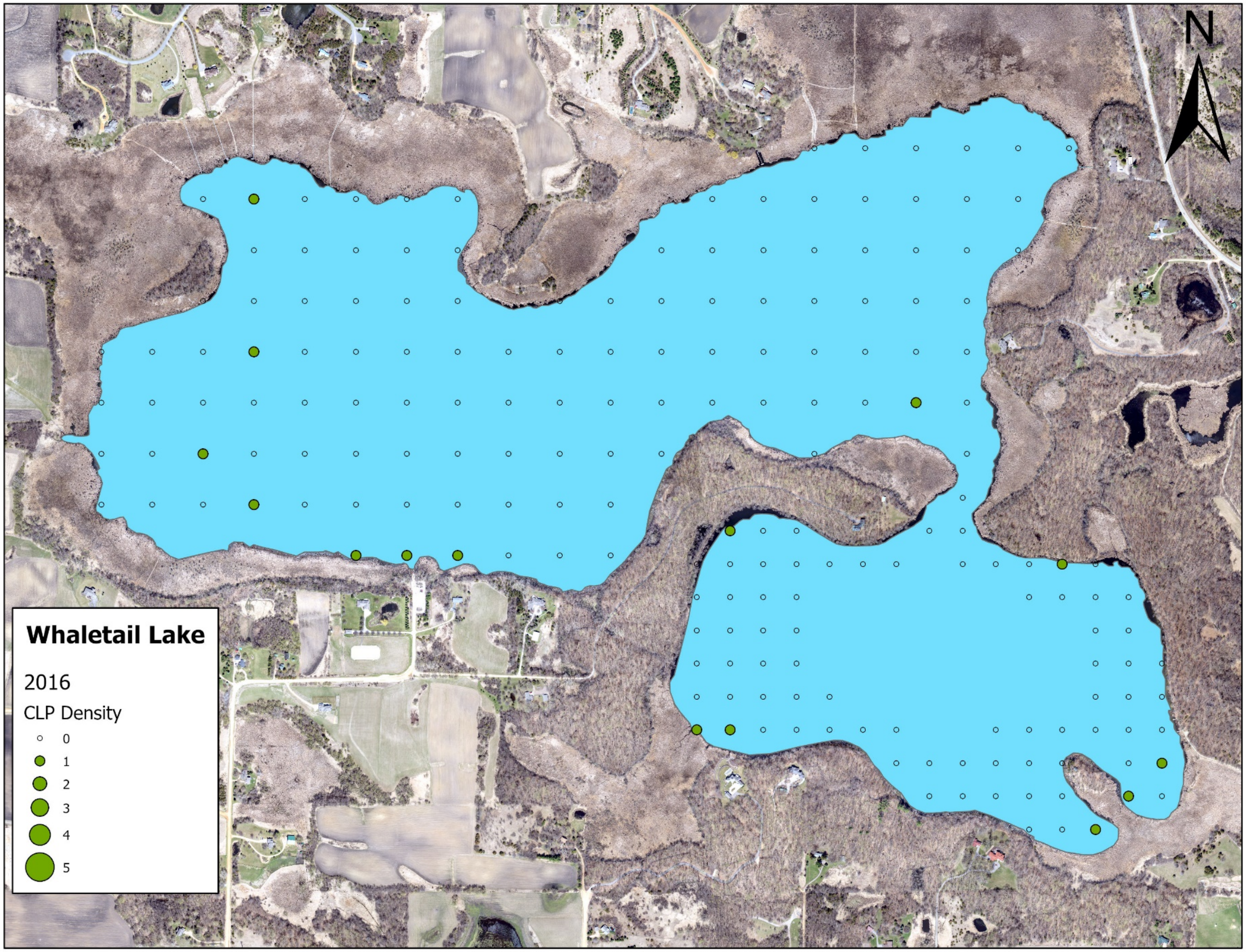
Watershed Land Use

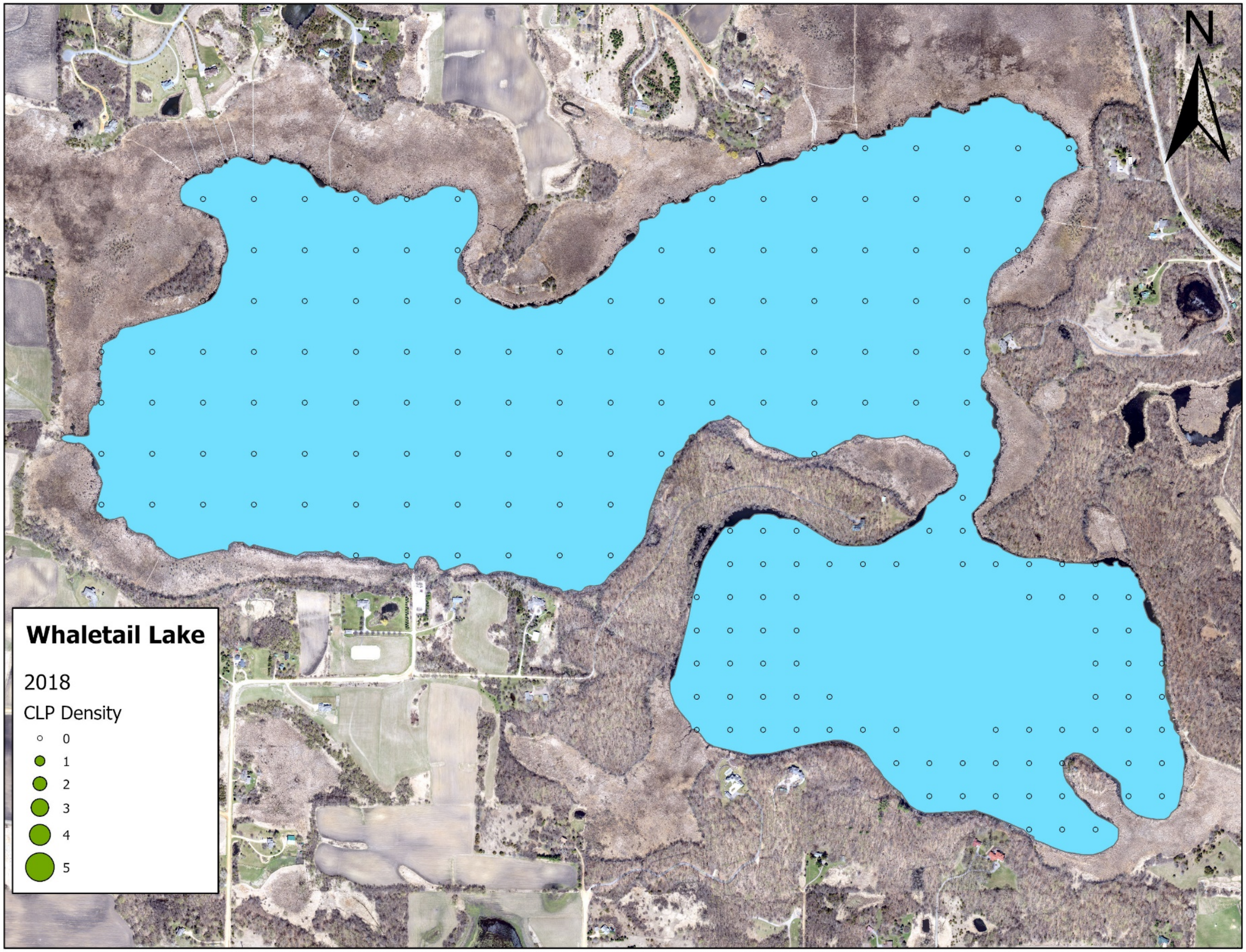

2010 Met Council Landuse
Little Long Lake
Whaletail Lake - N
Whaletail Lake - S
2020 Met Council Landuse
Minnetrista
Landuse
Agricultural
Single Family Residential
Multifamily Residential
Retail/Commercial
Industrial/Utility
Park/Recreational/Preserve
Transportation
Undeveloped
Water
0 0.25 0.5 1 1.5 2 Miles
N
Features
Pioneer Sarah Creek WMO
Watersheds of interest
Met Council 2030 MUSA
ThreeRivers PARK DISTRICT
Water Resource Department
Revised Date: 7/15/2022

Appendix E

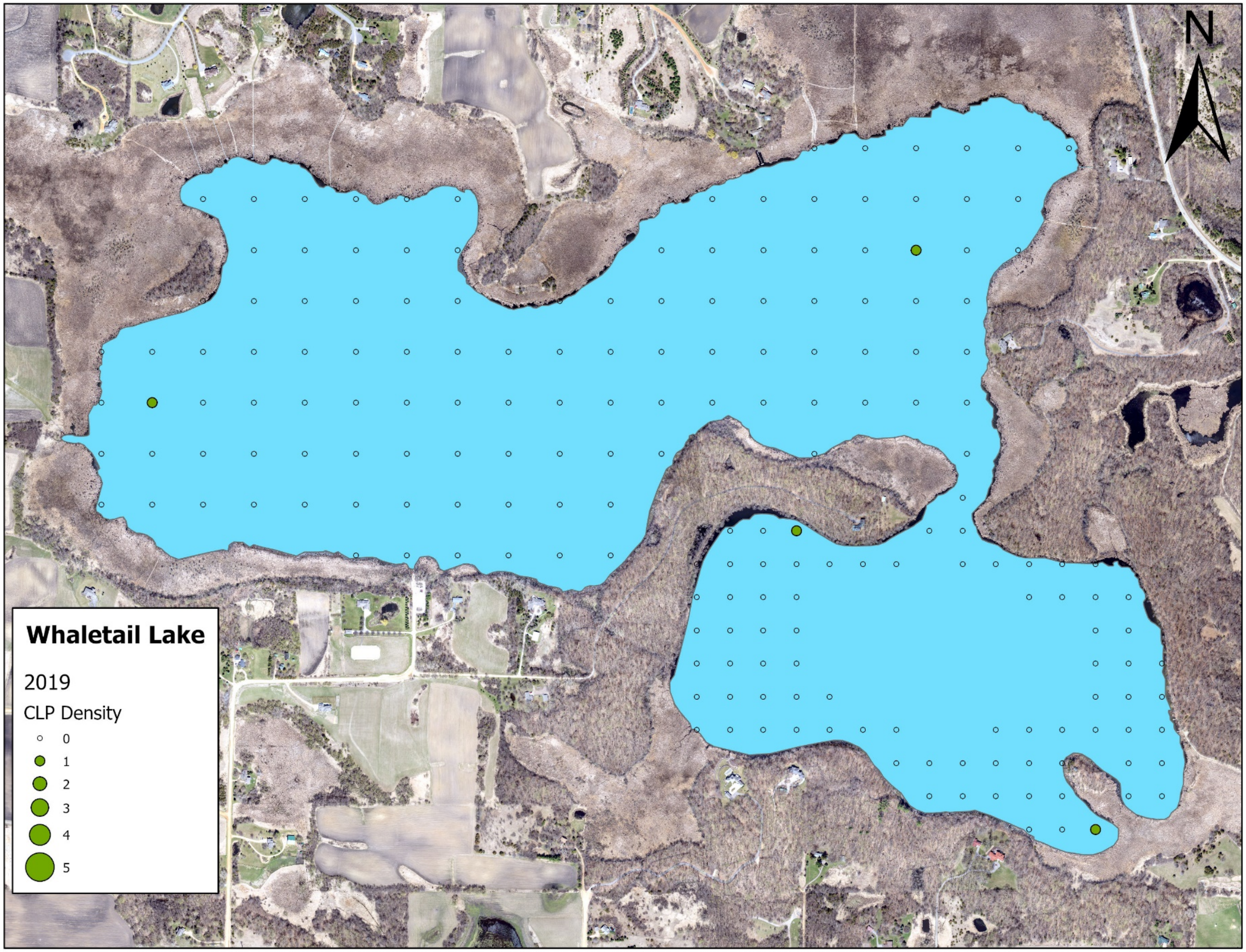
Whaletail Lake

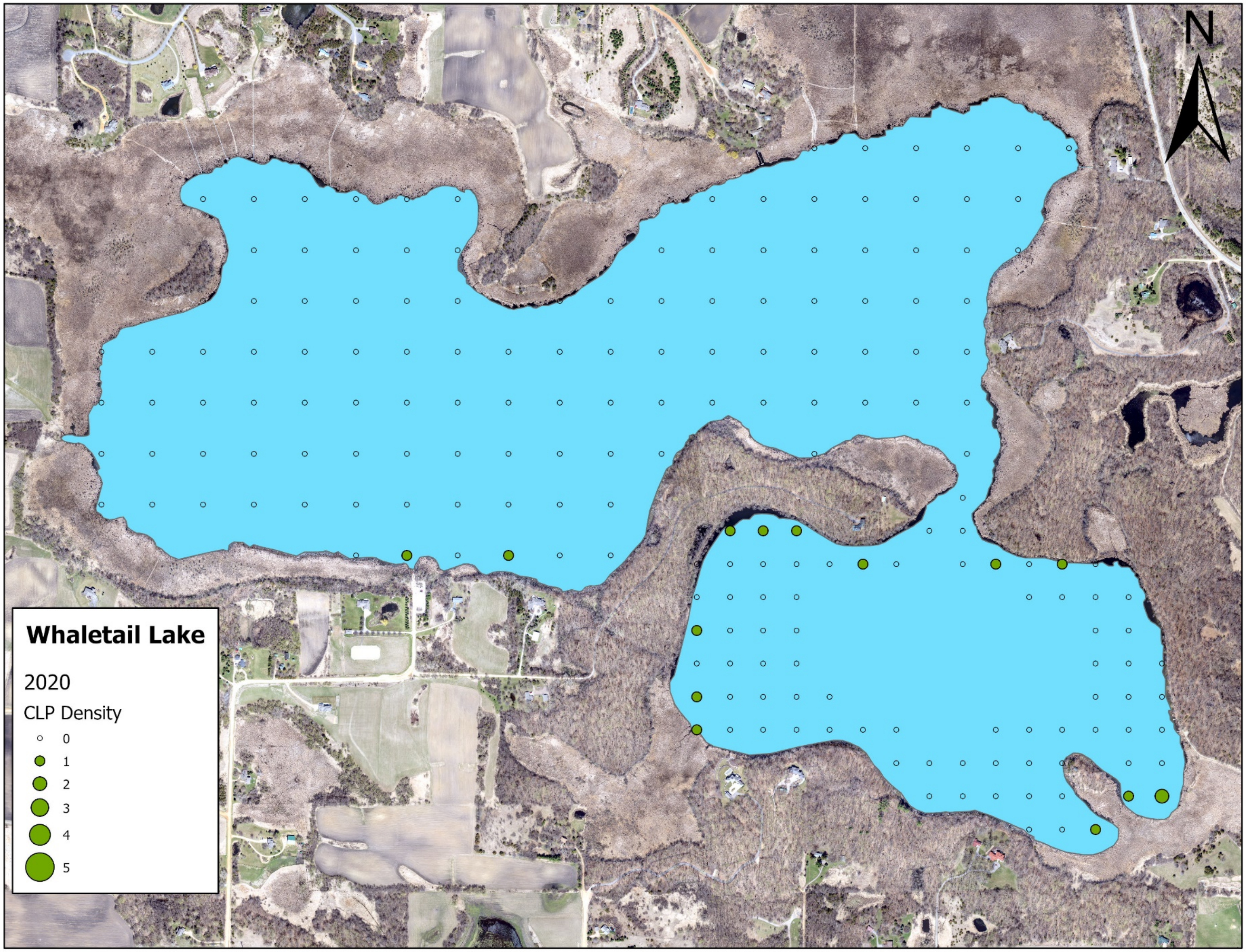
Aquatic Vegetation Surveys


N
Whaletail Lake
2016
CLP Density
0
1
2
3
4
5

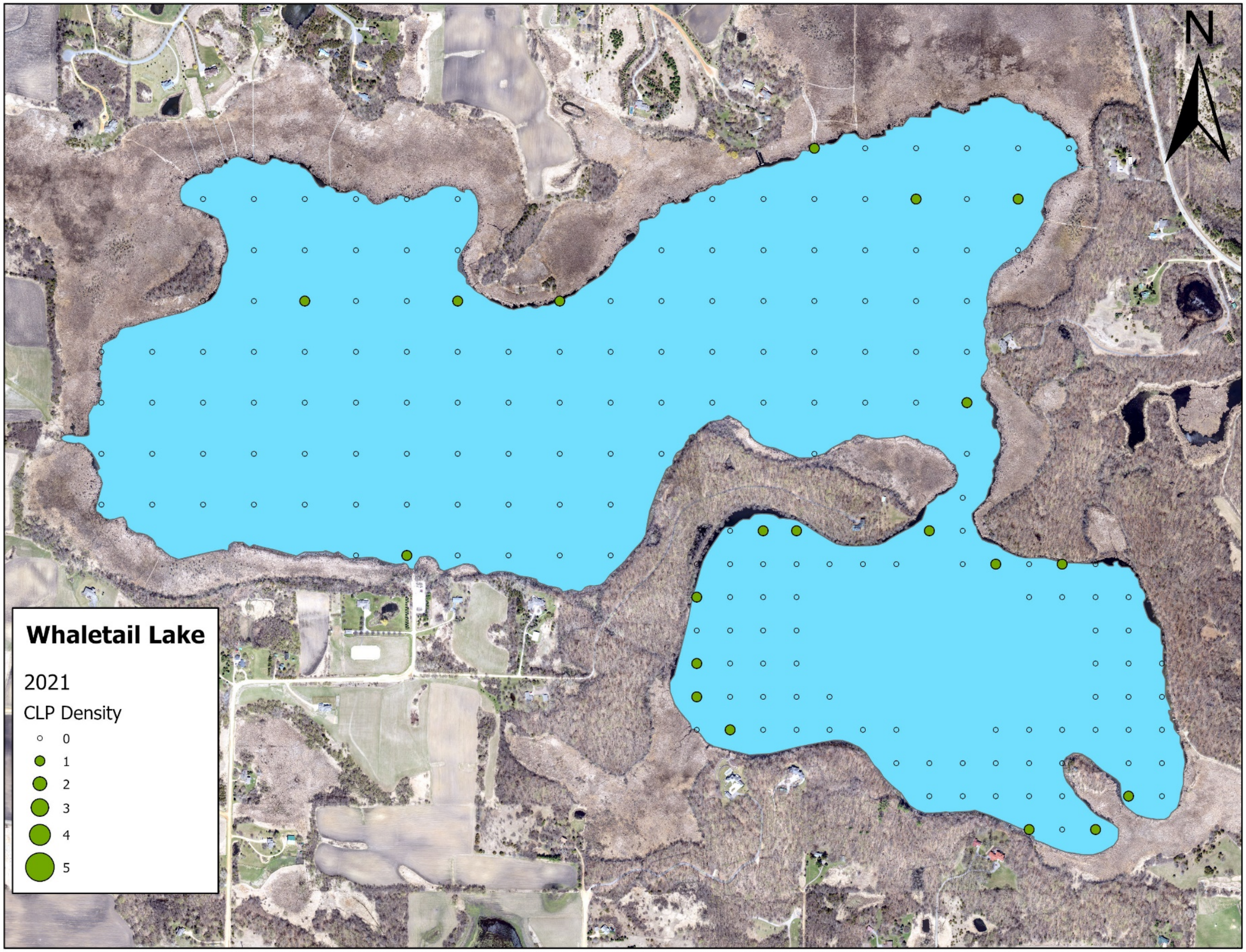


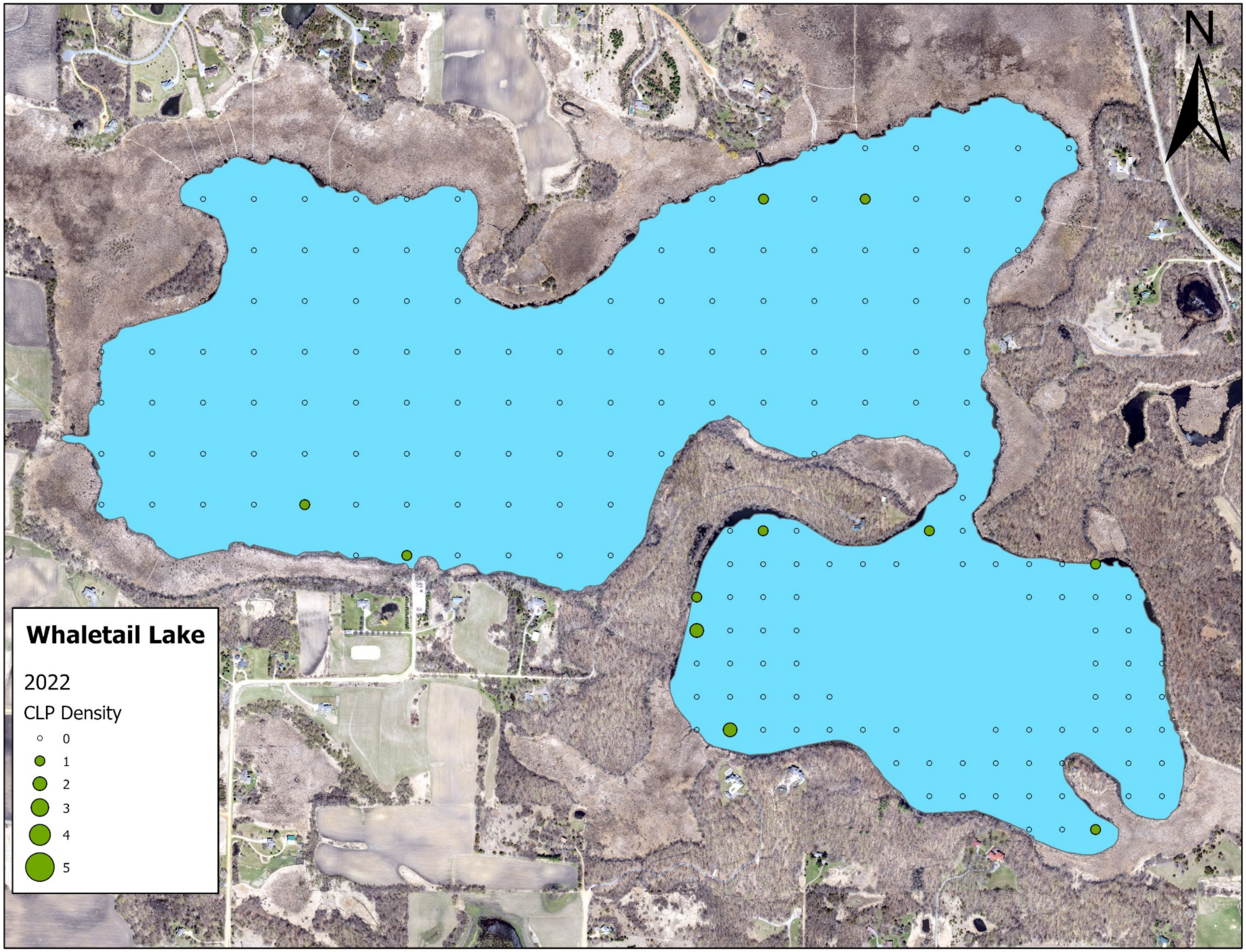
N
Whaletail Lake
2018
CLP Density
0
1
2
3
4
5


N
Whaletail Lake
2019
CLP Density
0
1
2
3
4
5



N
Whaletail Lake
2020
CLP Density
0
1
2
3
4
5


N
Whaletail Lake
2021
CLP Density
0
1
2
3
4
5


N
Whaletail Lake
2022
CLP Density
0
1
2
3
4
5

WT-S Early Summer Surveys									
			2016	2017	2018	2019	2020	2021	2022
Type	**Scientific Name**	**Common Name**							
Submerged	*Potamogeton crispus*	Curly Leaf Pondweed	9			3	15	15	9
	Myriophyllum demersum	Eurasian Water Milfoil	28		14	14	19	9	26
	Myriophyllum sibiricum	Northern Water Milfoil	3						
	Ceratophyllum demersum	Coontail	33		28	29	22	27	32
	Elodea canadensis	Elodea			1				
	Heteranthera dubia	Water Stargrass			1				
	Najas flexilis	Bushy Pondweed							
	Nitella spp	Nitella Spp							
	Potamogeton amplifolius	Large-Leaf Pondweed	10		4	5	3	4	6
	Potamogeton friesii	Fries Pondweed							4
	Potamogeton natans	Floating-leaf Pondweed	3						
	Potamogeton nodosus	Long Leaf Pondweed							
	Potamogeton praelongus	White-stem Pondweed	3				5	4	5
	Potamogeton spp	Narrow Pondweed Spp			3	3	4	4	
	Potamogeton zosteriformis	Flat-stem Pondweed	23		10	13	14	14	17
	Stuckenia pectinata	Sago Pondweed	3			1			
	Chara spp	Chara							
Floating Leaf	*Nelumbo lutea*	American Lotus	5		8	9	9	8	9
	Nuphar advena	Spatterdock	4		3	4	3	5	5
	Nymphaea odorata	White Water Lilly	26		21	21	14	14	26
Summary		**% Frequency of Native spp.**	36		31	29	27	29	33
		# Native submersed taxa	7		6	5	5	5	5
		# Non-native taxa	2		1	2	2	2	2
		Max Depth of Growth (m)	2.4		2	3.8	4.9	4.5	3

WT-S Late Summer Surveys

Type	Scientific Name	Common Name	2016	2017	2018	2019	2020	2021	2022
Submerged	*Potamogeton Crispus*	Culy-leaf Pondweed							
	Myriophyllum demersum	Eurasian Water Milfoil	14		4	14	10	19	
	Myriophyllum sibiricum	Northern Water Milfoil							
	Ceratophyllum Demersum	Coontail	27		24	25	26	27	
	Elodea Canadensis	Elodea							
	Heteranthera dubia	Water Stargrass							
	Najas Flexilis	Bushy Pondweed							
	Nitella Spp	Nitella spp							
	Potamogeton Amplifolius	Large-Leaf Pondweed	1				1	6	
	Potamogeton natans	Floating-leaf Pondweed							
	Potamogeton Nodosus	Long Leaf Pondweed				1			
	Potamogeton praelongus	White-stem Pondweed						1	
	Potamogeton Spp	Narrow Pondweed spp							
	Potamogeton zosteriformis	Flat-stem Pondweed	5		1	4	5	12	
	Stuckenia Pectinata	Sago Pondweed							
	Chara Spp	Chara							
Floating Leaf	*Nelumbo Lutea*	American Lotus	5		9	9	8	9	
	Nuphar advena	Spatterdock				3	3	5	
	Nymphaea Odorata	White Water Lilly	13		18	6	19	23	
Summary		**% Frequency of Native spp.**	26		25	26	27	28	
		# Native submersed taxa	3		2	3	3	4	
		# Non-native taxa	1		1	1	1	1	
		Max Depth of Growth (m)	3.4		3	4	4.3	3.7	

WT-N Early Summer Surveys									
			2016	2017	2018	2019	2020	2021	2022
Type	**Scientific Name**	**Common Name**							
Submerged	*Potamogeton crispus*	Curly Leaf Pondweed	7			2	2	7	4
	Myriophyllum demersum	Eurasian Water Milfoil			45	33	41	34	48
	Myriophyllum sibiricum	Northern Water Milfoil						1	
	Ceratophyllum demersum	Coontail	14		22	29	44	36	39
	Utricularia macrorhiza	Common Bladderwort				2			
	Elodea canadensis	Elodea	5		19	28	25	10	25
	Potamogeton spp	Narrow Pondweed Spp	5		4	4	4	4	14
	Nitella spp	Nitella Spp						1	
	Najas flexilis	Bushy Pondweed							
	Potamogeton amplifolius	Large-Leaf Pondweed	8		11	31	14	14	32
	Potamogeton zosteriformis	Flat-stem Pondweed			51	54	60	57	62
	Potamogeton natans	Floating-leaf Pondweed	2		3				
	Potamogeton praelongus	White-stem Pondweed	5		19	19	26	29	39
	Potamogeton illinoensis	Illinois Pondweed						3	9
	Stuckenia pectinata	Sago Pondweed	4		3	12	14		17
	Potamogeton nodosus	Long Leaf Pondweed	3					2	
	Chara spp	Chara	15		8	6	9	7	12
Floating Leaf	*Nelumbo lutea*	American Lotus							
	Nuphar advena	Spatterdock	2		2	4	4	2	6
	Nymphaea odorata	White Water Lilly	7		14	19	16	12	25
Summary		**% Frequency of Native spp.**	56		61	75	76	68	76
		# Native submersed taxa	9		9	9	8	11	9
		# Non-native taxa	1		1	2	2	2	2
		Max Depth of Growth (m)	2.2		2.1	3	2.5	2.8	2.5

WT-N Late Summer Surveys									
			2016	2017	2018	2019	2020	2021	2022
Type	**Scientific Name**	**Common Name**							
Submerged	*Potamogeton Crispus*	Culy-leaf Pondweed							
	Myriophyllum demersum	Eurasian Water Milfoil	23		37	31	34	50	
	Myriophyllum sibiricum	Northern Water Milfoil					4	4	
	Ceratophyllum Demersum	Coontail	18		29	42	44	41	
	Utricularia macrorhiza	Common Bladderwort	2		3				
	Utricularia gibba	Creeping Bladderwort			1				
	Elodea Canadensis	Elodea	1		19	21	9	18	
	Potamogeton Spp	Narrow Pondweed spp				2	3		
	Nitella Spp	Nitella spp							
	Najas Flexilis	Bushy Pondweed							
	Potamogeton Amplifolius	Large-Leaf Pondweed	4		25	11	12	18	
	Potamogeton zosteriformis	Flat-stem Pondweed	39		45	37	45	54	
	Potamogeton natans	Floating-leaf Pondweed			4		7		
	Potamogeton praelongus	White-stem Pondweed	11		12	18	18	27	
	Potamogeton illinoensis	Illinois Pondweed	4					1	
	Stuckenia Pectinata	Sago Pondweed	9		14	14	10	26	
	Potamogeton Nodosus	Long Leaf Pondweed				1			
	Heteranthera dubia	Water Stargrass							
	Chara Spp	Chara	5		8	7	8	4	
Floating Leaf	*Nelumbo Lutea*	American Lotus							
	Nuphar advena	Spatterdock	3		1	2	3	4	
	Nymphaea Odorata	White Water Lilly	13		15	10	19	33	
Summary		**% Frequency of Native spp.**	45		75	61	68	65	
		# Native submersed taxa	9		10	9	10	9	
		# Non-native taxa	1		1	1	1	1	
		Max Depth of Growth (m)	1.8		2.3	2.6	2.1	2.3	

Appendix F

Whaletail Lake

Carp Population and Biomass Assessment

CARP SOLUTIONS

2020 Carp Population and Biomass Report for Whaletail Lake

Prepared for: Three Rivers Park District
Attn.: Brian Vlach
Prepared by: Carp Solutions, LLC
Przemek Bajer, Jenna Barlow & Cameron Swanson
October 26, 2020
CarpSolutionsMN.com

Electrofishing Survey Methods

Carp Solutions completed three boat electrofishing surveys in Whaletail Lake to develop carp population and biomass estimates. Surveys were completed on July 20, August 10, and August 20 of 2020. During the first survey, the entire lake was surveyed in 9 transect stations (Figure 1).The following two surveys used a randomization method to select 6 of these 9 stations to survey. All carp captured were measured, the left pelvic fin was clipped to determine any recaptures, and released.

Results

Over the three surveys, 42 carp were caught, ranging in length from 540 mm (21 inches) to 830 mm (33 inches), with an average of 694 mm (27 inches). The length distribution of these carp can be seen in Figure 2. Almost half (20) of the total carp were caught during the second survey on August 10, whereas the other two days, only 13 (7/20) and 9 (8/20) carp were caught. This variation in catch rates is expected and is accommodated for by conducting several surveys spread out over time. The variation could be due to a number of factors including: weather, location of transects, and carp behavior. These variable catch rates caused a wide range in the resulting estimates. The carp population estimate from the three surveys ranged from 4840 to 10349 with an overall estimate of 6460. The overall biomass density estimate was 133 kilograms of carp per hectare of lake.

Management Recommendations

While the carp biomass density estimate in Whaletail Lake is slightly over the ecological threshold of 100 kg/ha that has been found to cause ecological damage, the abundance of aquatic vegetation suggests that the carp are not an immediate concern. Thus, carp removal is not a high priority for Whaletail Lake. Further, the large size of captured carp (all but one were between 600 mm and 900 mm) suggest lack of recruitment of young carp over the last decade or so. Occasional electrofishing surveys are recommended to ensure that recruitment of carp does not occur that would increase the population above the ecological threshold.

Figure 1: Electrofishing Station Map: Each color represents an independent transect from which six transects were randomly selected for the second and third surveys.

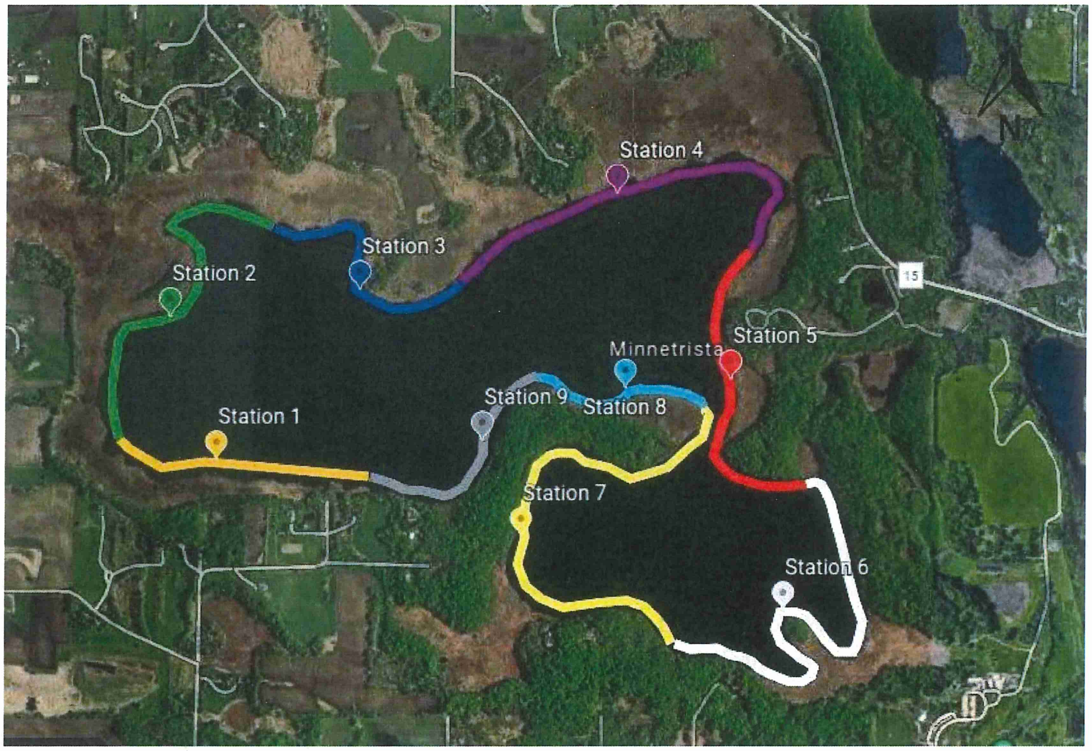


Figure 2: Size distribution of carp captured during the three electrofishing surveys

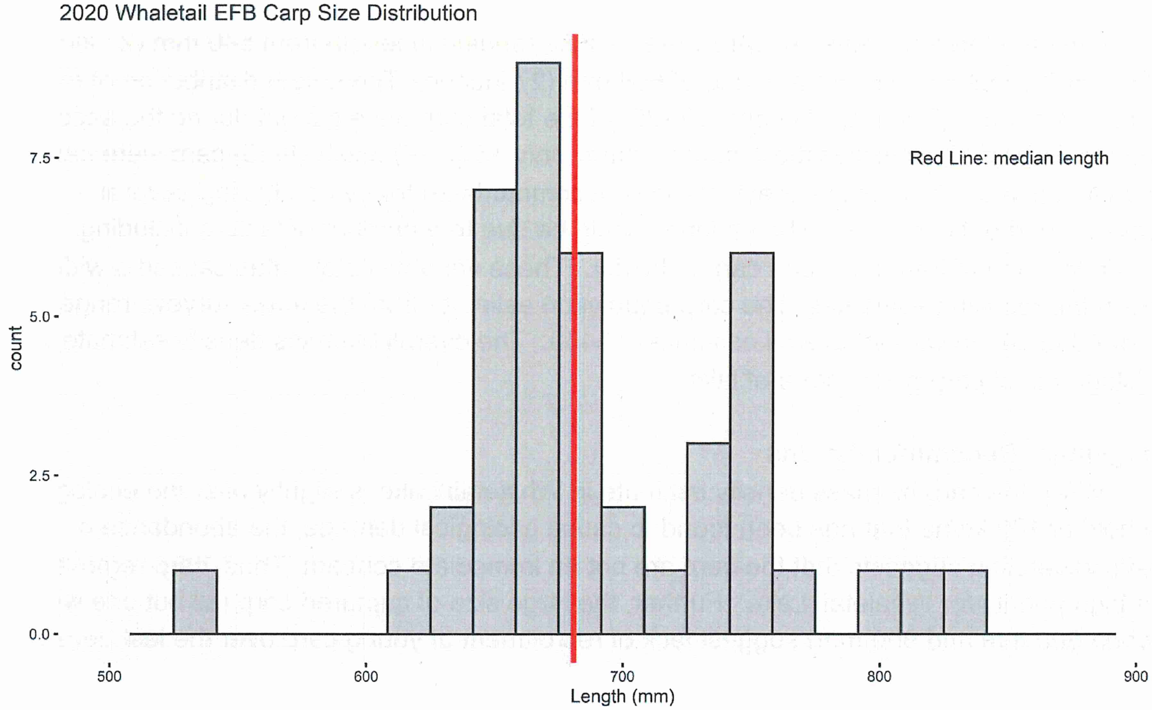


Table 1. Each of the transects completed on the 3 survey dates with associated catch and catch per unit effort (CPUE)

Date	Station	Time	Carp Caught	CPUE (per hour)
7/20/2020	1	20	1	3
	2	20	1	3
	3	20	3	9
	4	20	0	0
	5	20	0	0
	6	20	2	6
	7	20	1	3
	8	20	5	15
	9	9	0	0
8/10/2020	1	20	1	3
	2	20	3	9
	5	20	2	6
	7	20	4	12
	8	20	4	12
	9	20	6	18
8/20/2020	1	20	2	6
	2	20	0	0
	4	20	1	3
	5	20	1	3
	6	20	2	6
	7	20	3	9

Table 2. Data from three electrofishing surveys including how many 20 minute transects were completed each day, total catch for the day, catch-per-unit-effort (CPUE), average length and estimated weight, population estimate based on CPUE, and biomass density estimate in kilograms per hectare.

Date	Transects	Carp Caught	CPUE (per hour)	Avg. Length (mm)	Est. avg. Weight (kg)	Abundance	Biomass Density (kg/ha)
7/20/2020	9	13	4.3	703	4.4	4840	103.6
8/10/2020	6	20	10.0	704	4.4	10349	222.2
8/20/2020	6	9	4.5	658	3.7	5002	88.9
Total	21	42					
Averagel		14	6.0	694	4.26	6460	133.2

Bajer, P. G., & Sorensen, P. W. (2012). Using boat electrofishing to estimate the abundance of invasive common carp in small Midwestern lakes. *North American Journal of Fisheries Management*, 32(5), 817-822.